A vision for an ultra-high resolution integrated water cycle observation and prediction system

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Outline

1. *Global Water Cycle*
2. *Water Cycle Observations & Mission*
3. *Hyper Resolution Land Modeling*
4. *Advanced Integration (Data Assimilation)*

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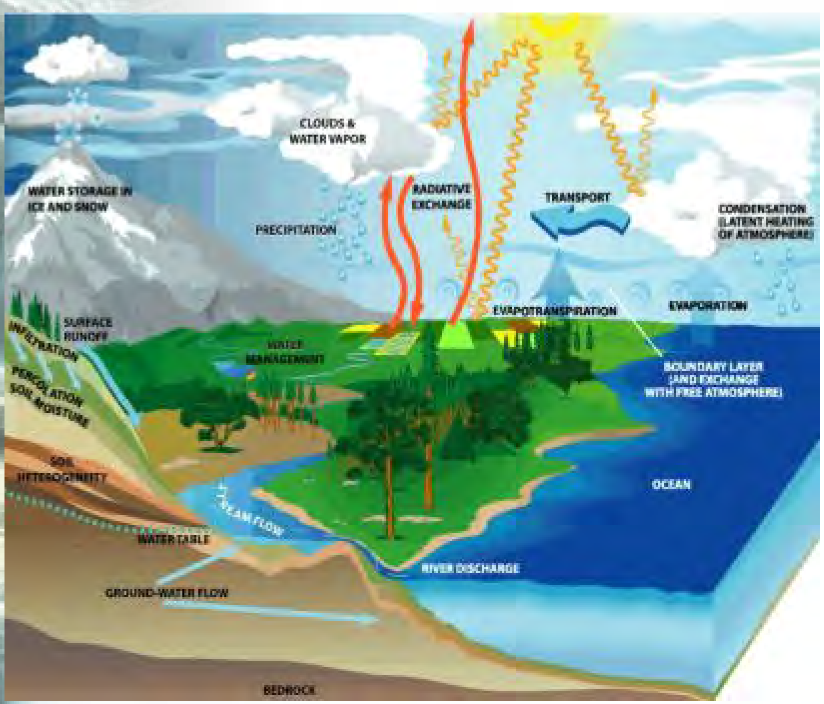
The Water and Energy Cycle

Water in the climate system functions on all time scales:
From hours to centuries



Role of the Water & Energy Cycle in the Climate System:

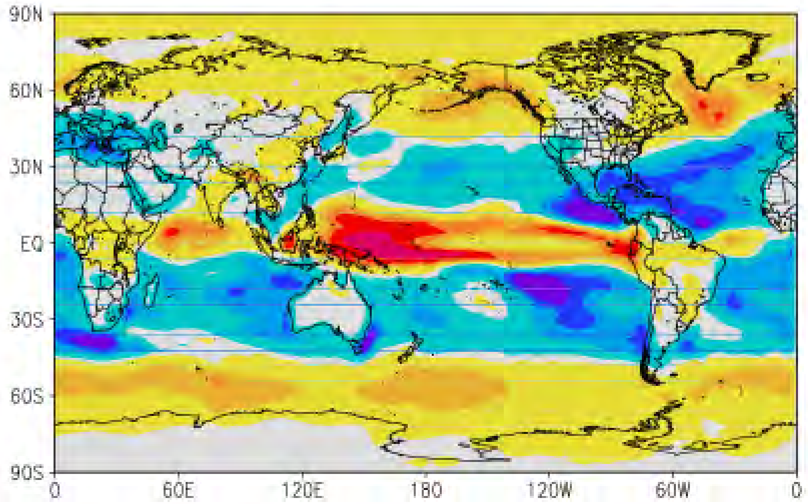
- *Water exists in all three phases in the climate system; its phase transitions regulate global and regional energy balances*
- *Water vapor in the atmosphere is the principal greenhouse gas; clouds represent both positive and negative feedbacks in climate system response*
- *Water is the ultimate solvent which mediates the biogeochemical and element cycles*
- *Water directly impacts and constraint human society and its well-being.*

The Energy and Water Cycle is *tightly intertwined*

- Solar radiation drives and feedbacks with the water cycle
- Energy is transferred through water movement and phase change

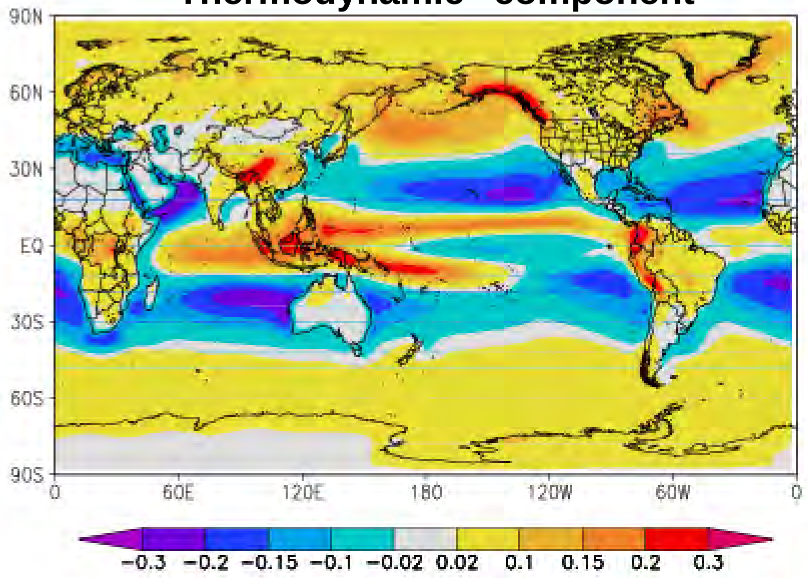
Multi-model ensemble mean change from IPCC GCMs

Change in (P-E) for 2100 minus 2000
"Dry regions get drier, wet regions get wetter"

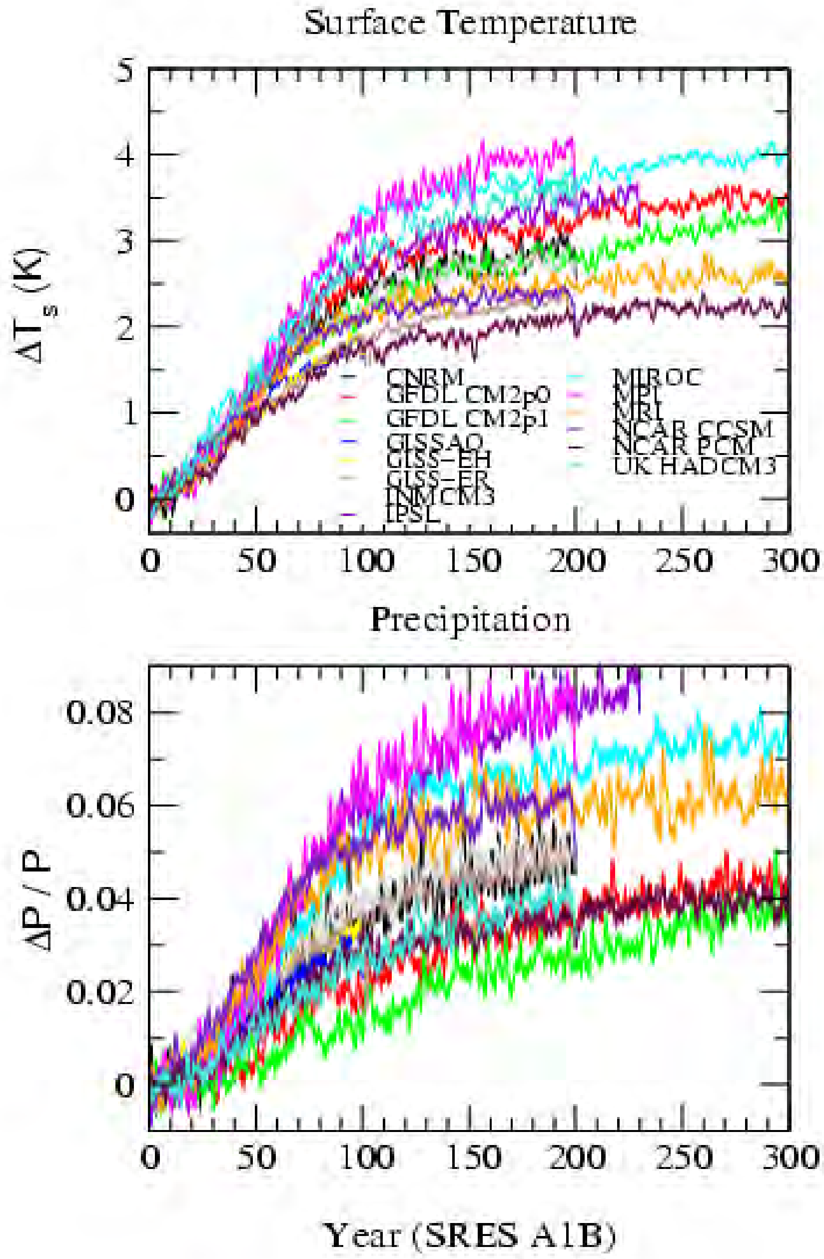


Held and Soden (2006)

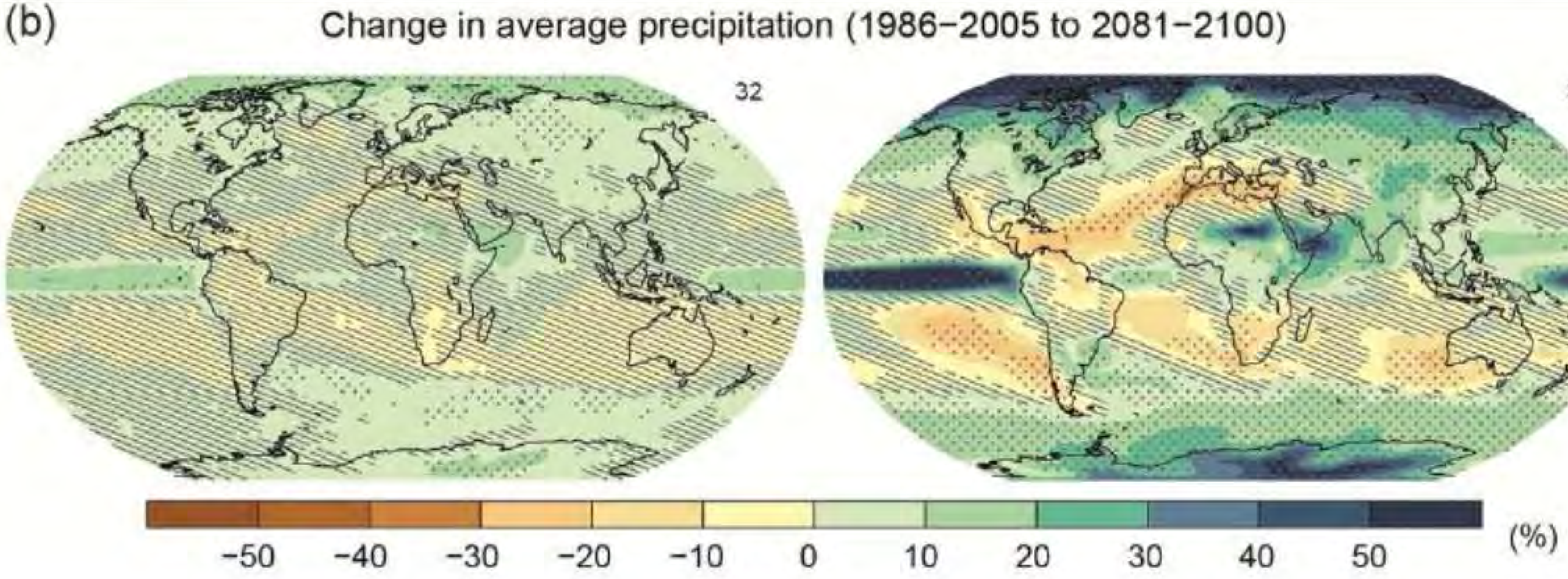
"Thermodynamic" component



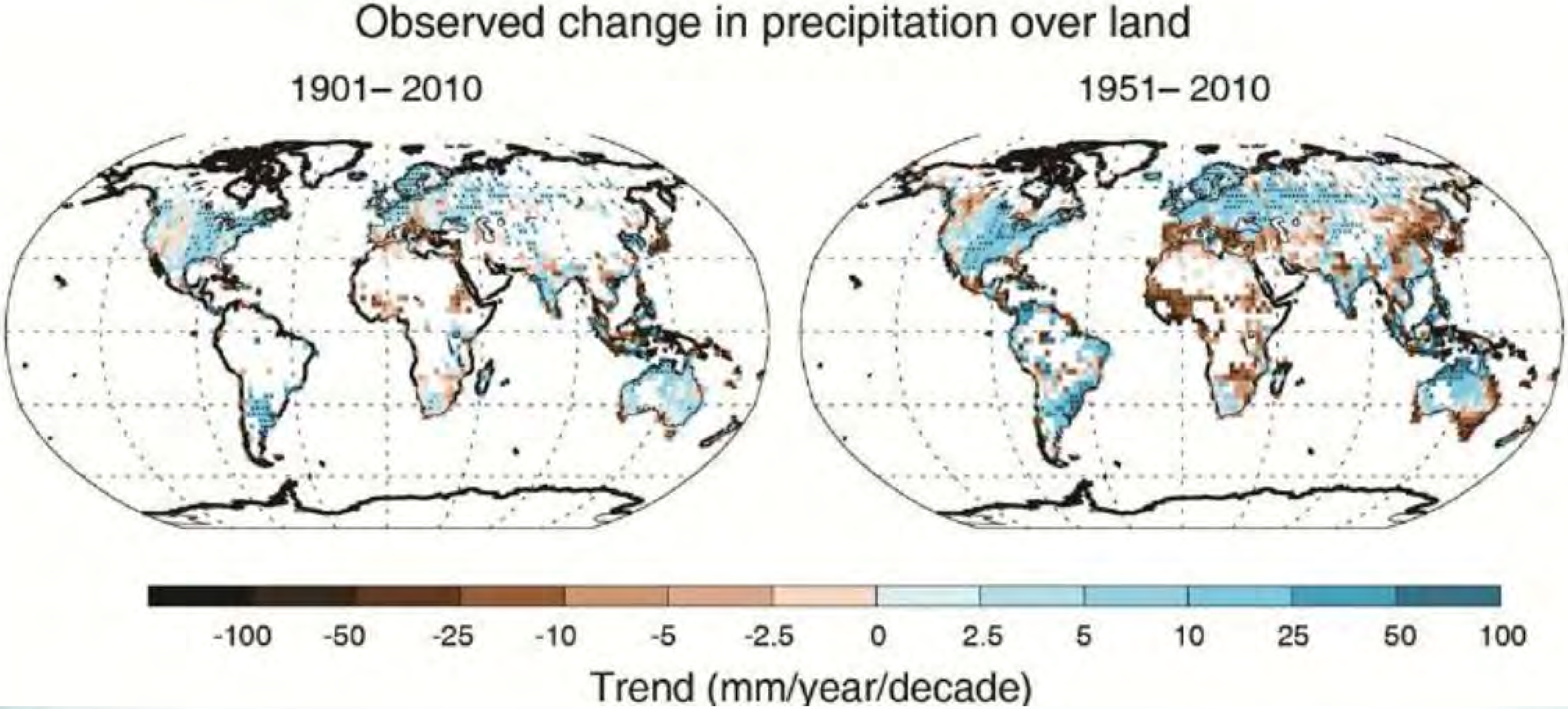
Δ(P-E) mm/da



Vecchi and Soden (2007)



(b) Change in average precipitation (1986−2005 to 2081−2100)



Observed change in precipitation over land

1901– 2010

1951– 2010

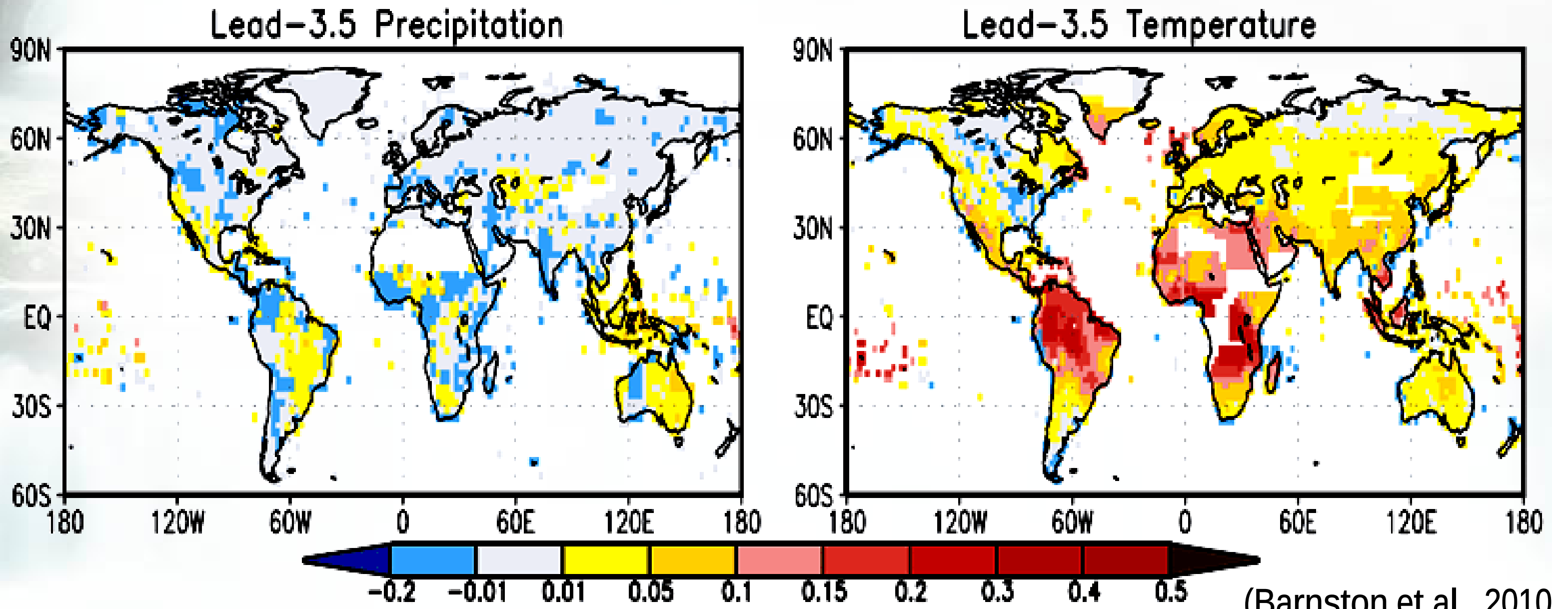
Trend (mm/year/decade)

Unfortunate Realities

- The fact is, we don't know how much water is stored in North America's lakes, reservoirs, streams, groundwater systems or snow packs which is fundamental knowledge needed to manage any resource

- Our knowledge of Earth's water environment at the surface and shallow subsurface remains appallingly insufficient.

- Our nation's hydroclimate modeling assets are simply not up to the task of addressing our most pressing societal issues of food, energy, water, and national security. We are behind where we need to be. (Famiglietti 2012)

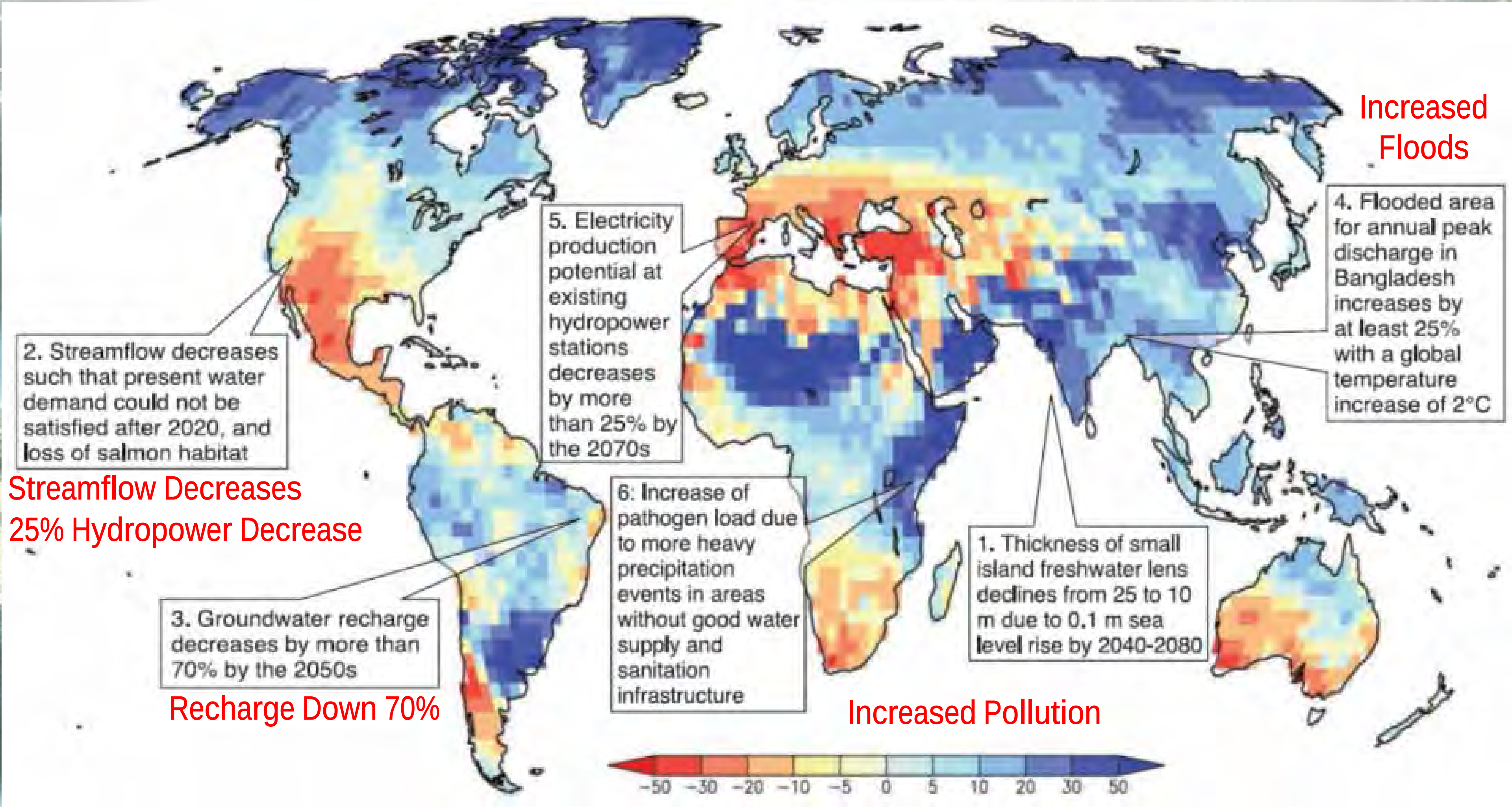


Prediction skill score

(Barnston et al., 2010).

The importance of Water

IPCC 100 year projected change in freshwater



Increased Floods

4. Flooded area for annual peak discharge in Bangladesh increases by at least 25% with a global temperature increase of 2°C

5. Electricity production potential at existing hydropower stations decreases by more than 25% by the 2070s

2. Streamflow decreases such that present water demand could not be satisfied after 2020, and loss of salmon habitat

Streamflow Decreases

25% Hydropower Decrease

6: Increase of pathogen load due to more heavy precipitation events in areas without good water supply and sanitation infrastructure

1. Thickness of small island freshwater lens declines from 25 to 10 m due to 0.1 m sea level rise by 2040-2080

3. Groundwater recharge decreases by more than 70% by the 2050s

Recharge Down 70%

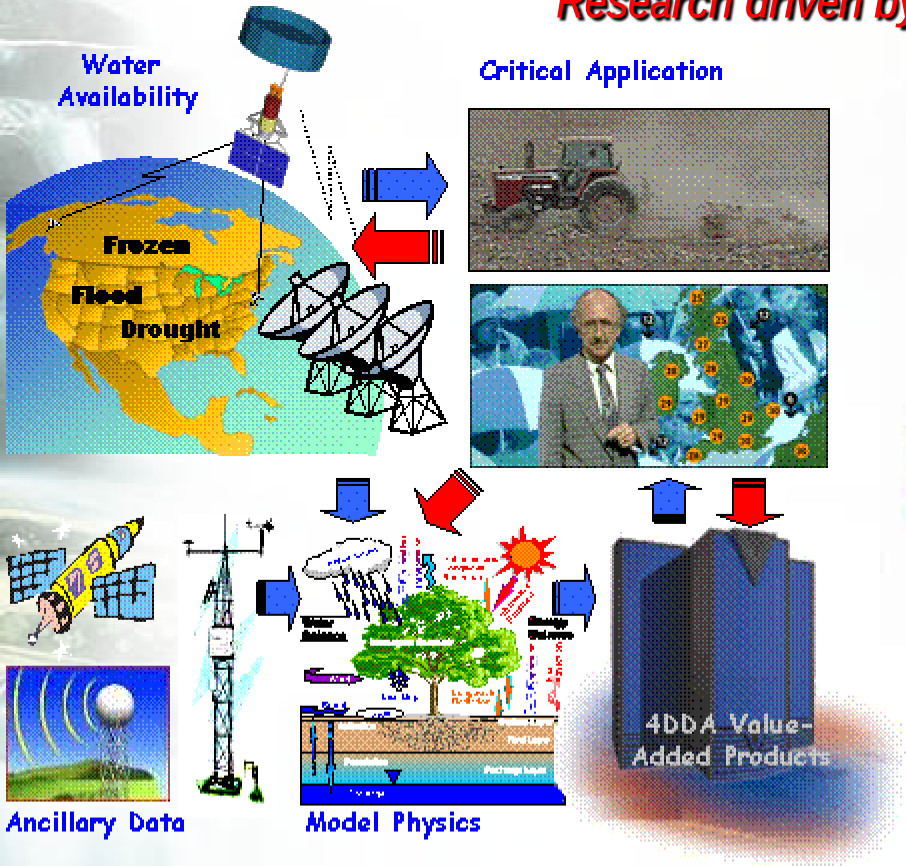
Increased Pollution

Figure 3.8. *Illustrative map of future climate change impacts on freshwater which are a threat to the sustainable development of the affected regions. 1: Bobba et al. (2000), 2: Barnett et al. (2004), 3: Döll and Flörke (2005), 4: Mirza et al. (2003) 5: Lehner et al. (2005a) 6: Kistemann et al. (2002). Background map: Ensemble mean change of annual runoff, in percent, between present (1981 to 2000) and 2081 to 2100 for the SRES A1B emissions scenario (after Nohara et al., 2006).*

Linking Science to Consequences

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

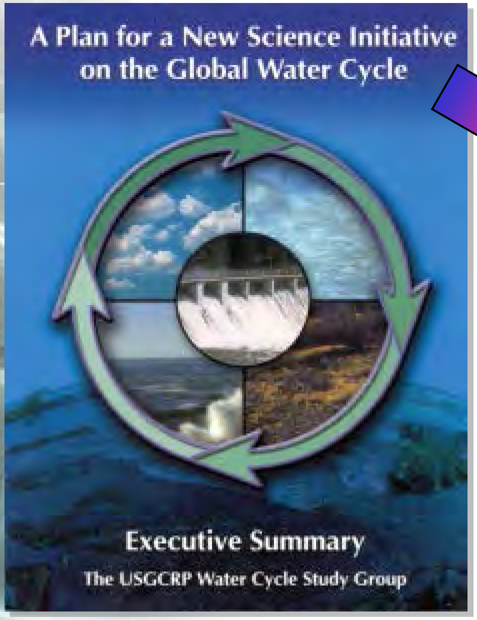
Research driven by the needs of society



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

Water Cycle Questions



A Plan for a New Science Initiative on the Global Water Cycle

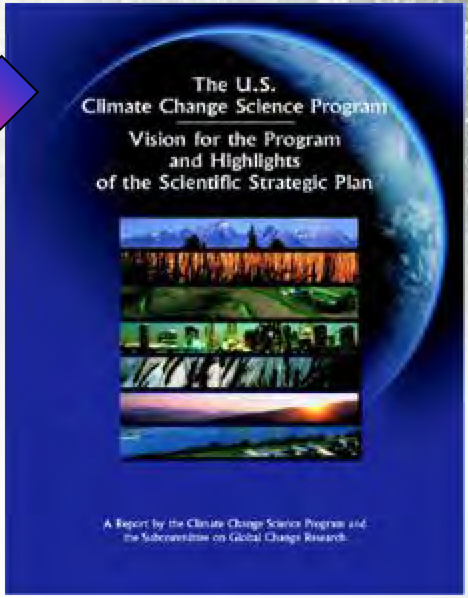
Executive Summary

The USGCRP Water Cycle Study Group

What are the causes of water cycle variations?

Are variations in the global and regional water cycle *predictable*?

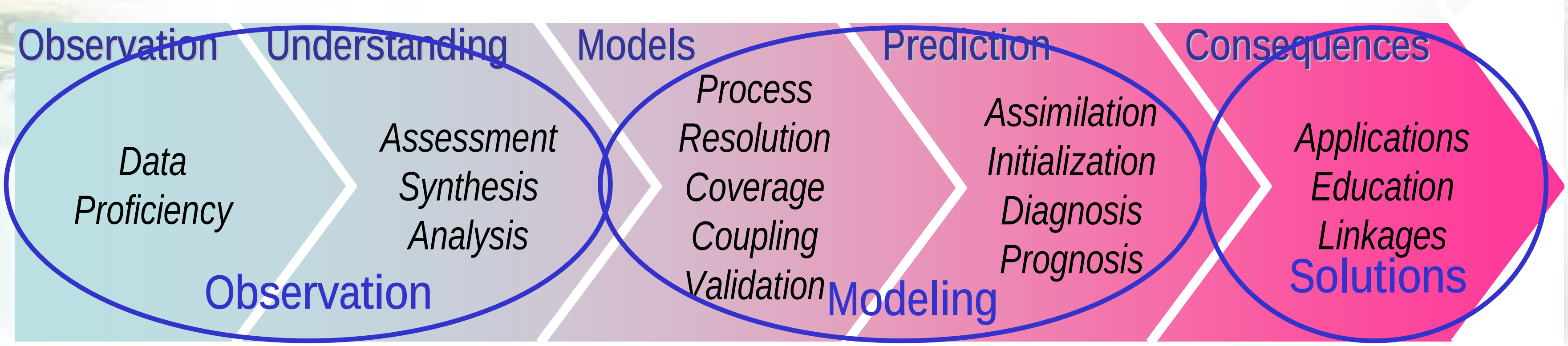
How are water and nutrient cycles linked?



The U.S. Climate Change Science Program

Vision for the Program and Highlights of the Scientific Strategic Plan

A Report by the Climate Change Science Program and the Subcommittee on Global Change Research



Observation

Data
Proficiency

Understanding

Assessment
Synthesis
Analysis

Observation

Models

Process
Resolution
Coverage
Coupling
Validation

Prediction

Assimilation
Initialization
Diagnosis
Prognosis

Modeling

Consequences

Applications
Education
Linkages

Solutions

State of the Water and Energy Cycle

Variable ↓ Sphere →	Ocean	Terrestrial	Atmosphere
Internal or State Variable	upper ocean currents (I/S) sea surface temperature (I/S) sea level/surface topography (I/S) sea surface salinity (I/S) sea ice (I/S) wave characteristics (I/S) mid- and deep-ocean currents (I) subsurface thermal structure (I) subsurface salinity structure (I) ocean biomass/phytoplankton (I/S) subsurface carbon(I), nutrients(I) subsurface chemical tracers(I)	topography/elevation (I/S) land cover (I/S) leaf area index (I) soil moisture/wetness (I/S) soil structure/type (I/S) permafrost (I) vegetation/biomass vigor (I/S) water runoff (I/S) surface temperature (I/S) snow/ice cover (I/S) subsurface temperature (I/S) subsurface moisture (I/S) soil carbon, nitrogen, phosphorus, nutrients (I)	wind (I/S) upper air temperature (I/S) surface air temperature (I/S) sea level pressure (I) upper air water vapor (I/S) surface air humidity (I/S) precipitation (I/S) clouds (I/S) liquid water content (I/S)
Forcing or Feedback Variable	ocean surface wind & stress (I/S) incoming SW radiation (I/S) incoming LW radiation (I/S) surface air temperature (I/S) surface air humidity (I/S) precipitation (I/S) evaporation (I/S) fresh water flux (I/S) air-sea CO_2 flux (I) geothermal heat flux (I) organic & inorganic effluents (I/S) biomass and standing stock (I/S) biodiversity (I) human impacts-fishing (I)	incoming SW radiation (I/S) incoming LW radiation (I/S) PAR radiation surface winds (I) surface air temperature (I/S) surface humidity (I/S) albedo (I/S) evapotranspiration (I/S) precipitation (I/S) land use (I/S) deforestation (I/S) land degradation (I/S) sediment transport (I/S) air-land CO_2 flux (I)	sea surface temperature (II/S) surface soil moisture (I/S) surface soil temperature (I/S) surface topography (I/S) land surface vegetation (I/S) CO_2 & other greenhouse gases, ozone & chemistry, aerosols (I/S) evapotranspiration (I/S) snow/ice cover (I/S) SW and LW surface radiation budget (I/S) solar irradiance (S)

BLUE=Water Cycle Variable; RED=Energy Cycle Variable; GREEN=Carbon/Chemistry Variable; BLACK=Boundary condition

Water & Energy Balance

$$\frac{d\langle Q\rangle}{dt} = \langle E\rangle - \langle P\rangle$$

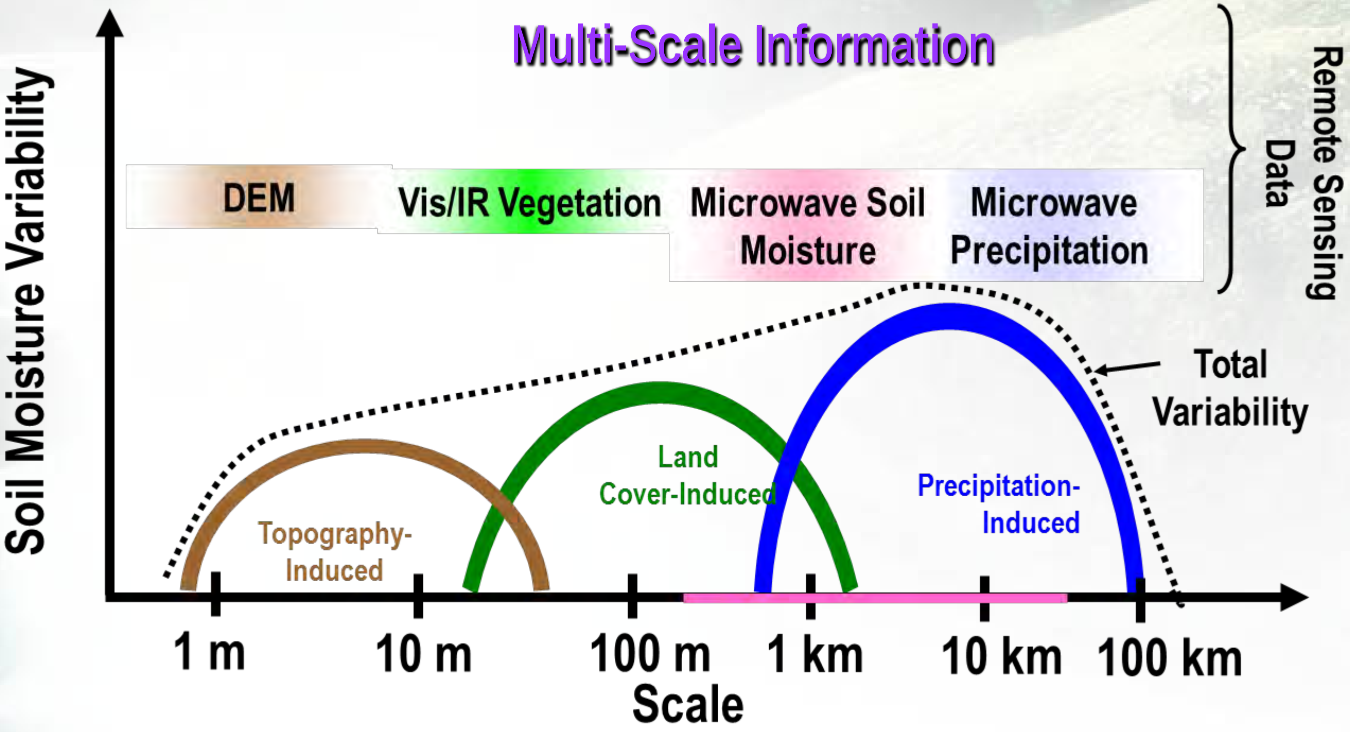
$$R = P - E \pm \Delta G$$

$$P_o = E_o - D_o + D_l = E_o - R$$
$$P_l = E_l + D_o - D_l = E_l + R$$

$$\frac{\partial S}{\partial t} = -\nabla_H \cdot \vec{R}_o - (E - P).$$

$$P + R_o + \Delta O + G_{do} = E$$

Multi-Scale Information

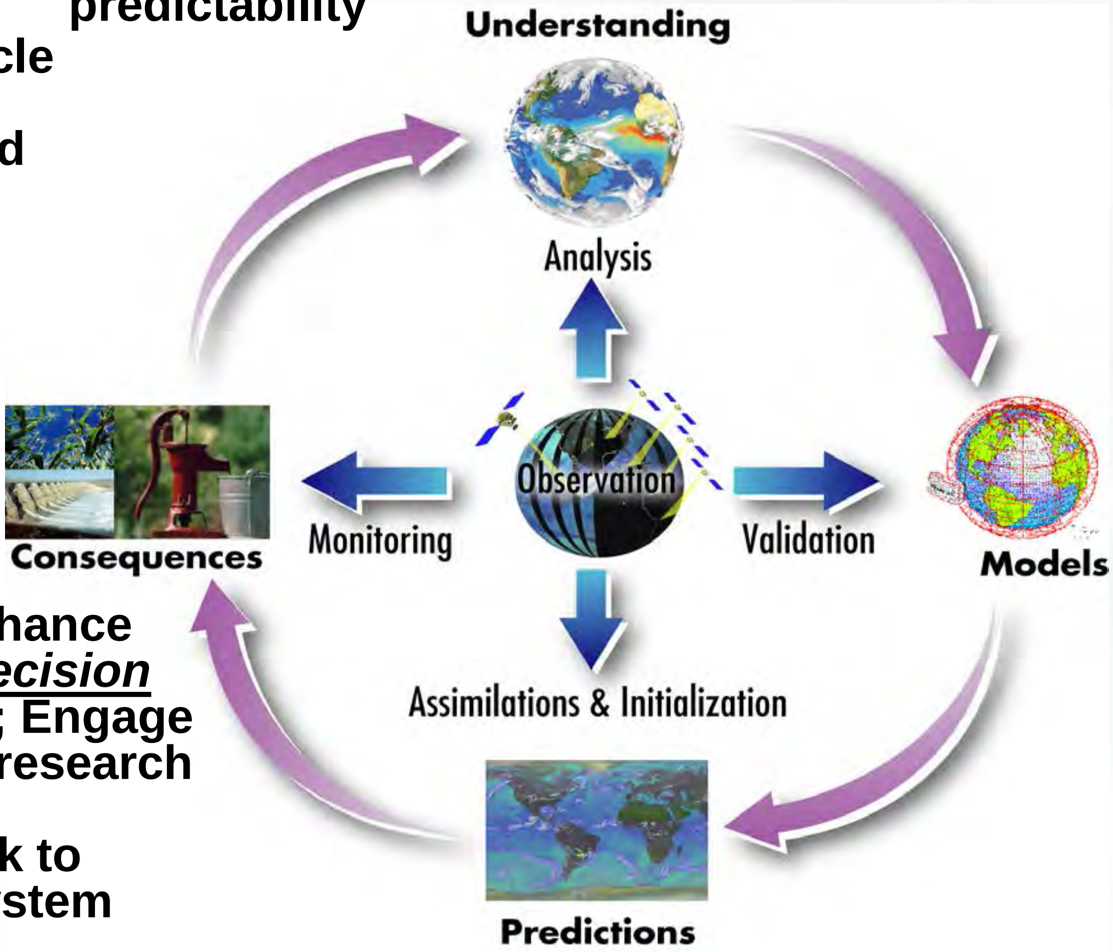


What does an 1/8 degree grid cell look like in real life?

Water Cycle Prediction Components

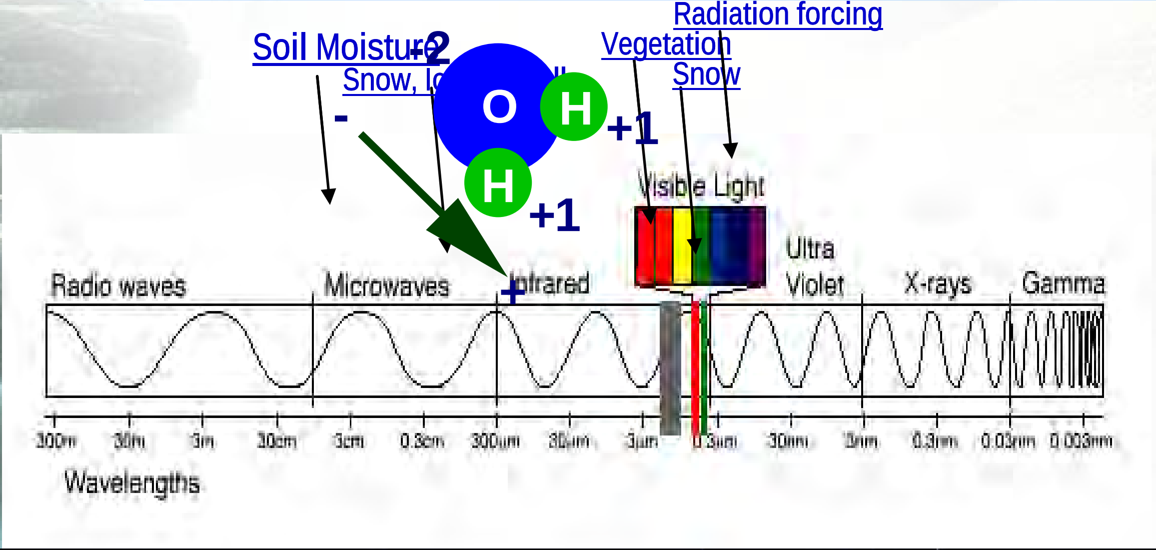
- **Modeling:** ***Diagnose*** **state-of-the-art "operational" Earth system models; conduct sensitivity and predictability experiments; infuse *process-scale* understanding to predict *water cycle extremes,* enhance prediction through *observational constraints*; explore limits of water cycle predictability**

- **Observation:** **Quantify long-term water cycle *trends* & *variability*; progress toward a coordinated water cycle observation system; extract knowledge and understanding from diverse observations.**



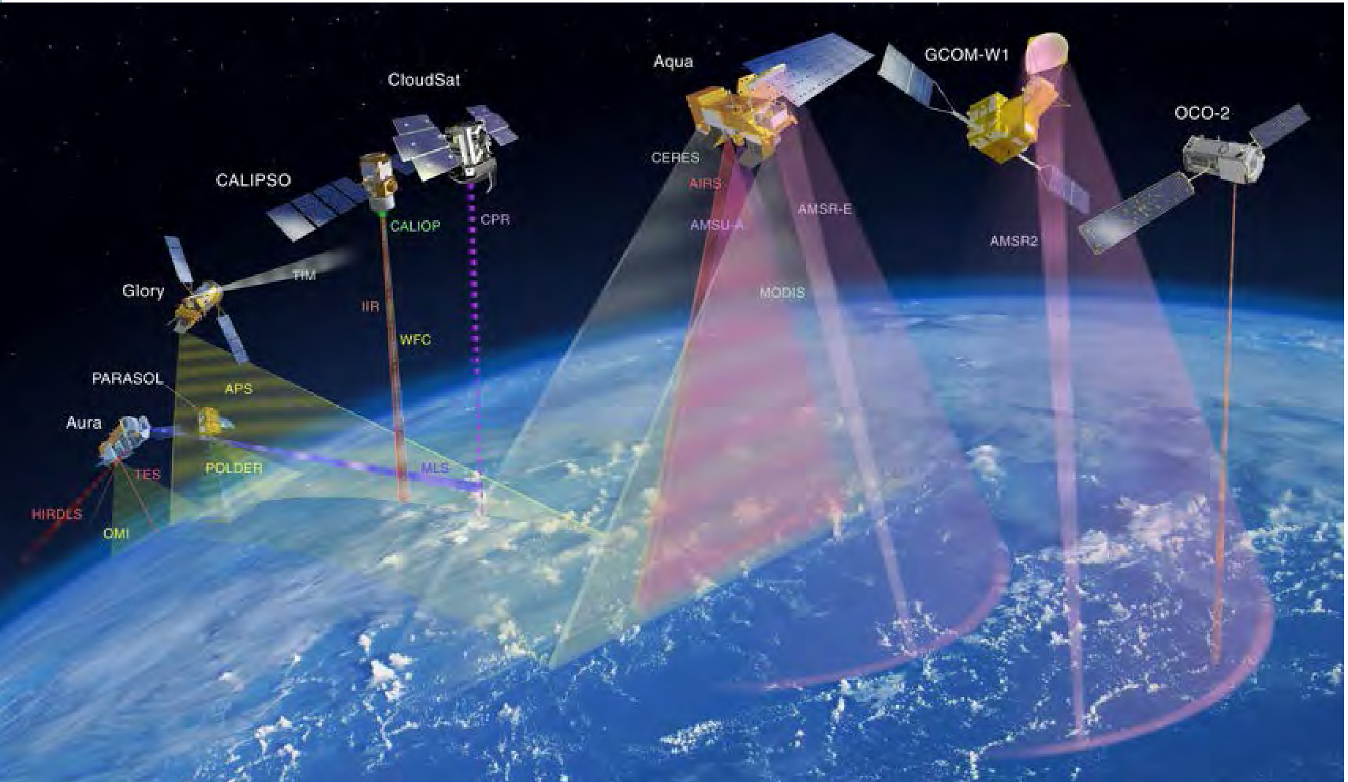
- **Solutions:** **Enhance operational *decision support tools*; Engage in public and research community *education;* link to other earth system components**

Water Cycle Remote Sensing



Types of Microwave Sensors:

1. Microwave radiometers: Emission
2. Non-imaging RADARs
    - Altimeters – measure elevation
    - Scatterometers –microwave backscatter
3. Imaging RADARs
    - Synthetic Aperture Radars – map variations in microwave backscatter



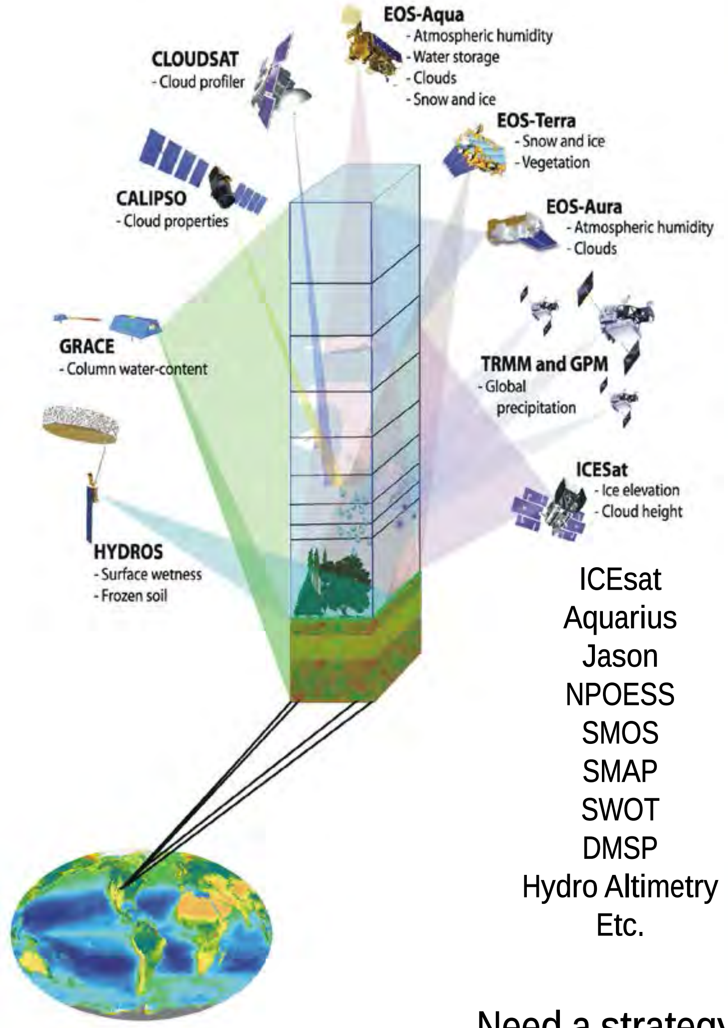
The “A-Train”

AMSR-E radiometer (6-89 GHz)
AMSU-A (15 channels 15-90 GHz)
HSB profiler (150, 183 GHz)
CloudSat Radar (94-GHz)

The “W-Train”?

TRMM TMI radiometer (10.7-85.5 GHz)
GPM (active/passive)
TRMM-PR (radar at 13.6 and 35 GHz)
Aquarius/SMAP (1.413GHz A/P).
SMOS (1.4GHz radiometer)

Global Water and Energy Cycle: Observation Strategy



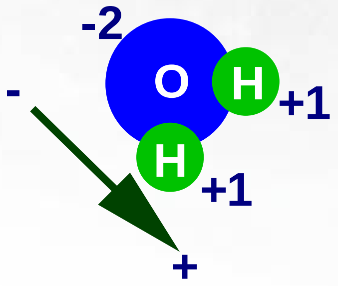
ICEsat
Aquarius
Jason
NPOESS
SMOS
SMAP
SWOT
DMSP
Hydro Altimetry
Etc.

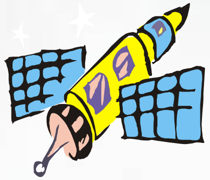
Primary missing global observations: *Precipitation, Soil Moisture, Snow*

Need a strategy to compare and integrate and make sense of existing observations

Future: *Water Cycle Mission*

Observation of water molecules through the atmosphere and land surface using an *active/passive hyper spectral* microwave instrument.





Quantity	Spatial Res.	Temporal Res.	Frequency
Groundwater	50km	Monthly	100 MHz
Soil Moisture	1km	Daily	1.4 GHz
Freeze/Thaw	1km	Daily	1.4 GHz
Rain	5km	Hourly	10-90 GHz
Snow	100m	Daily	10-90 GHz
Ice	100km	Weekly	10-90 GHz
TPW/Vapor	10km	Hourly	6-37 GHz
Lakes/Rivers	10m	Daily	30-40 GHz
ET	10km	Daily	1-90 GHz

Water Cycle Mission:

Microwave radiation is modified strongly by the dipole of water molecules

- Through the earth's surface and in the atmosphere
- Dependent on the microwave radiation source and frequency and on the water phase and concentration.
- soil moisture, rainfall, snowfall, snow cover, water vapor, total precipitable water, soil freeze-thaw, ocean salinity, vegetation water-content, surface inundation, streamflow

There is the potential of developing a water cycle mission:

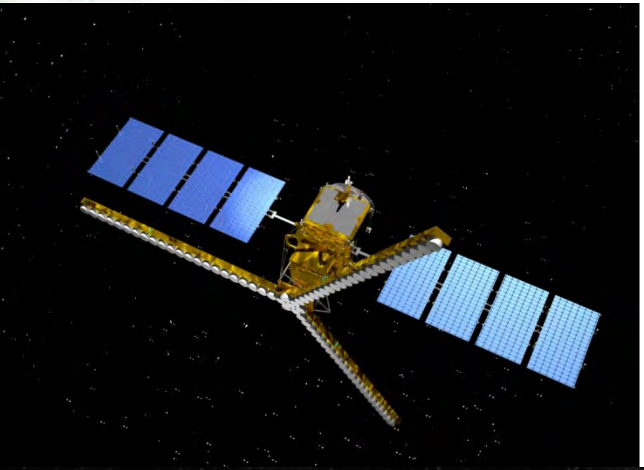
- high-resolution, active-passive, multi-frequency microwave mission
- make simultaneous observations of almost every critical water-cycle process, and bring water-cycle science to a more *compelling level*.
- This mission could be built around a *single, elegant, highly-integrated large aperture* (10's of meters in size) multi-frequency active/passive microwave antenna
- Could be deployed in a geostationary orbit, or as part of a polar orbiting constellation

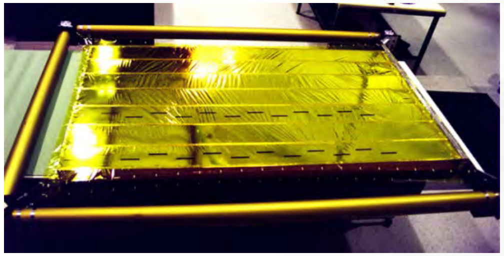
If we want to achieve this goal, we will need to take decisive, calculated steps:

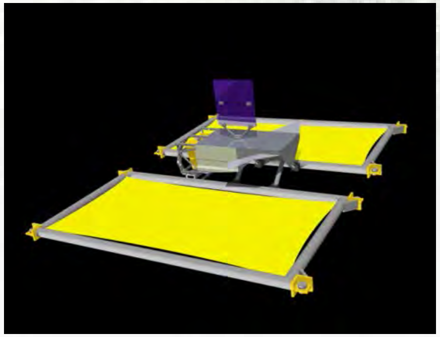
- Focused experimental ground, air, and space based instruments (i.e. TRMM,GPM,HYDROS,AQUARIUS).
- Development of robust microwave radiative-transfer algorithms to derive the desired quantities.
- Develop mission concept options in the near-term.

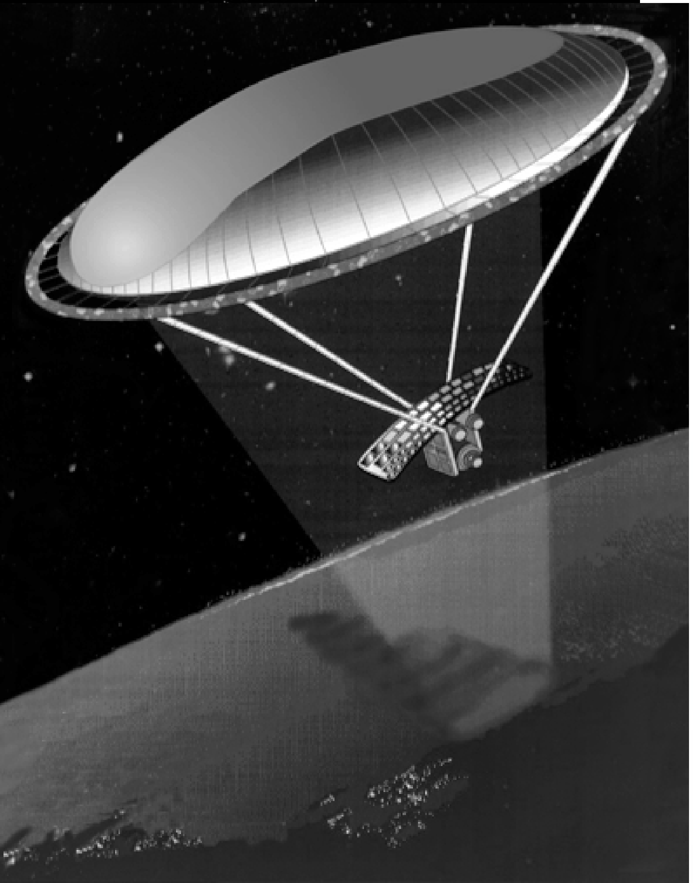
Non-microwave water cycle observations involving visible and infrared derived snow cover, surface temperature, and cloud top temperature, as well as lidar or radar altimetry derived river and lake levels would further increase the relevance of a potential "water cycle" mission.

Water Cycle Mission: Options?









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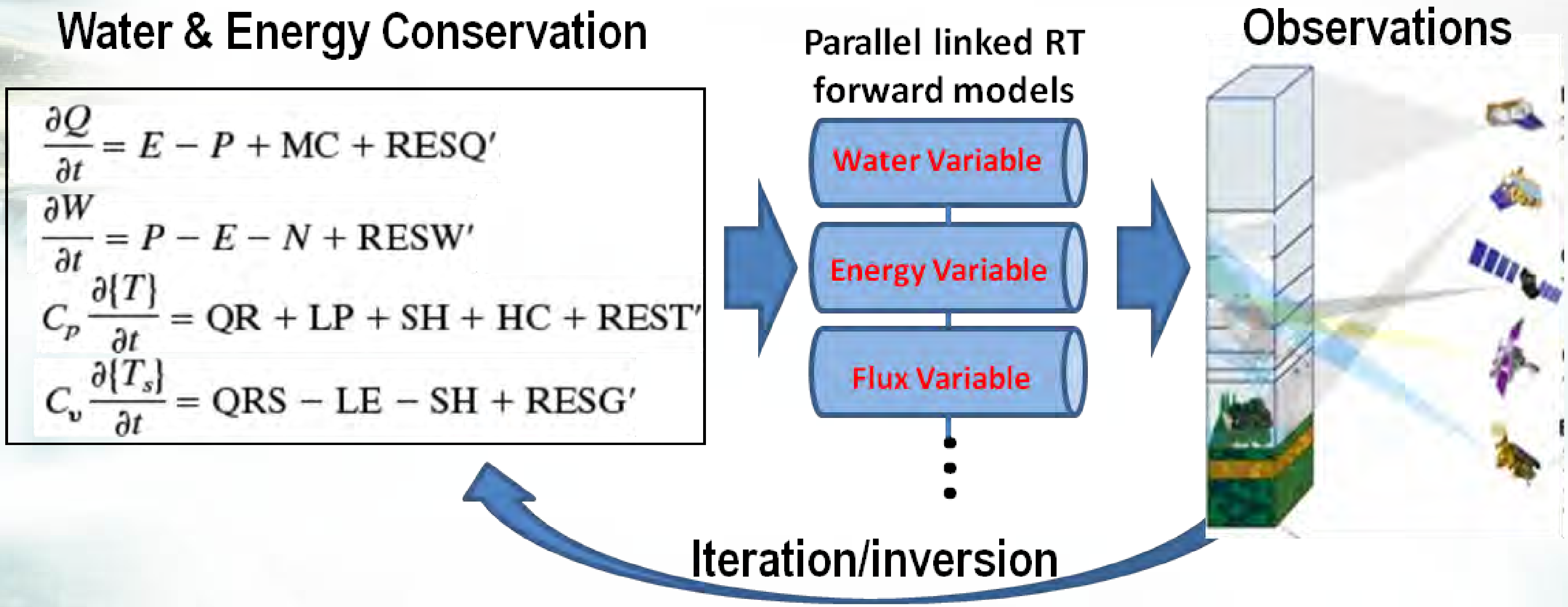
Water Cycle Mission: Demonstration?

Challenge: progress from single-variable water-cycle instruments to multivariable integrated instruments.

Vision: dedicated high-resolution water-cycle microwave-based satellite mission may be possible based on large-aperture antenna technology that can harvest the synergy that would be afforded by simultaneous multichannel active and passive microwave measurements.

Demonstration: A partial demonstration of these ideas can be *realized with existing microwave satellite observations to support advanced multivariate retrieval methods that can exploit the totality of the microwave spectral information*.

Impact: *Simultaneous multichannel active and passive microwave retrieval would allow improved-accuracy retrievals that are not possible with isolated measurements.*



Water & Energy Conservation

$$\frac{\partial Q}{\partial t} = E - P + \mathrm{MC} + \mathrm{RESQ}'$$

$$\frac{\partial W}{\partial t} = P - E - N + \mathrm{RESW}'$$

$$C_p \frac{\partial \{T\}}{\partial t} = \mathrm{QR} + \mathrm{LP} + \mathrm{SH} + \mathrm{HC} + \mathrm{REST}'$$

$$C_v \frac{\partial \{T_s\}}{\partial t} = \mathrm{QRS} - \mathrm{LE} - \mathrm{SH} + \mathrm{RESG}'$$

Parallel linked RT forward models

Water Variable

Energy Variable

Flux Variable

Observations

Iteration/inversion

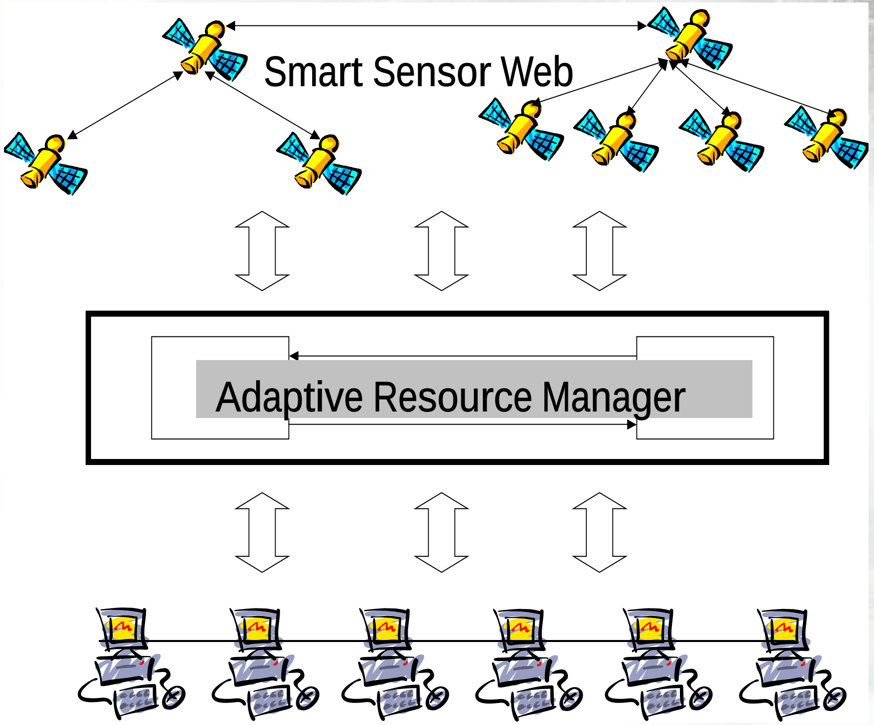
Today:

Large space-based Observatories

Single sensor retrievals
Spatial/temporal inconsistency
Parameter-driven requirements

Tomorrow:

Integrated environmental information system



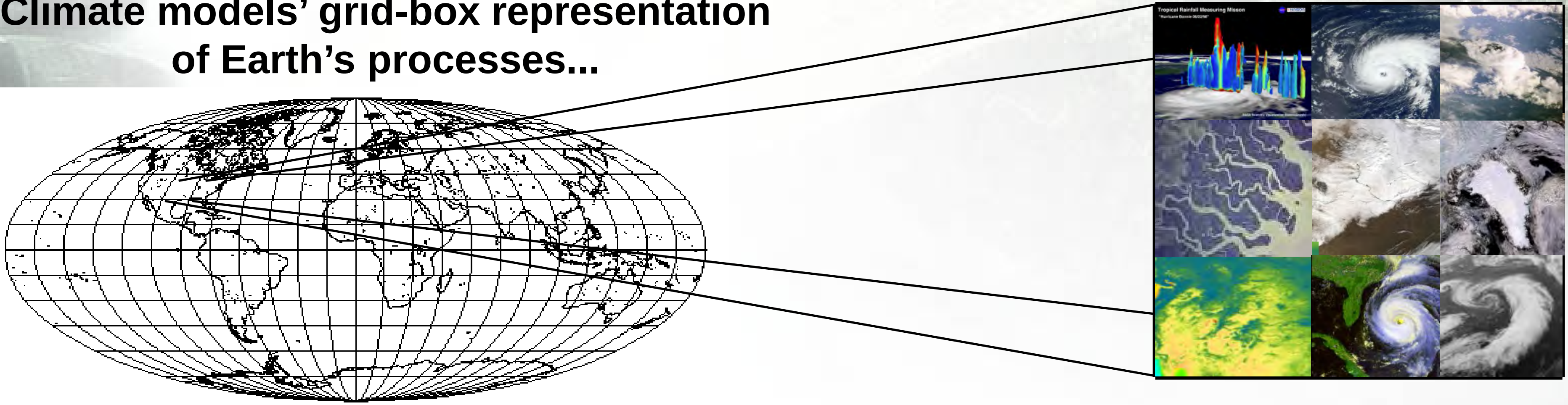
Smart Sensor Web

Adaptive Resource Manager

- Coordination for distributed monitoring, processing, and decision making
- Easy deployment of technology and scalability
- Multiple sensor retrievals
- Spatial/temporal consistency
- Integrated cross-sensor calibration
- System-driven requirements
- Reconfigurable ground and space information systems

Advance Understanding and Model Physics

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.

How can climate models effectively represent the controlling processes of the global water cycle?

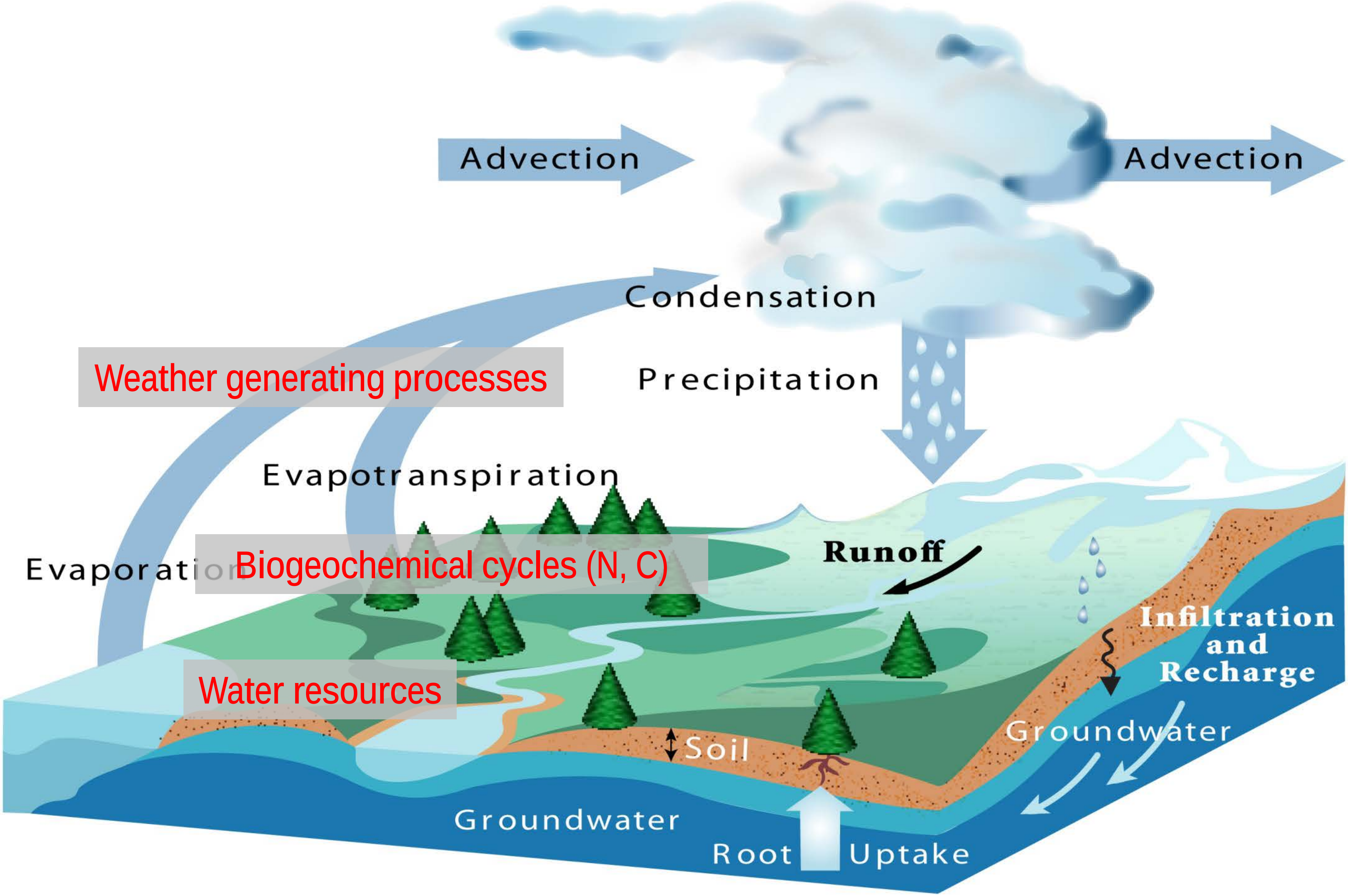
“Conventional” approach: make the model grid-boxes smaller (increase resolution)

- Slow progress: may take ~50 years to be computationally feasible

Breakthrough approach: *Simulate a sample* of the small-scale physics and dynamics using high resolution *process-resolving models* within each climate model grid-box

- “Short-cut” the conventional approach (~10 years to implement)

Terrestrial hydrologic cycle: many coupled processes



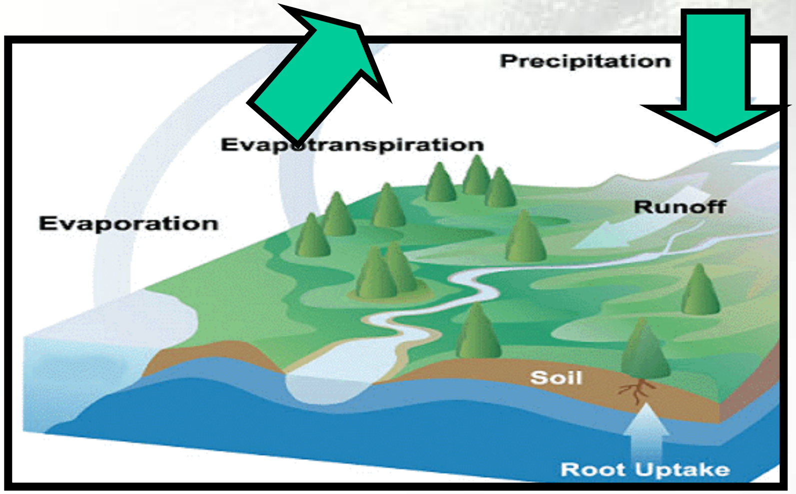
Weather generating processes

Biogeochemical cycles (N, C)

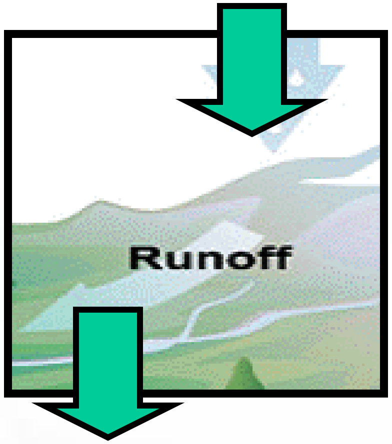
Water resources

Yet it is usually simulated with disconnected models

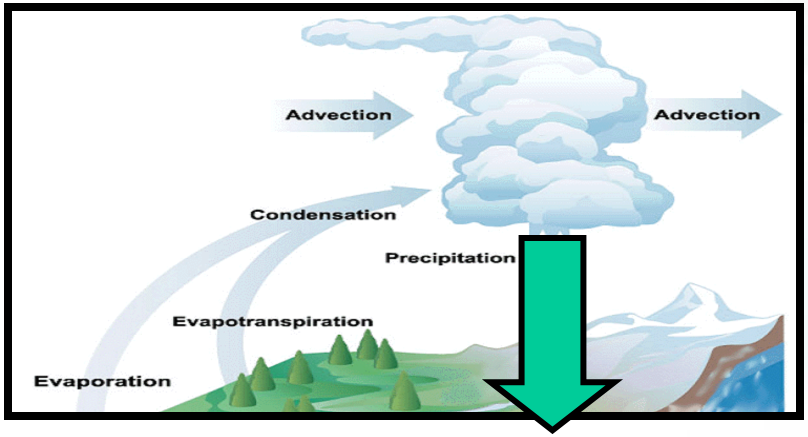
Groundwater/Vadose Model



Land Surface Model



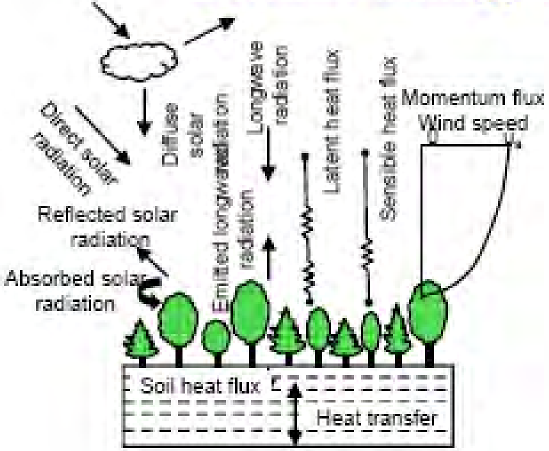
Surface Water Model



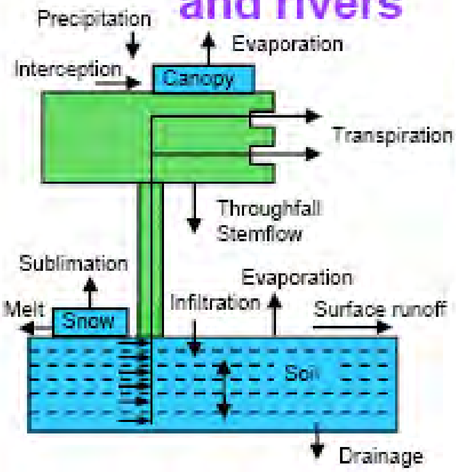
Atmospheric Model

CLM4 - First (zero) generation land component of ESM

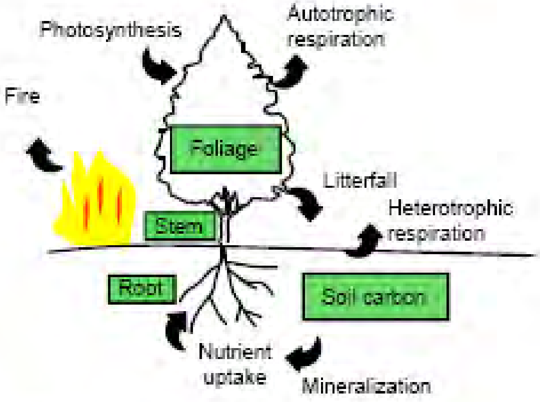
Surface energy fluxes



Hydrology and rivers

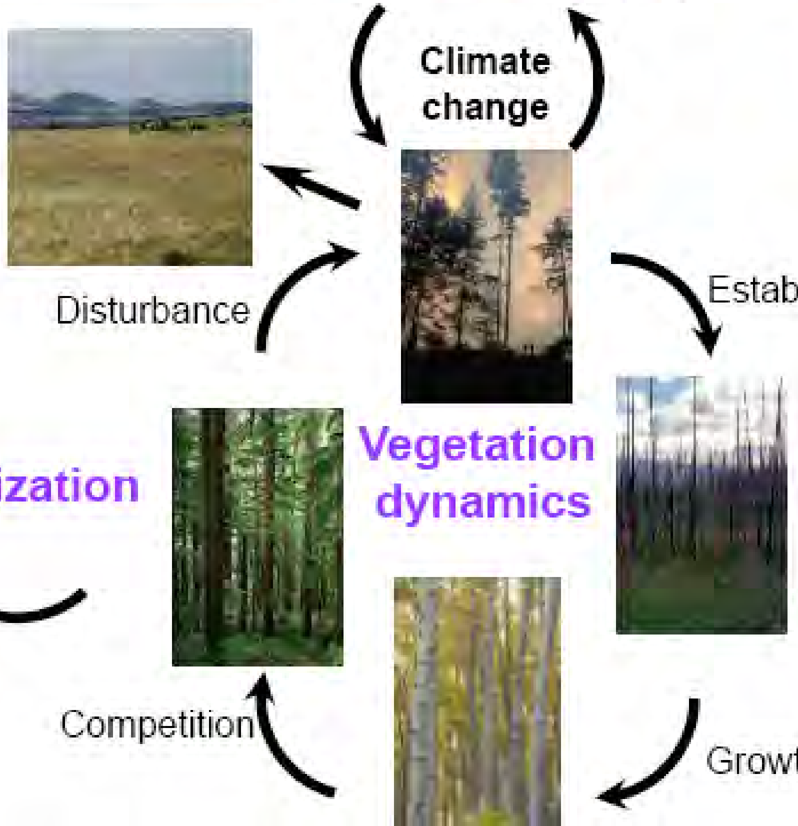


Carbon cycle



Ice sheets

Vegetation dynamics



Urbanization

Land use

Deforestation

Reforestation

Future of Hyper-Resolution Land Modeling

Future Land Modeling Grand Challenges:

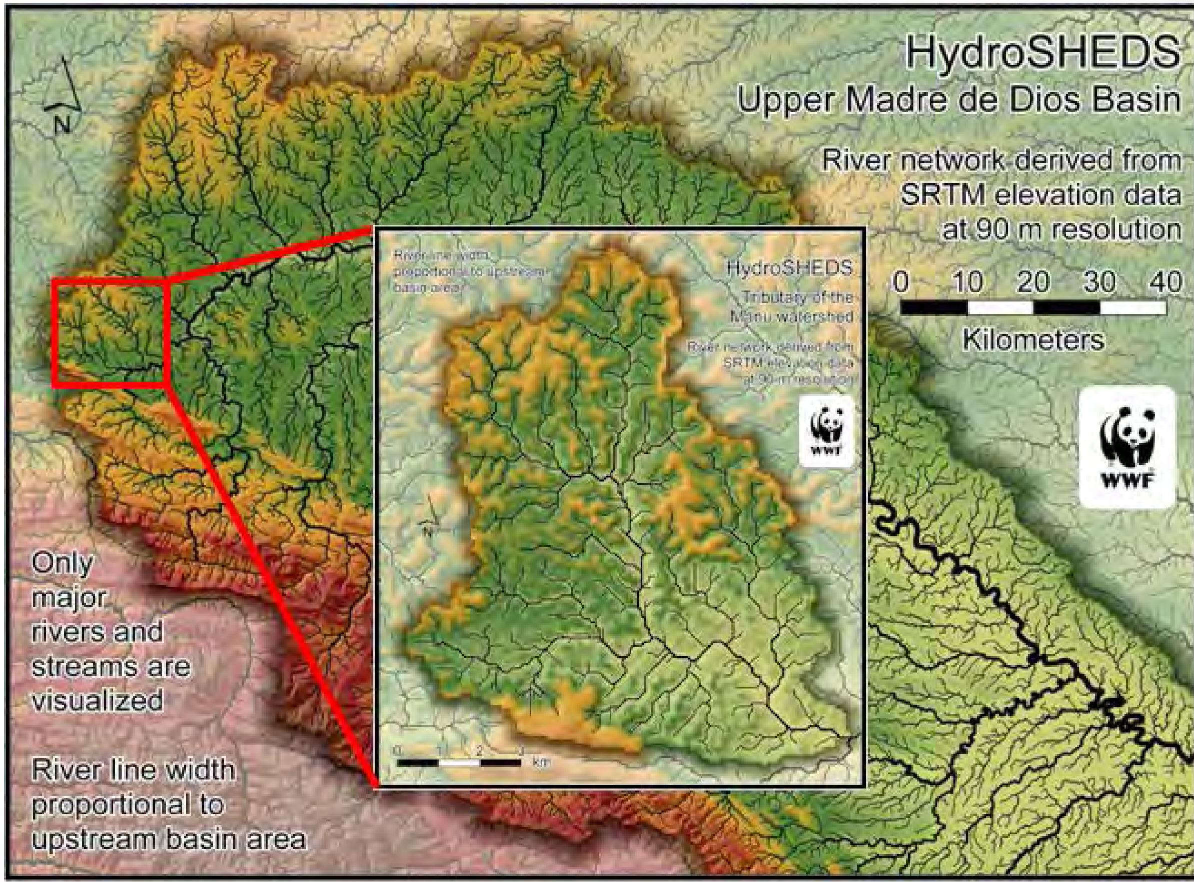
- Surface-Subsurface dynamics: Stream-Groundwater interaction, river networks, etc..
- Land-Atmosphere interactions: Small scale lateral feedbacks
- Water quality: Nutrient transport, CO2, and pollution
- Human Impacts: anthropogenic abstractions, urban, storage, diversions, land change.
- Computational considerations: Land Data Assimilation, Observations, etc.
- Observations & Data: how to use the observations to constrain, calibrate and learn

Wood et al., 2011

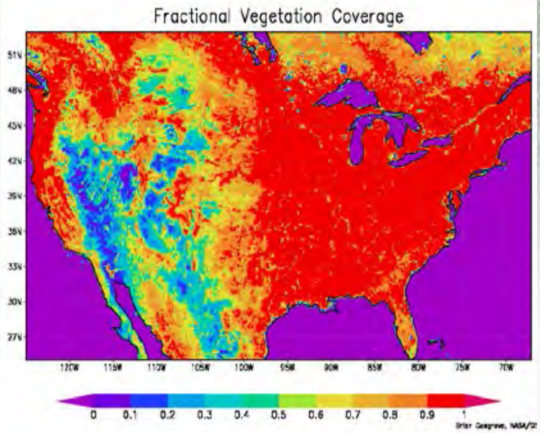
Goal:

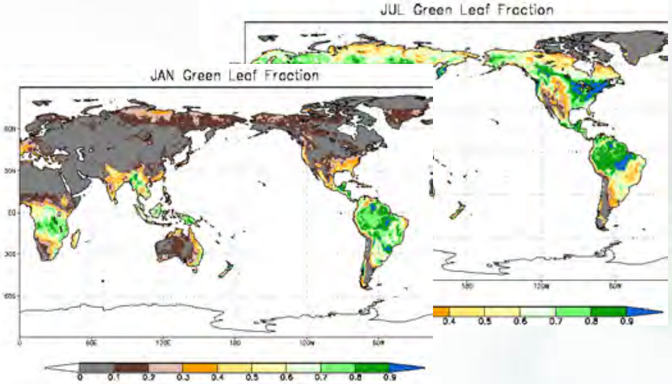
Progress toward a fully process-scale resolving model of land surface hydrology, atmospheric dynamics, and cloud processes over the global domain.

Integrate all obviously interdependent land-atmosphere processes into a common ultra-resolution (100's of meters) framework for Earth system modeling, through fusion of traditional land surface hydrology modules with boundary-layer turbulence and cloud process modules.



North American LDAS: Specifics 2





Vegetation: DeFries et al., University of Maryland

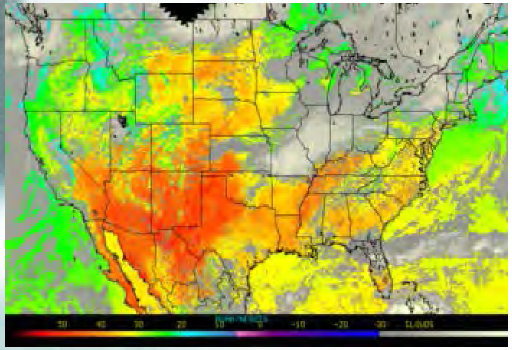
- Can be modified by 1km Max Fractional Vegetation, Zeng & Dickinson
- Seasonal cycle specified by NESDIS green vegetation product

Data Availability: Real-time and short-term retrospective

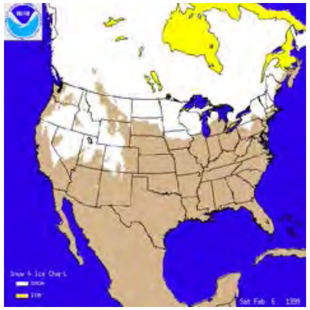
- "Modern" forcing available from 1996 - uses the same modern forcing and resolution as is used in the real-time LDAS

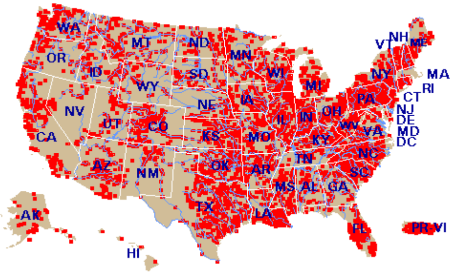
LDAS Forcing Product	Time Res.	Space Res.	Archive	Real-Time
Eta EDAS Analysis	3hr	40km	June 1996	5hr
Eta 3hr Forecast	3hr	40km	June 1999	5hr
Eta 6hr Forecast	6hr	40km	June 1996	5hr
NESDIS GOES SW dwn	1hr	1/2 degree	June 1999	2hr
Pinker GOES SW dwn	1hr	1/2 degree	Jan 1996	2hr
Stage-4 Gage-Radar Ppt	1hr	4, 15km	May 1996	10hr
RFC Gage-Only Precip	24hr	4km	Jan 1998	18hr
CPC Gage Only Precip	24hr	1/4 degree	July 1997	12,24hr

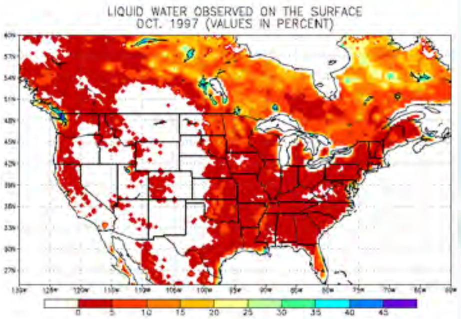
Other Data: GOES-Temps, Snow, Streamflow, SSMI Products



Skin temperature derived from NOAA/NESDIS GOES.



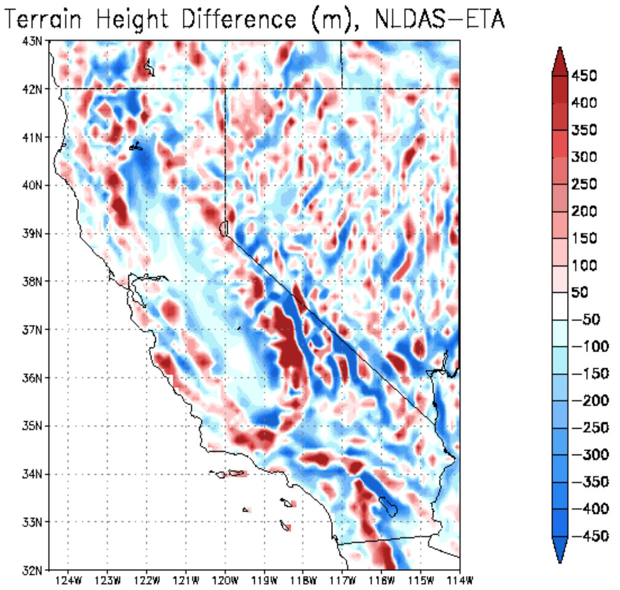


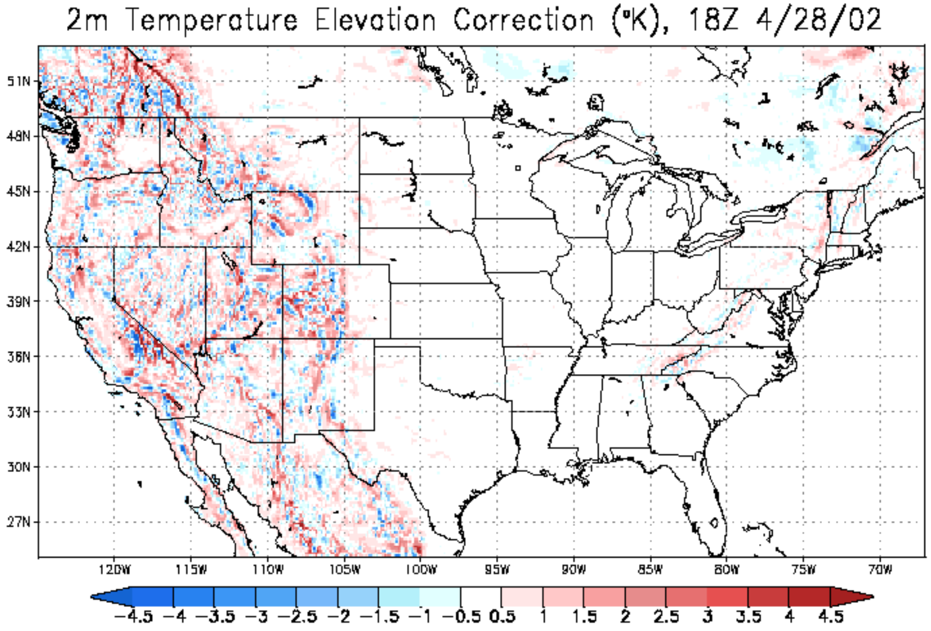


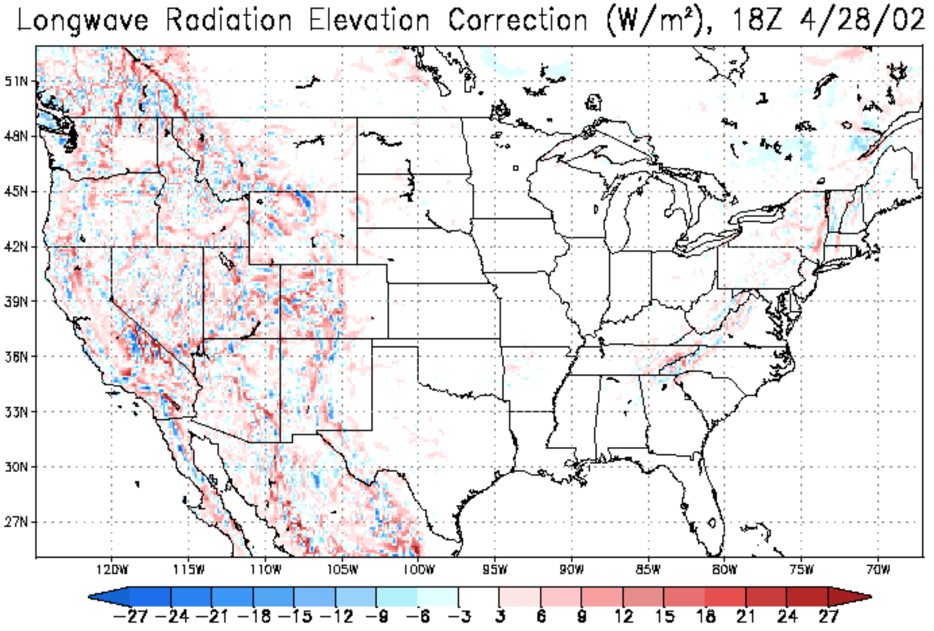
North American LDAS: Terrain Height Adjustment

- Quality of land surface model (LSM) output is closely to the quality of the meteorological forcing data used drive the model

- Temperature, pressure, humidity and longwave radia adjusted for terrain height using standard lapse rate a holding relative humidity constant
- Corrections of up to 6K, 120mb, $40W/m^2$, 2 g/kg


Terrain Height Difference (m), NLDAS−ETA

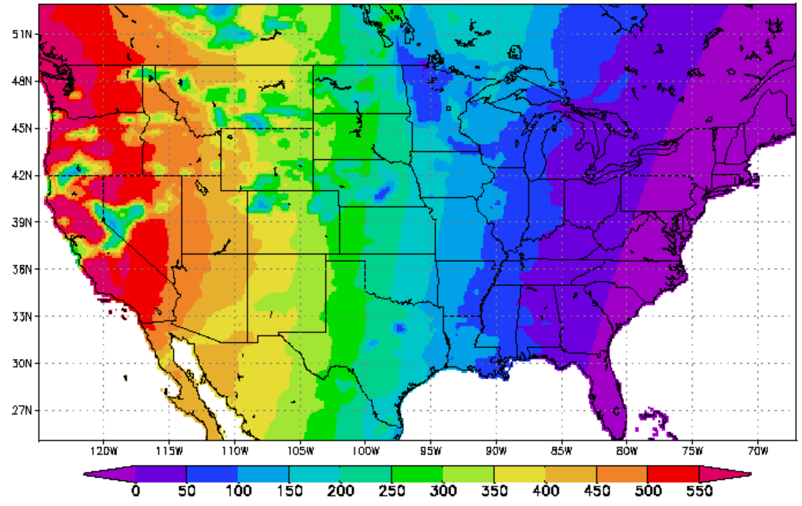

2m Temperature Elevation Correction (°K), 18Z 4/28/02


Longwave Radiation Elevation Correction (W/m²), 18Z 4/28/02

North American LDAS: Insolation

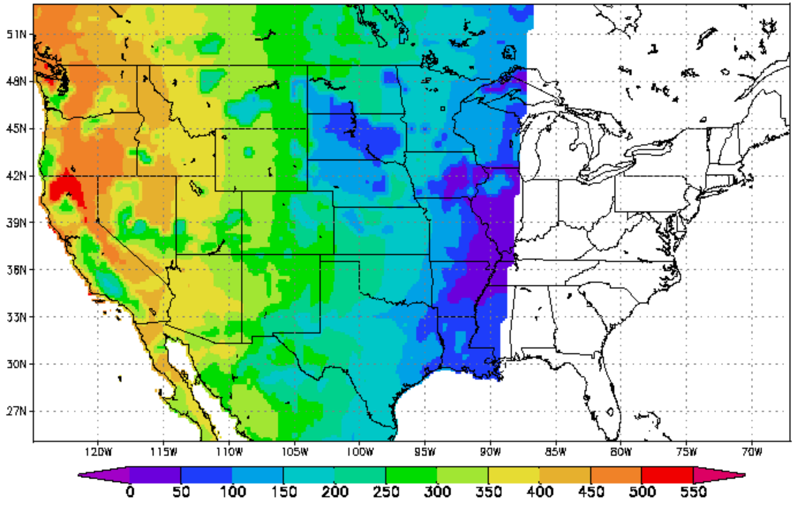
Model Surface Shortwave

EDAS Downward Shortwave Radiation (W/m²) 00Z 4/29/02



Geostationary Surface Shortwave

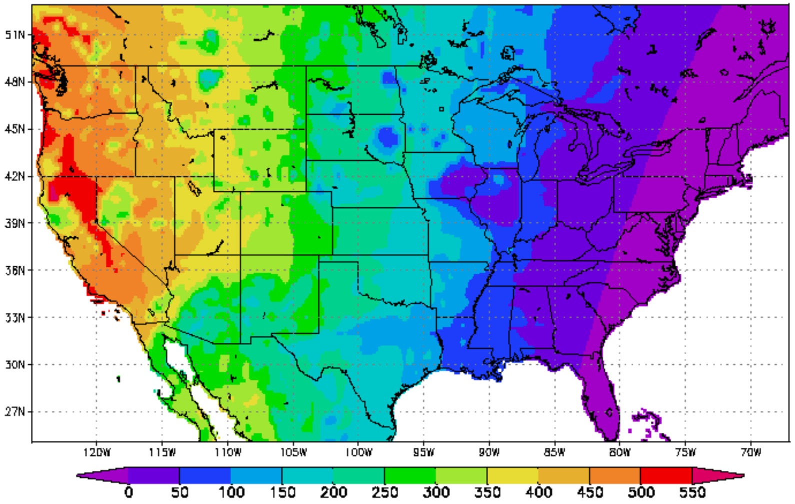
GOES Downward Shortwave Radiation (W/m²) 00Z 4/29/02



Combine

Merged LDAS Surface Shortwave

Merged Downward Shortwave Radiation (W/m²) 00Z 4/29/02



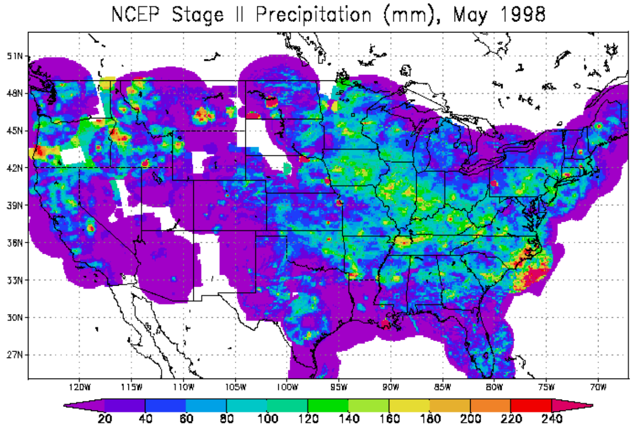
GOES shortwave radiation is zenith angle corrected, used in place of ETA data when possible

GOES undefined at low sun angles over eastern seaboard, so EDAS used in merged product as filler over this region

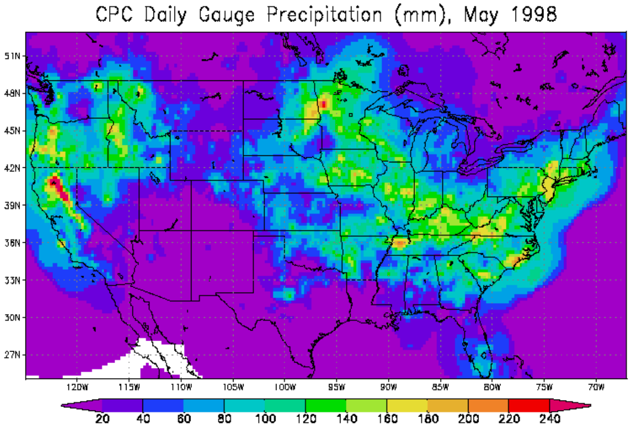
North American LDAS: Precipitation

Data	Advantages	Disadvantages
NCEP Stage II Doppler radar / RFC gauge	Hourly, 4km	Errors in radar magnitude Holes in coverage
CPC daily rain gauge data	Accurate	Coarse temporal resolution Sparse coverage over Canada, Mexico 0.25 Degree Resolution
CPC Reprocessed daily rain gauge data	Most accurate (additional stations and qc checks)	Coarse temporal resolution Light coverage over Canada, Mexico 0.25 Degree Resolution Only through 1998

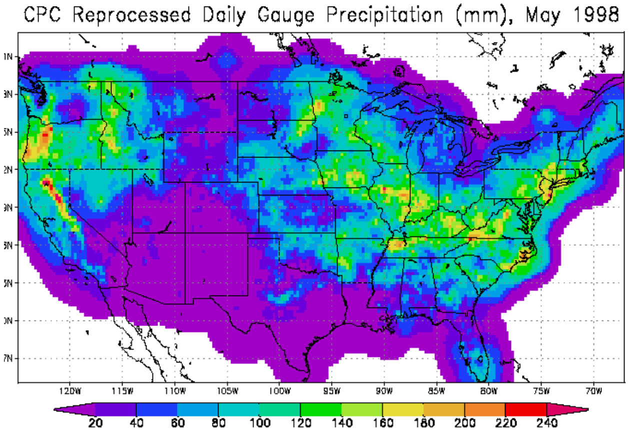
Doppler Radar Precipitation



Interpolated Gage Precipitation



Merged LDAS Precipitation



- Use ETA model, Stage II and CPC data to form best available product—a temporally disaggregated hourly CPC gage value

Global Hyper-resolution Terrestrial Forcing (HTF)

- PROPOSE: a global, hourly, 500-m Hyper-resolution Terrestrial Forcing (HTF) land surface weather boundary condition dataset (air temperature/humidity, wind, LW/SW radiation, pressure, precip), starting in 2010.

- APPROACH: Globally downscaled numerical weather forecast analysis first guess, integrated with satellite observed precipitation, radiation and temperature.

- Temporal and spatial downscaling will be performed using a combination of physically-based downscaling techniques (temperature/humidity lapse rate corrections, radiation slope corrections, land use, etc.) and validated with high-resolution weather observation networks.

- 5-year hyper-resolution (hourly, 500-m) terrestrial forcing dataset:
  - 135 million km^2 (excluding Greenland and Antarctica) = 540 million pixels
  - Dataset approaching 1-pb (uncompressed).

HTF Datasets

- Near-Real Time Atmospheric Analysis:
  - NASA GEOS-5: Real Time Met Analysis, 5/16 x ¼-deg (5-km by 2016).
  - NOAA Global Forecast System (GFS) : 27-km (July 2010), and T1534 (13km) in 2014.
  - ECMWF Integrated Forecast System: T1279 (16-km) since January 2010.
- Precipitation Products: (now GPM)
  - TRMM Multi-satellite Precipitation Analysis (TMPA): 3-hr, 0.25-deg, 60S-60N.
  - Hydro-Estimator: ½-hr, 0.045-deg, 60S-60N:
  - PERSIANN: ¼ degree – 4km, ½-hr, 60S-60N:
  - CMORPH: ½-hr, 8-km, 60S-60N:
  - GSMaP: ½-hr, 0.1-deg, 60S-60N:
- Radiation Products:
  - SRB Surface Radiation Budget (SRB): global 1-deg, 3-hr, surface LW and SW:
  - UMD (R. Pinker): 3-hr, ½ deg, surface incident longwave and shortwave:
- *Elevation Products:*
  - SRTM: 30 to 90-m:
  - Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010): 250-m global:
  - ASTER Global Digital Elevation Model Version 2 (GDEM V2): 30-m global:
- *Land Use Products:*
  - MODIS Land Cover: Yearly 500-m global:
  - MODIS Vegetation Indices 16-Day Global 250-m:
- Satellite Air Temperature: Global 4-km 60N-60S, ½-hr IR temperatures from geostationary.
- High-resolution weather networks: *DOE-ARM sites and the Oklahoma mesonet.*

Physical Downscaling

- Spatial Interpolation to the 500-m hourly grid (conservation interpolation).
- Temporal Interpolation: (linear except for SW zenith angle interpolaton).

- Physical corrections:
  - Topography corrections to temperature, humidity, longwave radiation.
  - Land use and land cover Temperature Corrections – generally temperatures are cooler near water or forests, and hotter near cities and bare ground.
  - Precipitation Corrections: elevation and orography (PRISIM), NDVI disaggregation
  - Terrain Adjustments: slope-aspect correction to shortwave radiation, wind corrections.
  - Roughness correction: wind field correction based on land cover information and topographic data.
  - Adjust variance: include missing small-scale variance with available high-resolution data from research networks or mesonets.

- Observation corrections:
  - Integrate high-resolution observations when available
    - Geostationary radiation & temperature, satellite precipitation, etc..

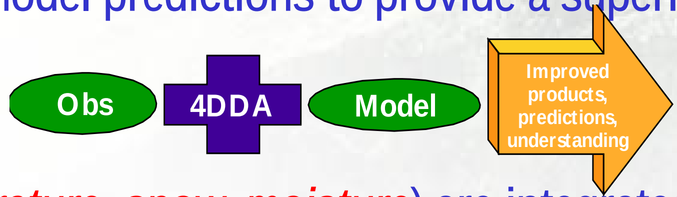
- Quality Control and Uncertainty Evaluation
  - *Theory, realism or sanity checks*; *Buddy checks*; *Background checks; Bias determination and correction*; *Observation withholding*

- *Other downscaling ideas?*

Data Assimilation

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

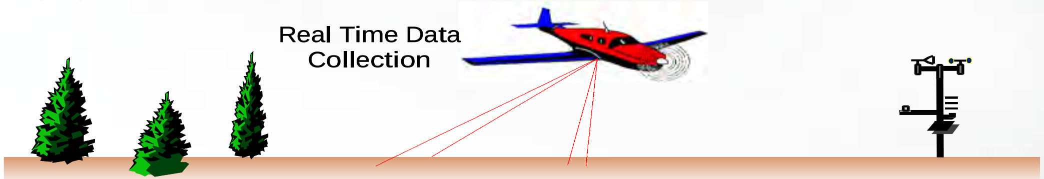
$$\partial x / \partial t = dynamics + physics + \Delta x$$



Land State or storage observations (*temperature, snow, moisture*) are integrated with models.

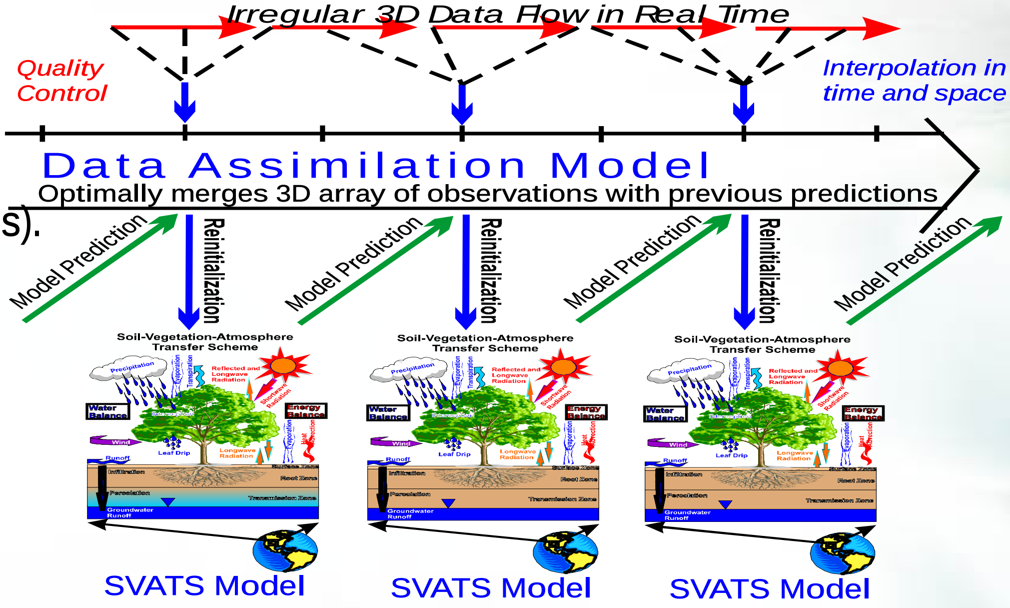
Data Assimilation Methods: Numerical tools to combine disparate information.

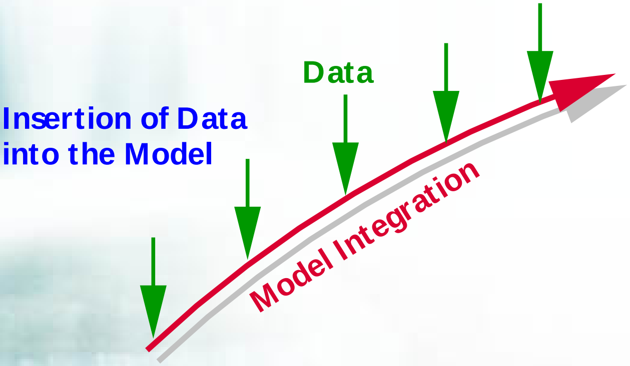
1. Direct Insertion, Updating, or Dynamic Initialization:
2. Newtonian Nudging:
3. Optimal or Statistical Interpolation:
4. Kalman Filtering: EKF & EnKF
5. Variational Approaches - Adjoint:



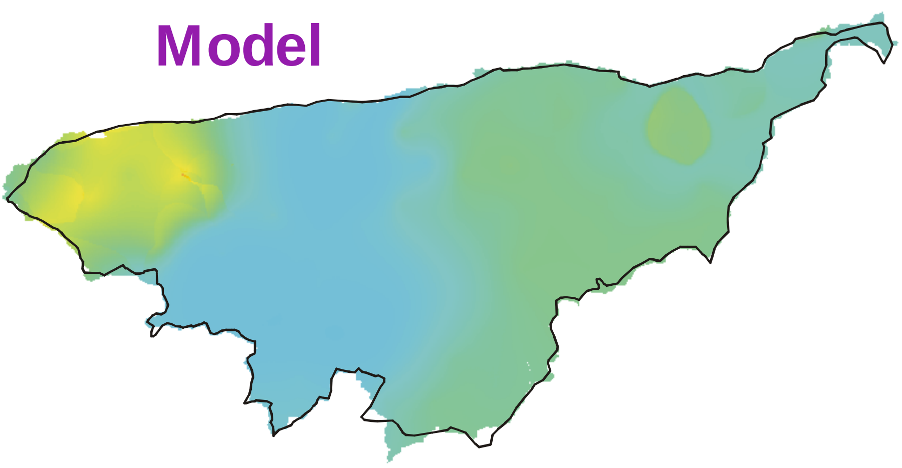
Observations have error and are irregular in time and space

- Model errors result from:
- Initialization error.
- Errors in atmospheric forcing data.
- Errors in LSM physics (model not perfect).
- Errors in representation (sub-grid processes).
- Errors in parameters (soil and vegetation).

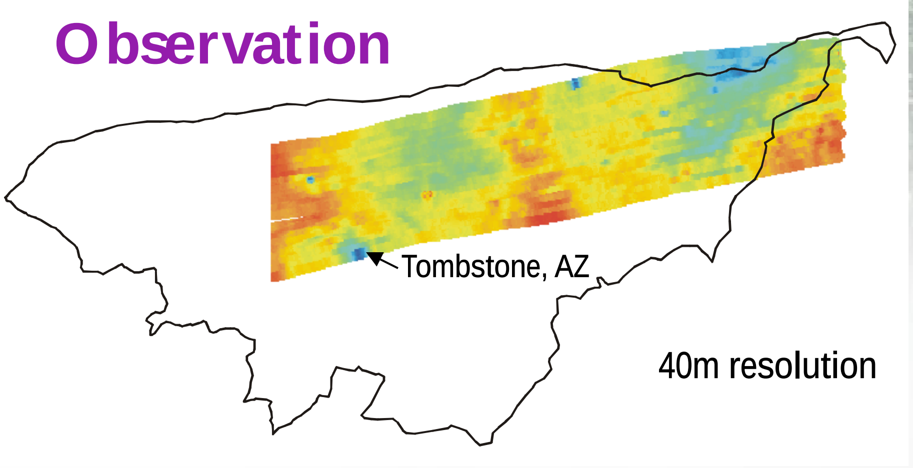




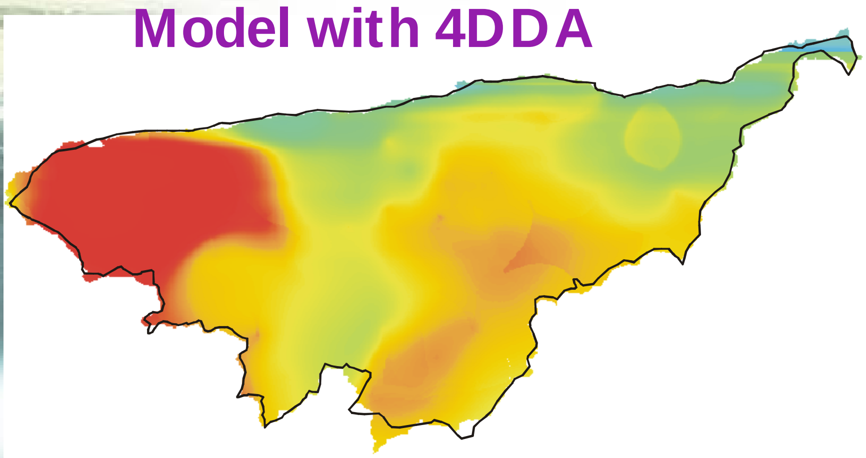
Soil Moisture Assimilation: Walnut Gulch (Monsoon 90)



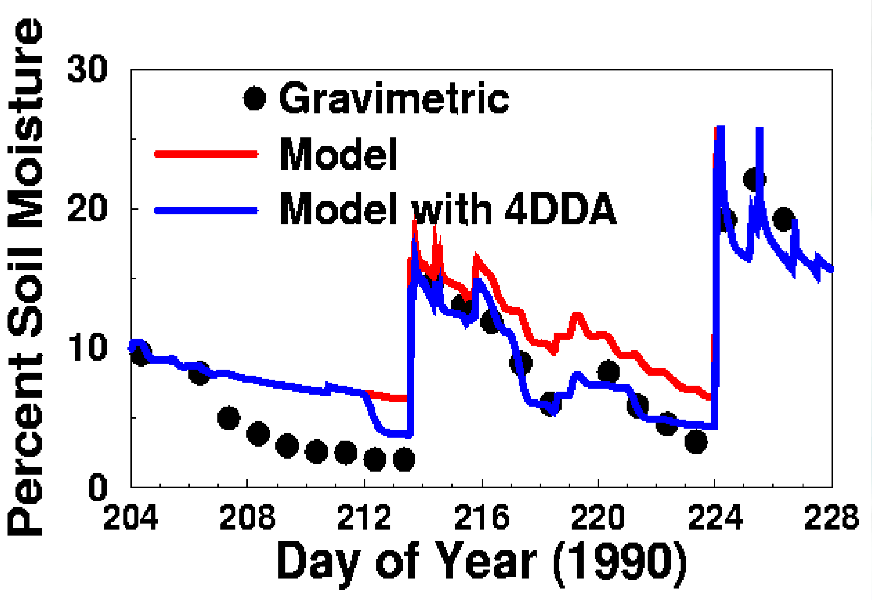
Model



Observation



Model with 4DDA



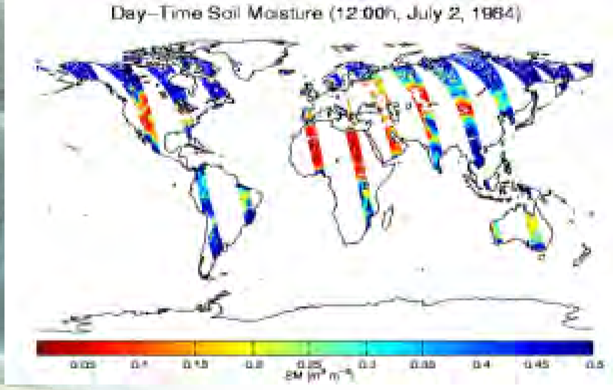
Houser et al., 1998

Land Surface Data Assimilation Summary

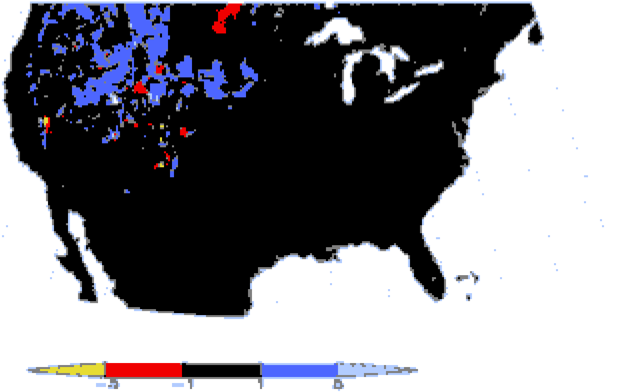
Data Assimilation merges observations & model predictions to provide a superior state estimate.

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.

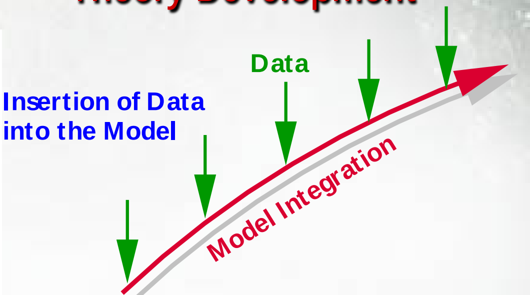
Soil Moisture Assimilation



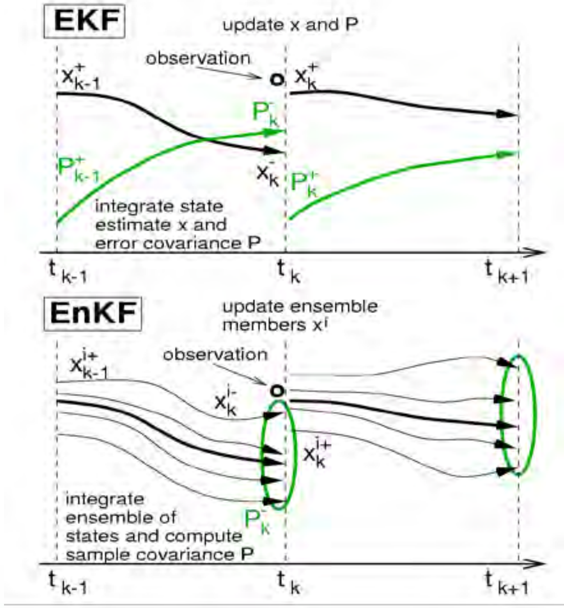
Snow Cover Assimilation



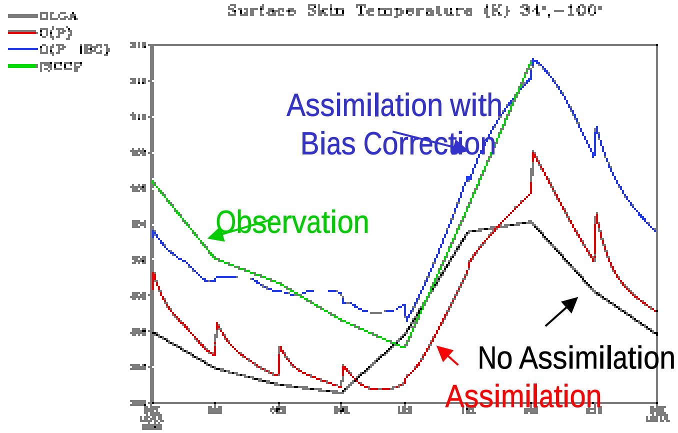
Theory Development



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



Skin Temperature Assimilation



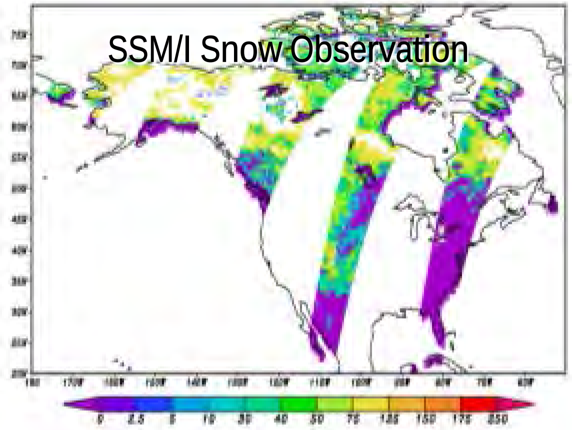
Assimilation with Bias Correction

Observation

No Assimilation

Assimilation

Snow Water Assimilation



Land Data Assimilation: Future

Data Assimilation Algorithm Development:

- Land models are highly nonlinear -> push for *model independent assimilation algorithms*.
- *Radiance Assimilation* – use forward models in the assimilation to assimilate brightness temperatures directly.
- *Link calibration and assimilation* in a logical and mutually beneficial way.
- Understand the potential of data *assimilation downscaling*

Land Modeling:

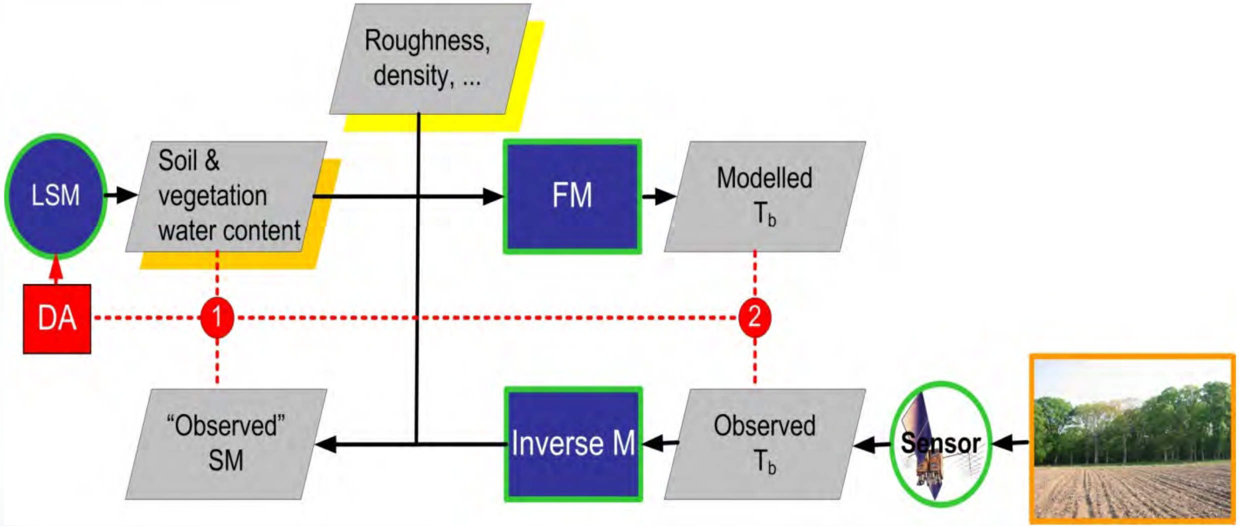
- Better *correlation* of land model states with observations
- Advanced processes: *River runoff/routing*, *vegetation and carbon dynamics, groundwater interaction*
- Parallel development of land model and their *adjoints*

Assimilate new types of data:

- Hyper-Spectral Active Passive Forward Model(s) for multi-variate water cycle retrieval
- Streamflow, Vegetation dynamics, and Groundwater/total water storage (Gravity)
- Boundary layer structures/evapotranspiration
- OSSE’s for optimizing future system planning

Coupled feedbacks:

- Understand the impact of land assimilation feedbacks on coupled system predictions.



Land Information System

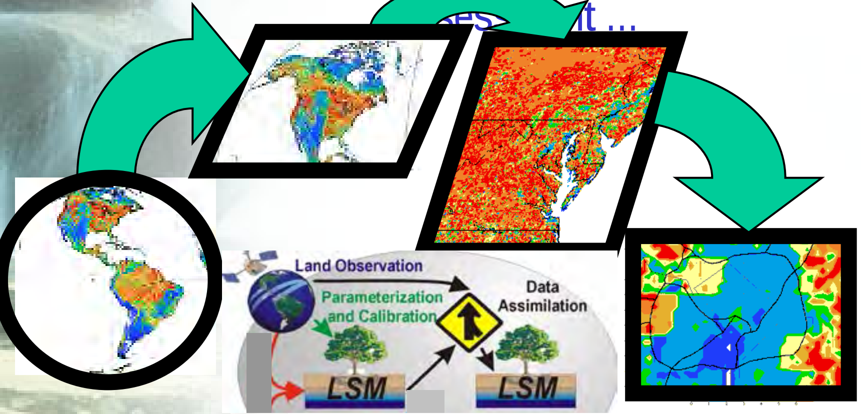
http://lis.gsfc.nasa.gov

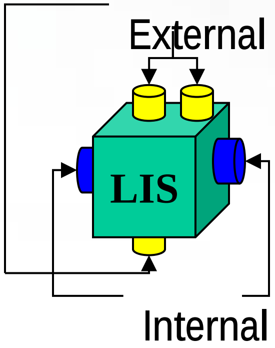
Co-PIs: P. Houser, C. Peters-Lidard

2005 NASA SOY co-winner!!

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

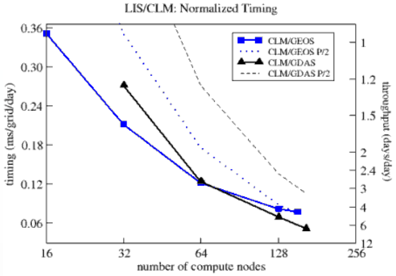
Applications: Weather and climate model initialization and coupled modeling, Flood and water resources, precision agriculture, Mobility ses it ...

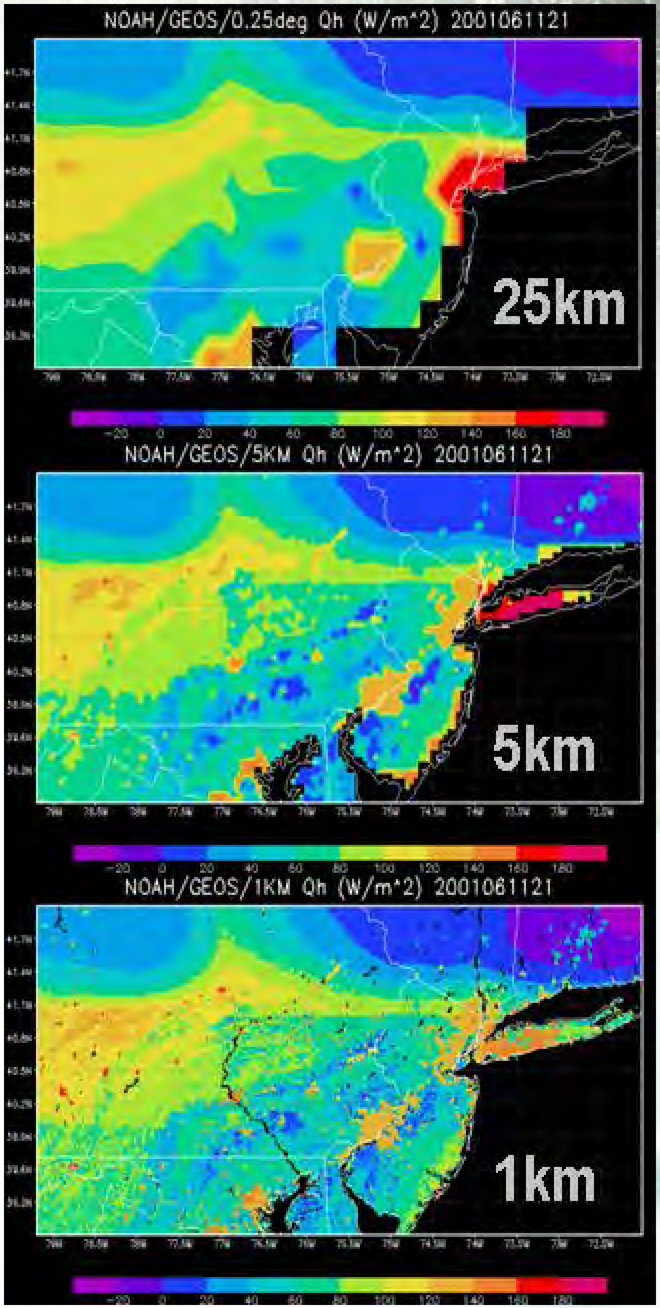




	Memory (MB)	Wallclock time (minutes)	CPU time (minutes)
LDAS	3169	116.7	115.8
LIS	313	22	21.8
reduction factor	10.12	5.3	5.3

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

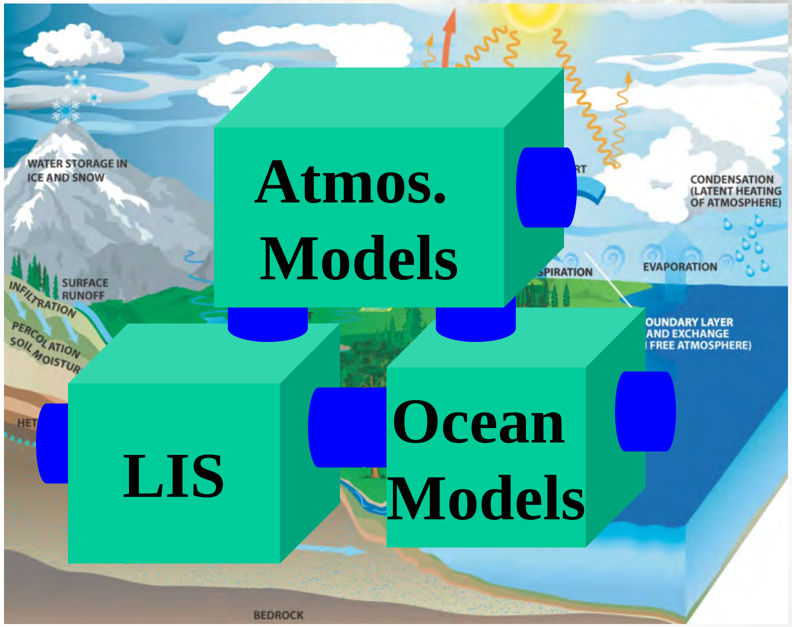




LIS: Enabling Process-Resolving Earth System Models

LIS uses interoperability standards:

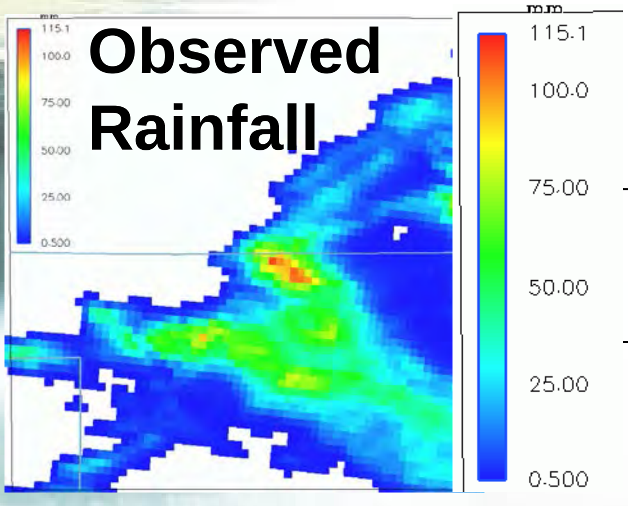
- The Earth System Modeling Framework (ESMF)
- Assistance for Land Modeling Activities (ALMA)
- GrADS Data Server (GDS)
- Open-source Project for a Network Data Access Protocol (OPeNDAP)



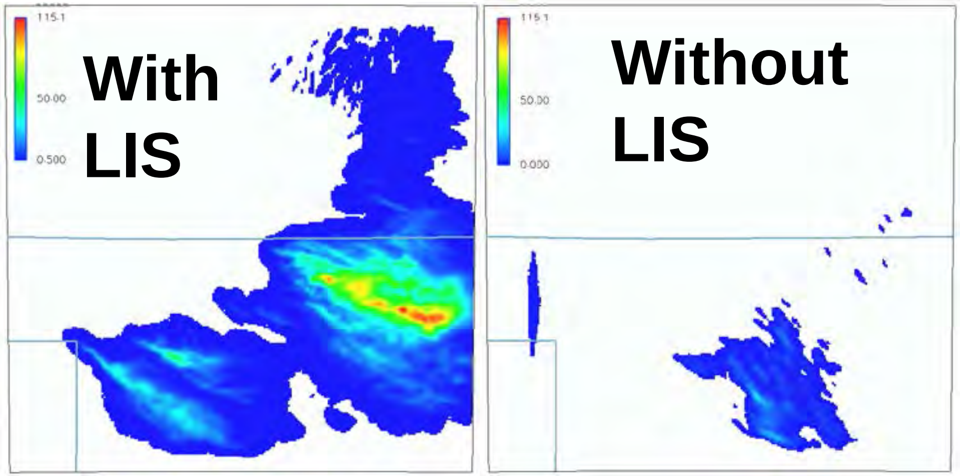
Enables LIS integration with other components:

- Weather Research and Forecasting (WRF) model
- Goddard Cumulous Ensemble (GCE) model
- etc.

LIS Impact Example: Coupling LIS to a Weather Model



12-Hours Ahead Atmospheric Mod
Forecasts

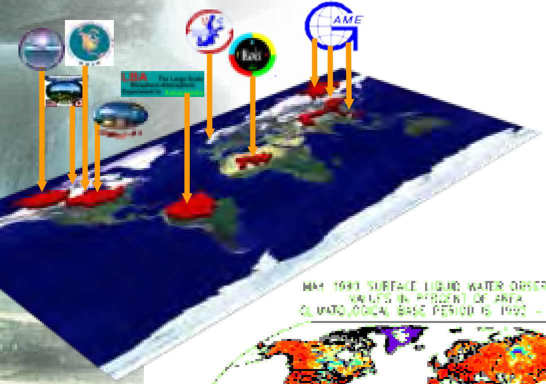


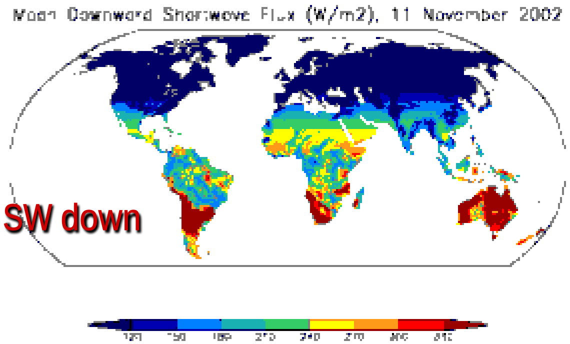
Paul R. Hous

Global Land Data Assimilation System

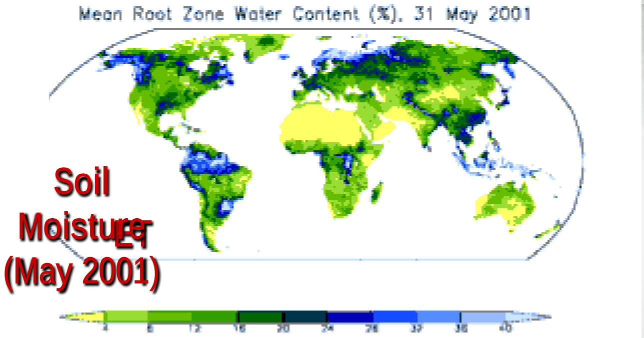
Objective: A 1/4 degree (and other) global land modeling and assimilation system that uses all relevant observed forcing, storages, and validation. Expand the current N. American LDAS to the globe. 1km global resolution goal

Consistent Global Intercomparison

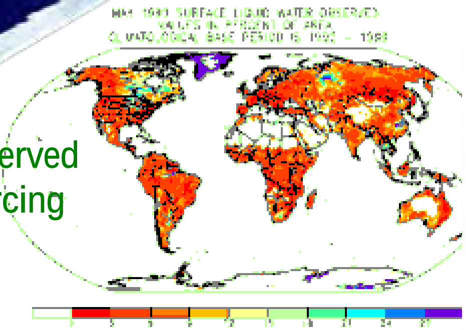




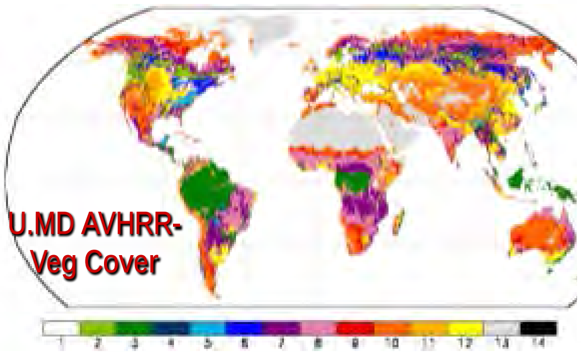
SW down



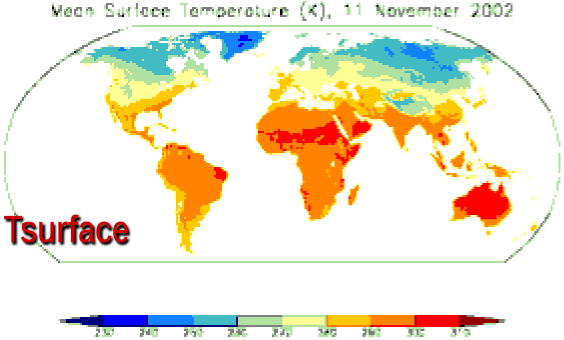
Soil Moisture ET (May 2001)



Observed Forcing

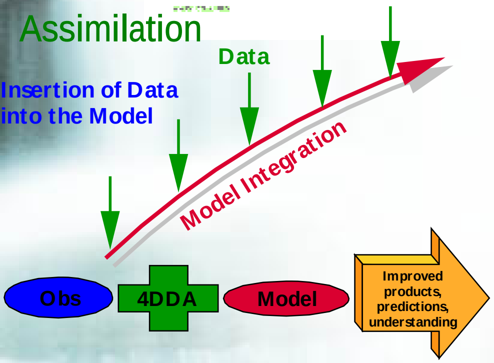


U.MD AVHRR-Veg Cover



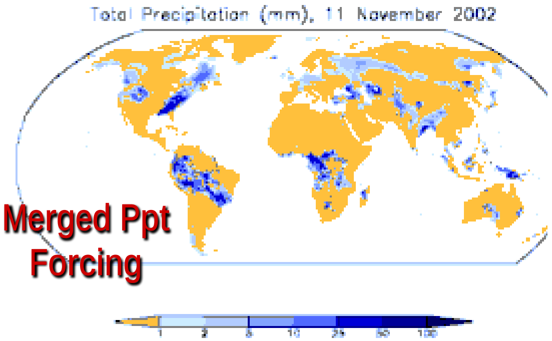
Tsurface

Land Data Assimilation

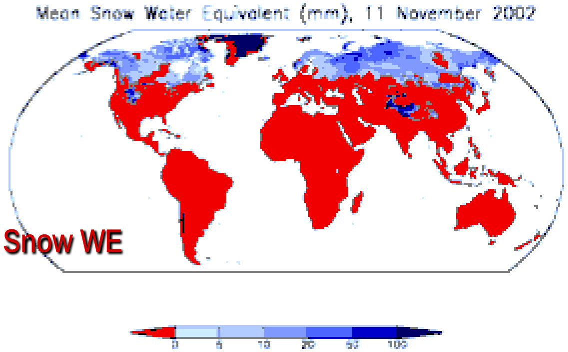


Insertion of Data into the Model

Obs
4DDA
Model
Improved products, predictions, understanding



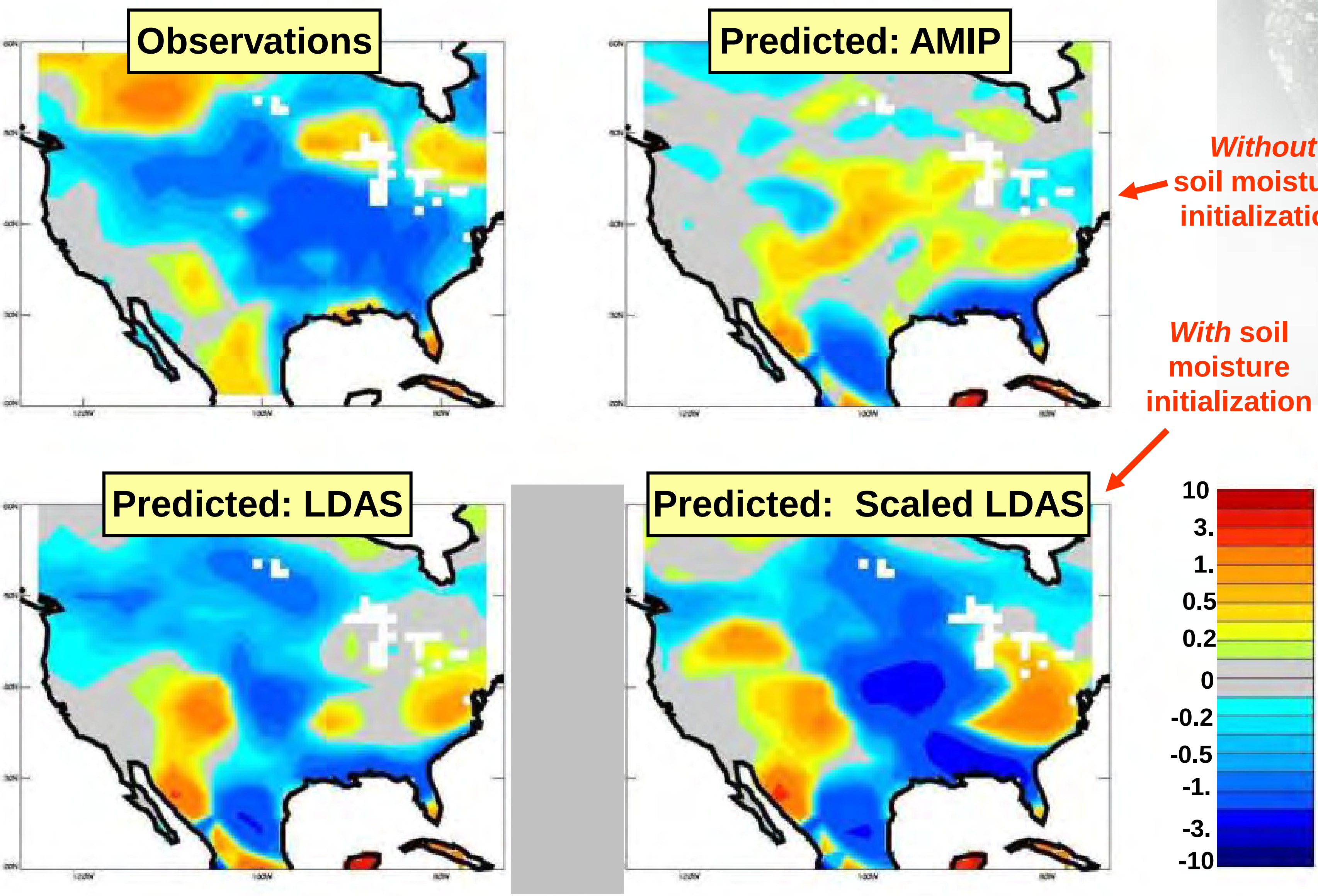
Merged Ppt Forcing



Snow WE

Coupled Model Forecast: 1988 Midwestern U.S. Drought

(JJA precipitation anomalies, in mm/day)



Observations

Predicted: AMIP

Predicted: LDAS

Predicted: Scaled LDAS

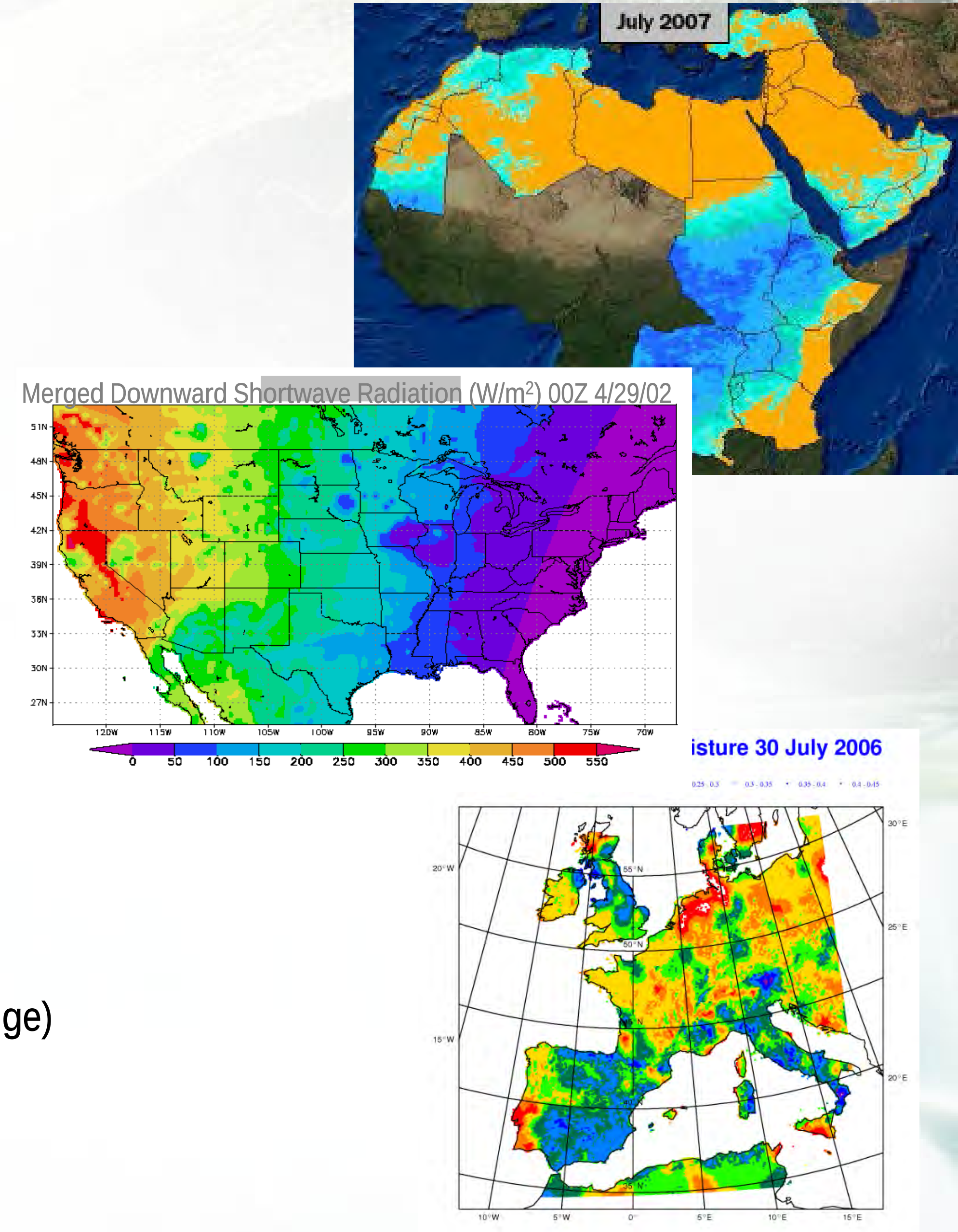
Without soil moisture initialization

With soil moisture initialization

Koster et al., 2004

Summary of Selected LDAS Projects

Global	GSWP (Dirmeyer)
MENA	A-LDAS (Bolton)
U.S.	NLDAS (NOAA/NASA)
Global	GLDAS (Rodell)
S. America	SALDAS (Degoncalves)
Europe	ELDAS (Van Den Hurk)
West Africa	AMMA/African LDAS
Japan	CALDAS (Koike)
Korea	KLDAS (Byun)
Canada	CALDAS (Belair)
Australia	Australian LDAS
France	French LDAS (Boone)
U.S.	HRLDAS (Chen)
U.S.	Ameriflux DAS (Oak Ridge)
	EO-LDAS (ESA)
China	CN-LDAS (Xin)

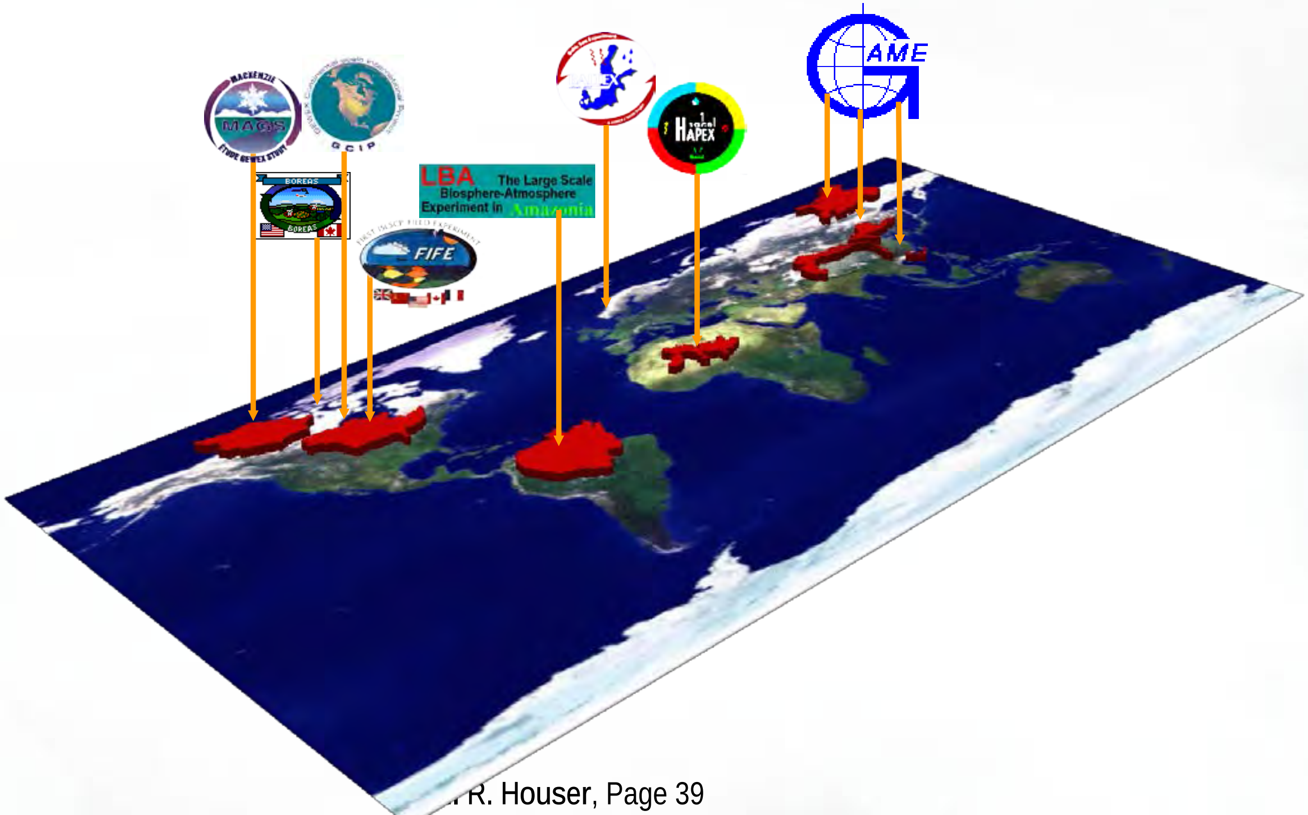


Vision: A near-real time "patched" Global LDAS

Action: Overlay high-res regional LDAS model forcing and output over baseline low-res GLDAS model for best local information

Advantage: Share land-hydrology data/forcing globally in a Hydrologic "GTS" framework

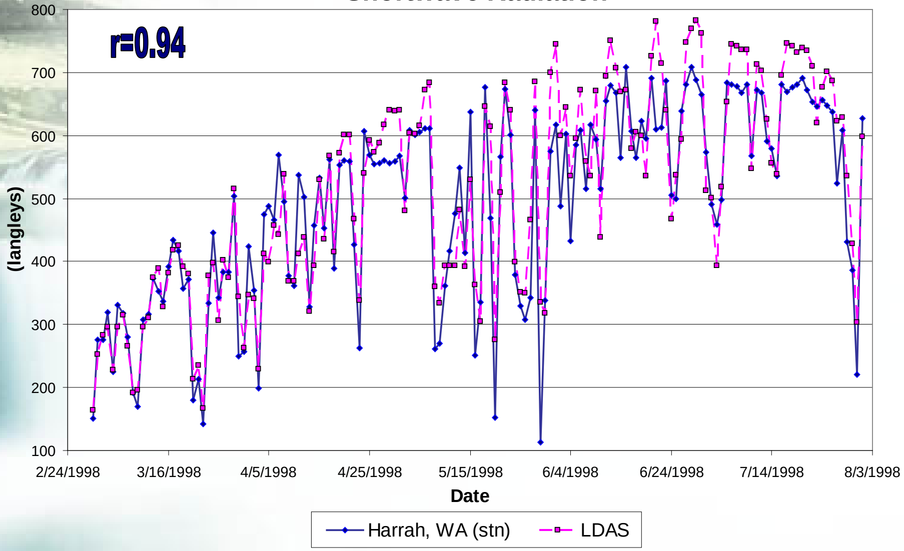
Issues: Global consistency studies

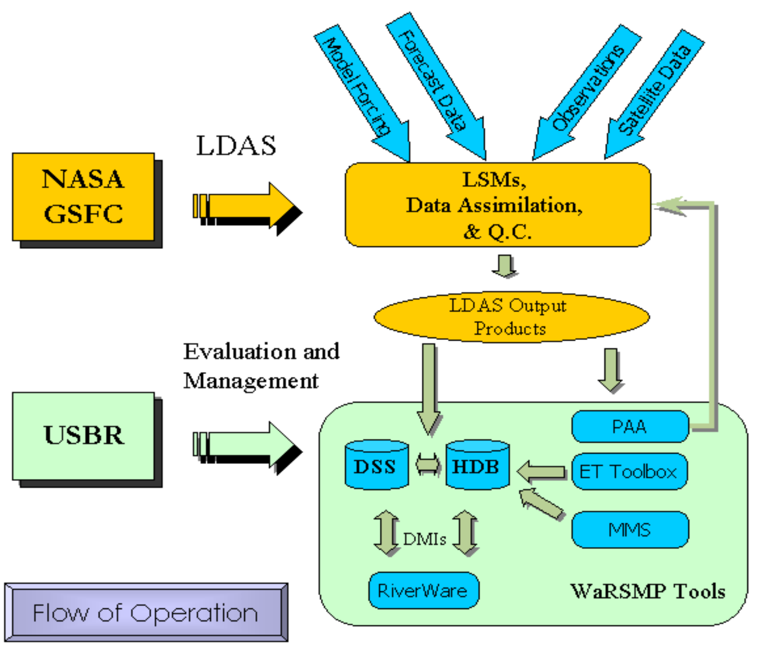


Linking to Water Resource Applications

- ➢ Collaborating with other agencies, e.g., the U.S. Bureau of Reclamation, to integrate the use of LDAS products in water resource management issues
- ➢ Developing retrospective studies and working to maintain land surface model simulations in both near real-time and forecast settings to be used by water resource managers and policy/decision makers

Harrah, WA. Station Compared to LDAS: 1998 Downward Shortwave Radiation

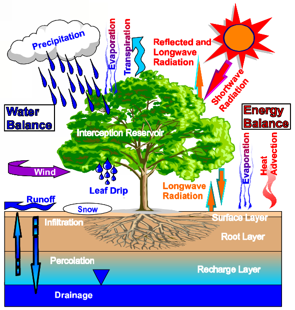




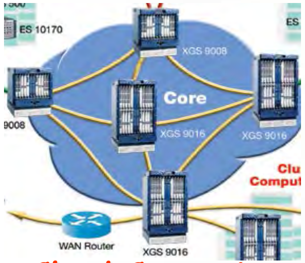
- ➢ **Evaluation of NLDAS in on-going case investigations to monitor and forecast extreme flooding and drought events**
- ➢ **Produce successful demonstration of these applications-based studies and begin applying to other countries facing water resource-related issues**

Observation and prediction tools are advancing

Satellite Sensor Web

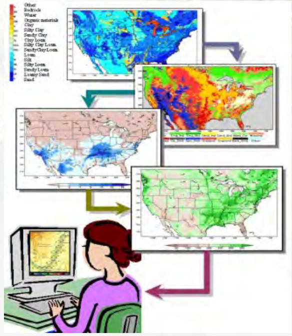


Prediction Models



Cloud Computing

?



Decision Support Systems

Critical Application

Can we link these advanced tools reduce uncertainties in end-uses?

A vision for the future:

Ultra-high resolution integrated water cycle observation and prediction system

- Integration of
  - Hyper-spectral microwave water cycle sensors or smart sensor webs (in-situ, airborne, and space-based)
  - Ultra-High resolution high-performance prediction systems (Global-scale, locally relevant)
  - Advanced data assimilation and calibration systems
  - Decision support tools (planning, management, operations)