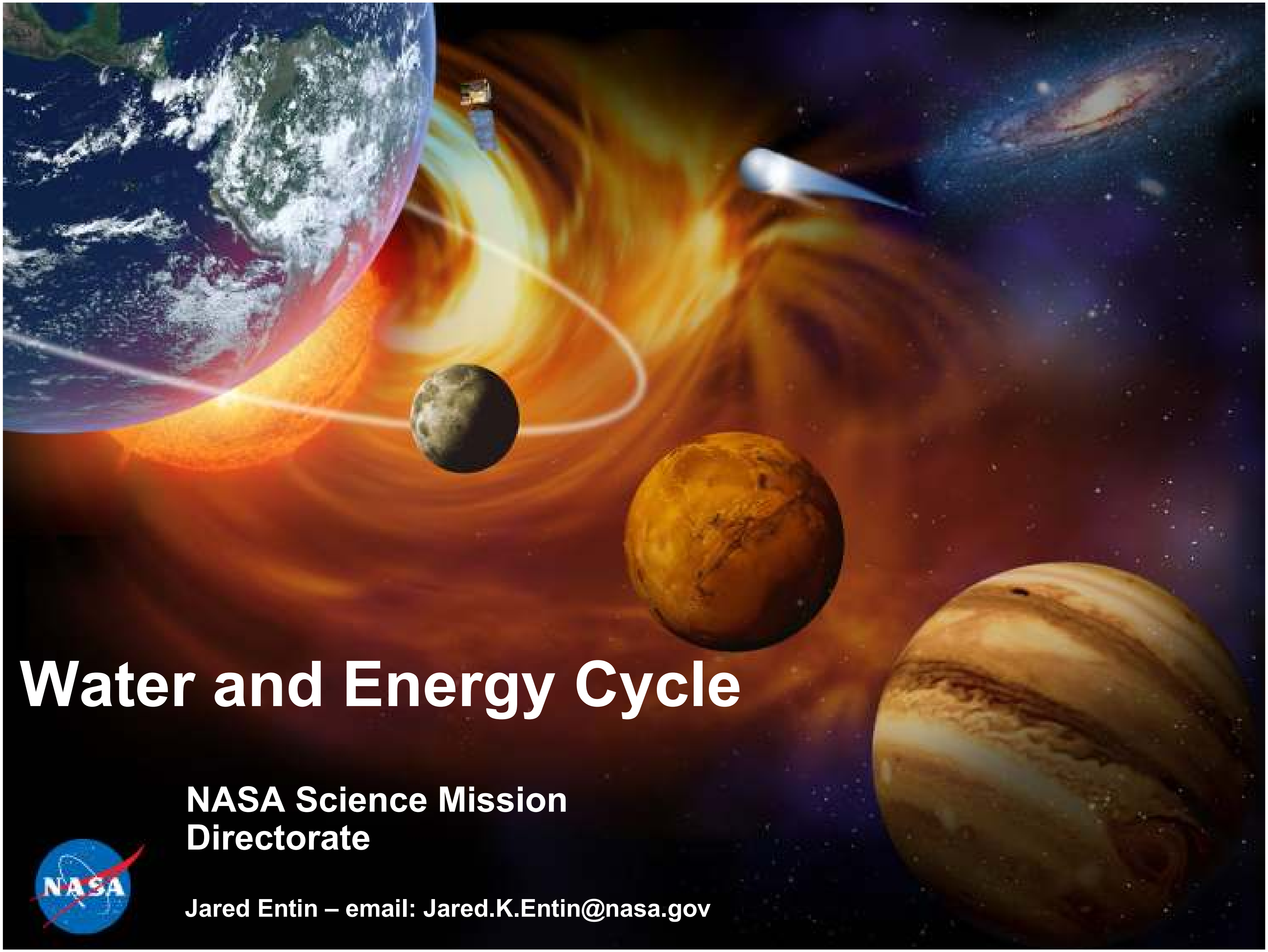
Water and Energy Cycle

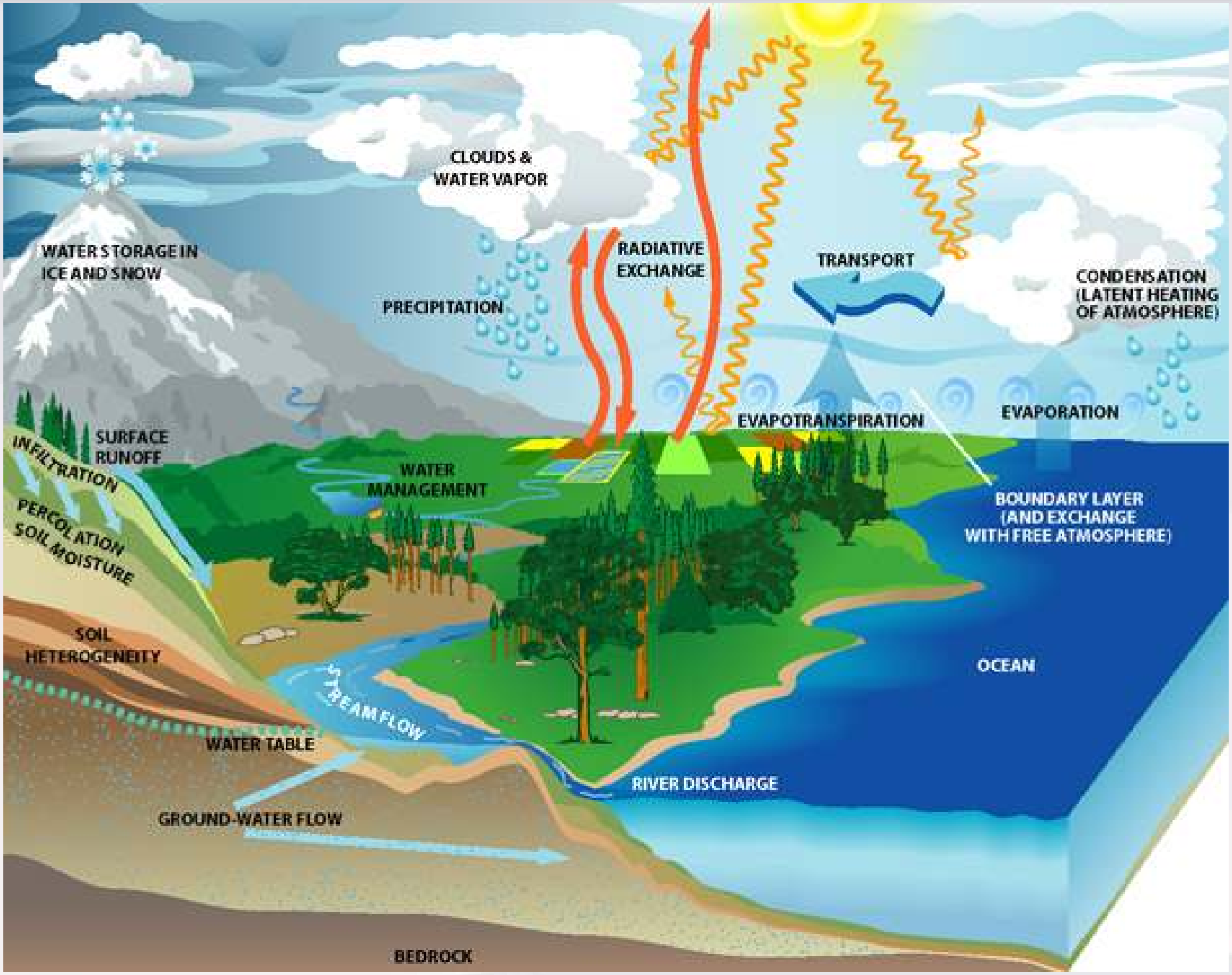


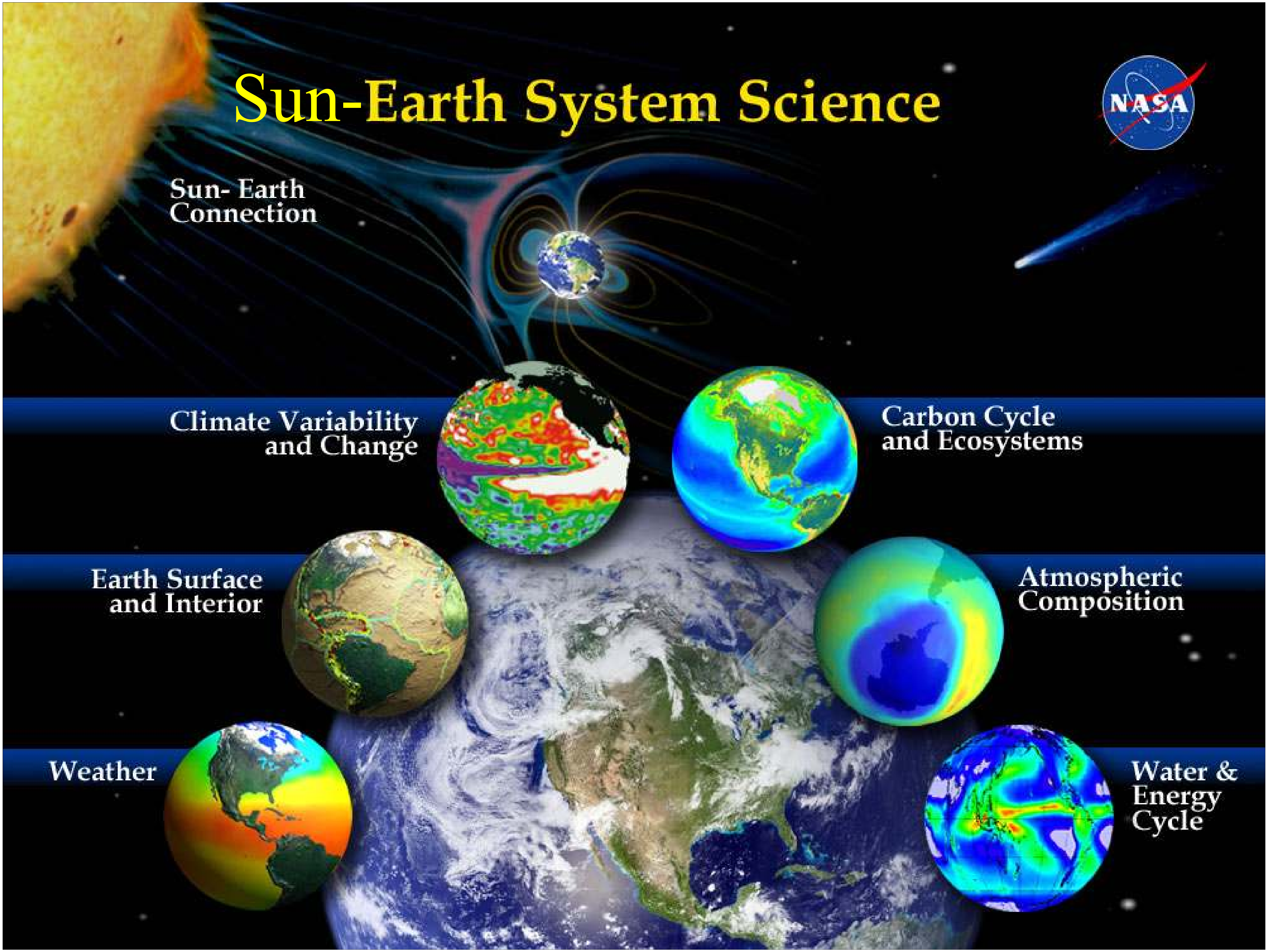
Water and Energy Cycle

NASA Science Mission Directorate

Jared Entin – email: Jared.K.Entin@nasa.gov

Water & (Energy) Cycle





Sun-Earth System Science
Sun- Earth Connection
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

W&E-C Overlaps

Atmospheric Composition – Atmospheric Water Vapor, Aerosols, (Radiation Sciences Program)

Carbon Cycle and Ecosystems – LS Evaporation, Land Cover/Use Change

Weather – Precipitation, Atm. Boundary Layer

Water and Energy Cycle

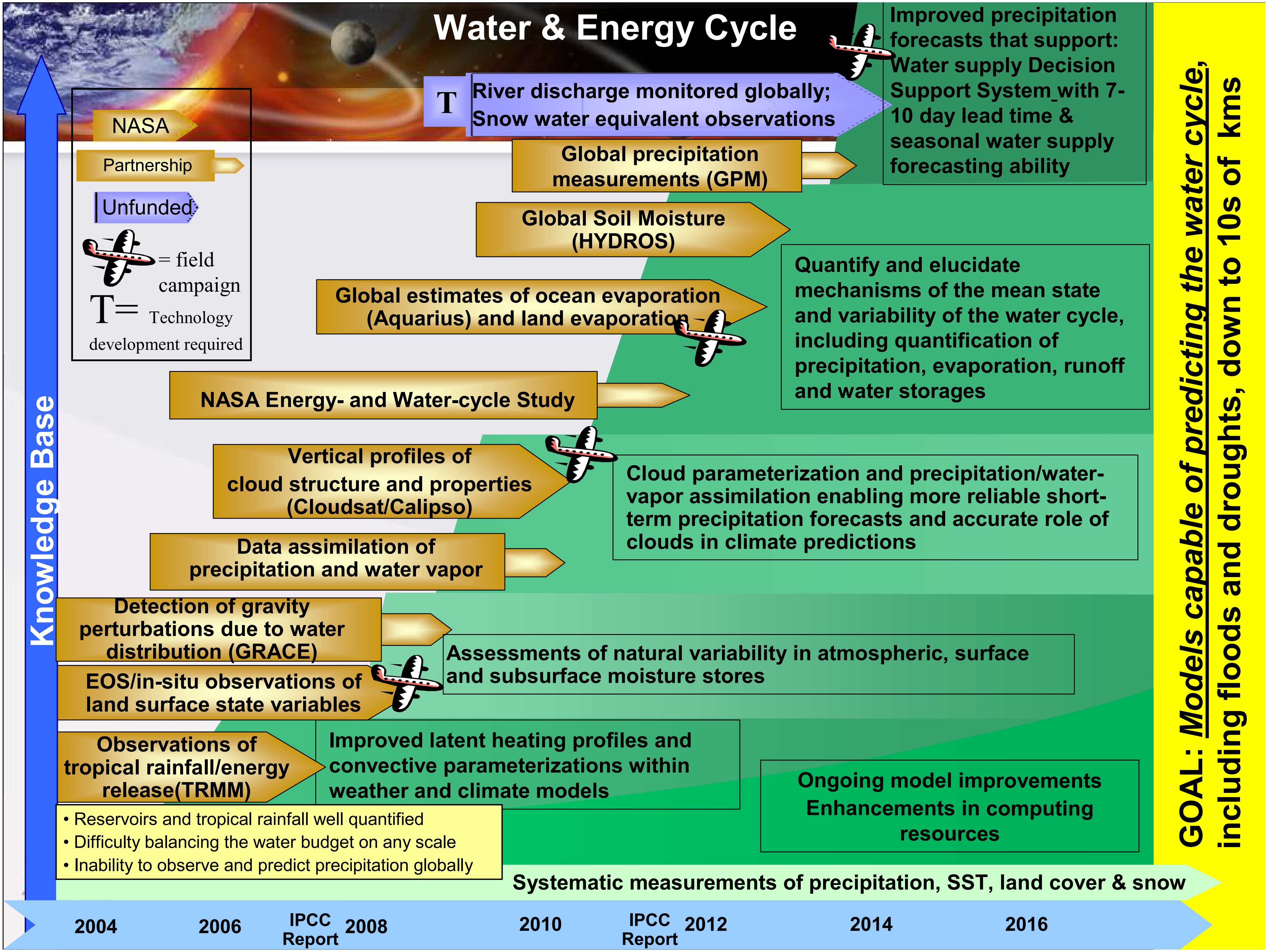
Terrestrial Hydrology [Soil Moisture, Snow, etc.]

Precipitation

½ Radiation Science

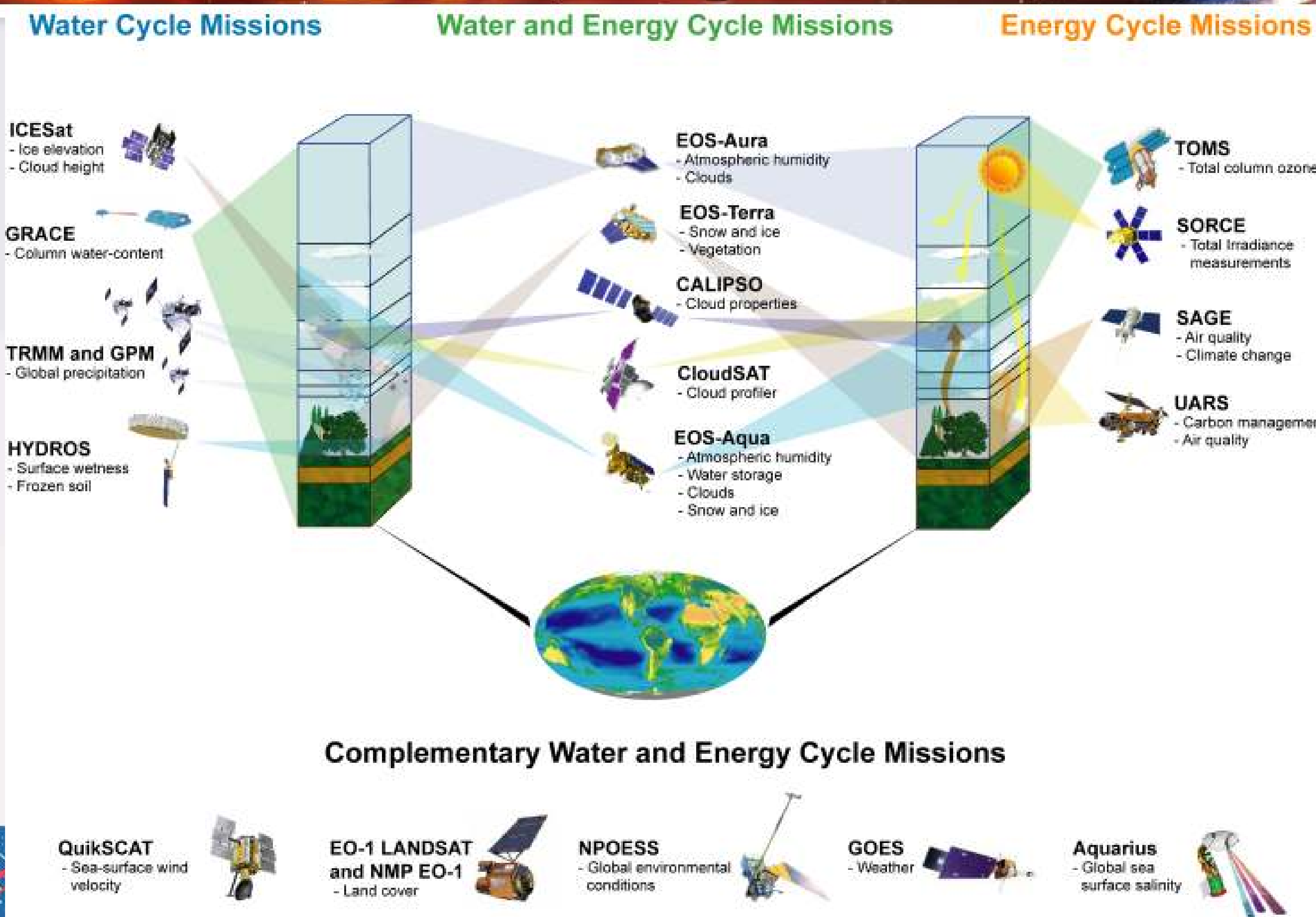
Climate – Oceans, Cryosphere, Modeling

Earth Surface and Interior – Gravity



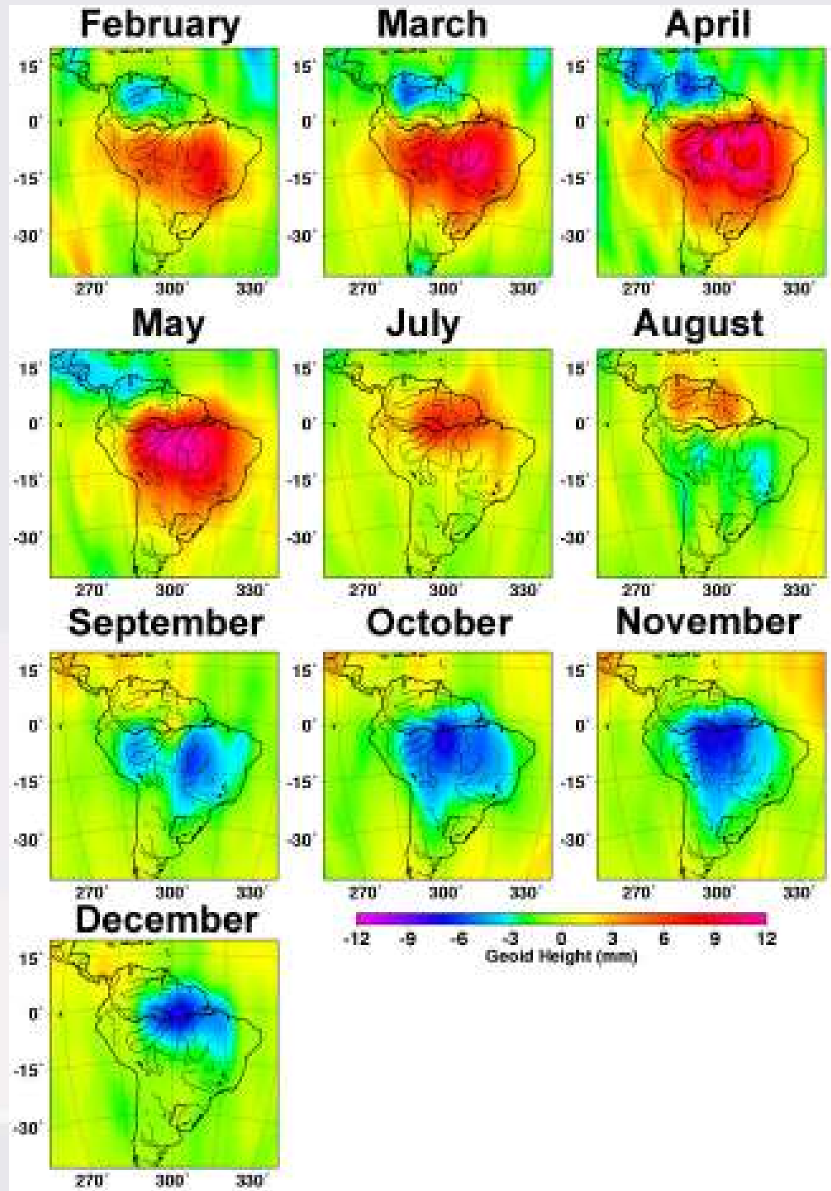
Water & Energy Cycle
Knowledge Base
NASA
Partnership
Unfunded
= field campaign
T= Technology development required
T
River discharge monitored globally; Snow water equivalent observations
Global precipitation measurements (GPM)
Global Soil Moisture (HYDROS)
Global estimates of ocean evaporation (Aquarius) and land evaporation
NASA Energy- and Water-cycle Study
Vertical profiles of cloud structure and properties (Cloudsat/Calipso)
Data assimilation of precipitation and water vapor
Detection of gravity perturbations due to water distribution (GRACE)
EOS/in-situ observations of land surface state variables
Observations of tropical rainfall/energy release(TRMM)
• Reservoirs and tropical rainfall well quantified
• Difficulty balancing the water budget on any scale
• Inability to observe and predict precipitation globally
Improved precipitation forecasts that support: Water supply Decision Support System with 7-10 day lead time & seasonal water supply forecasting ability
Quantify and elucidate mechanisms of the mean state and variability of the water cycle, including quantification of precipitation, evaporation, runoff and water storages
Cloud parameterization and precipitation/water-vapor assimilation enabling more reliable short-term precipitation forecasts and accurate role of clouds in climate predictions
Assessments of natural variability in atmospheric, surface and subsurface moisture stores
Improved latent heating profiles and convective parameterizations within weather and climate models
Ongoing model improvements
Enhancements in computing resources
Systematic measurements of precipitation, SST, land cover & snow
2004
2006
IPCC Report
2008
2010
IPCC Report
2012
2014
2016
GOAL: Models capable of predicting the water cycle, including floods and droughts, down to 10s of kms

Water and Energy cycle Missions

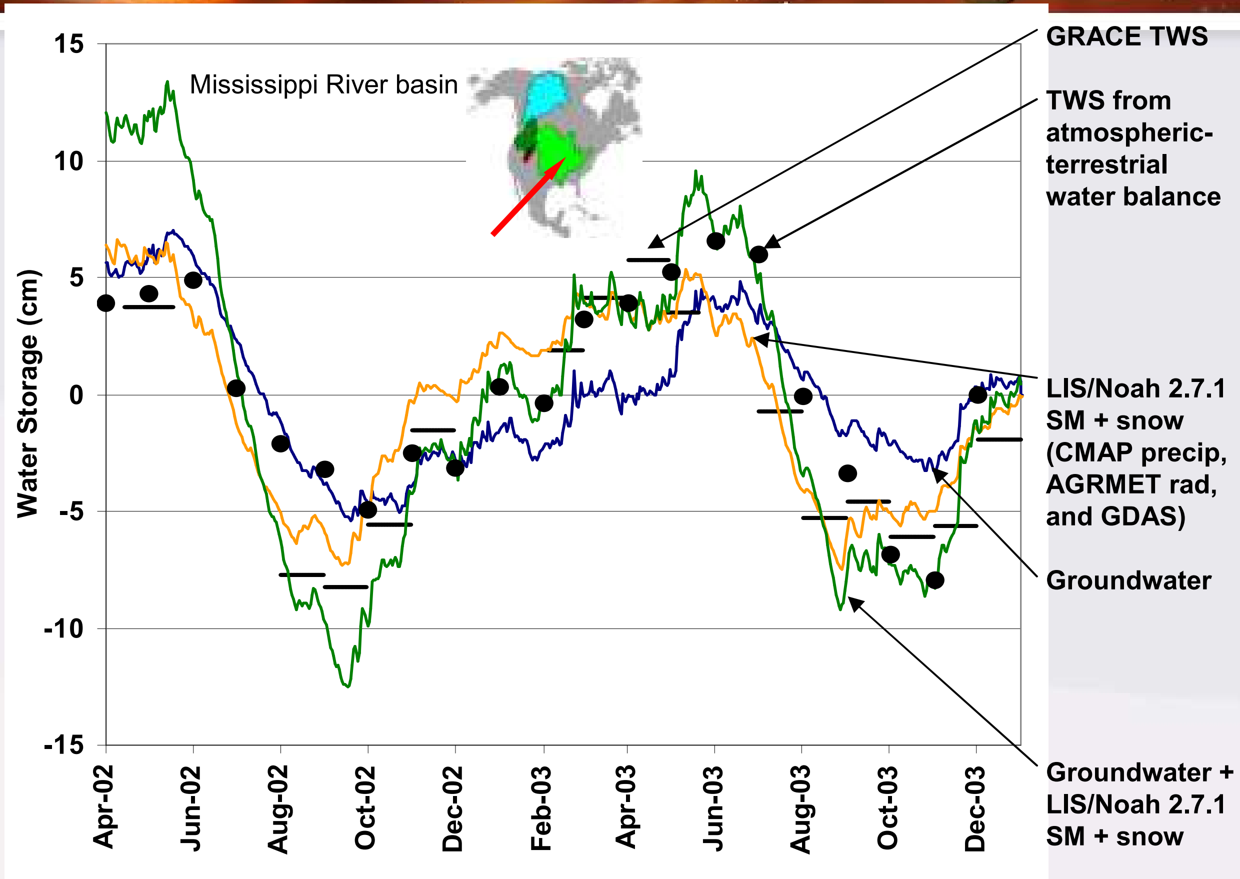


GRACE

Results published in *Science* show monthly changes in the distribution of water and ice masses could be estimated by measuring changes in Earth's gravity field. The GRACE data measured the weight of up to 10 centimeters (four inches) of groundwater accumulations from heavy tropical rains, particularly in the Amazon basin and Southeast Asia. Smaller signals caused by changes in ocean circulation were also visible.



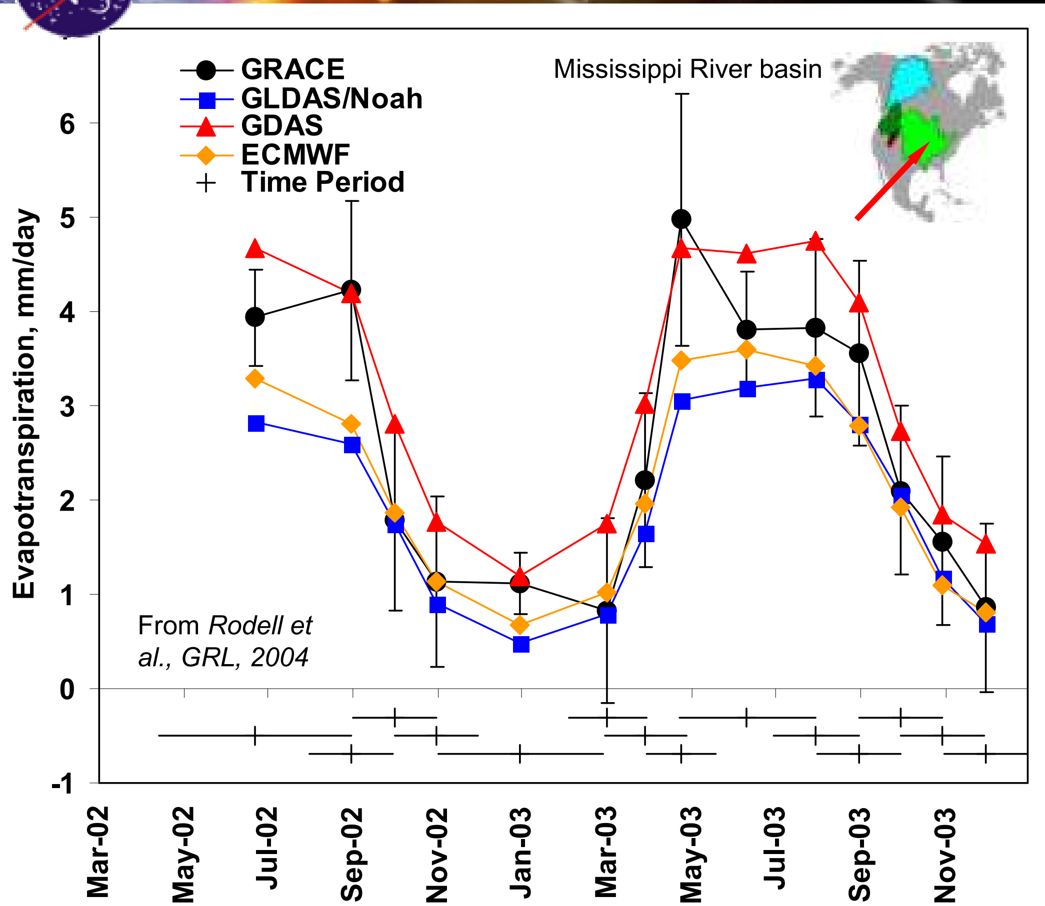
Estimating Ground Water Variability Using GRACE



Estimated time series of total terrestrial water storage and its components averaged over the Mississippi River basin, from observations, a water balance, and a land surface model (from *Rodell et al., in preparation, 2005).*

- Ground water storage may be an important indicator and predictor of climate variability
- New results (left) demonstrate that the contribution of ground water to total terrestrial water storage variations is on the same order as that of near surface (soil moisture + snow) water stores
- Ground water is vital for irrigation, industrial, and municipal water supplies
- GRACE provides the only opportunity for monitoring ground water variability in most of the world
- Longer time series are needed in order to understand and predict the climatological variability of ground water

Estimating Evapotranspiration Using GRACE



GRACE = GRACE based water budget estimates of ET

GLDAS/Noah = Global Land Data Assimilation System driving Noah land surface model

GDAS = NOAA's Global Data Assimilation System atmospheric analysis and forecast system

ECMWF = European Centre for Medium Range Weather Forecasts analysis and forecast system

Terrestrial water balance:

$$ET = P - Q - \Delta S$$

Observation based precipitation product

River runoff observations

From GRACE

- Evapotranspiration (ET) estimated as residual of a terrestrial water budget
- GRACE provides previously unavailable input: terrestrial water storage change (ΔS)
- Used for validating and calibrating land surface and weather models – leads to improved predictions
- Improved spatial resolution and error reduction would increase value for validation
- Longer time series needed to understand ET climatology

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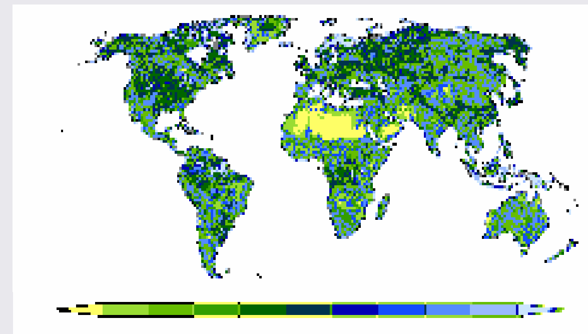
Hydrological Sciences Branch, NASA GSFC

Land Data Assimilation System (LDAS)

GOAL: Produce optimal output fields of land surface states and fluxes.

APPROACH: Parameterize, force, and constrain multiple, sophisticated land surface models with data from advanced ground and space-based observing systems.

SIGNIFICANCE: Results will be used for initialization of weather and climate prediction models and application investigations.



Root zone soil water content [%]

FORCING DATA

- Precipitation
- Temperature
- Radiation
- Other variables

PARAMETERS

- Vegetation Types
- Soil Classes
- Elevation
- Other data

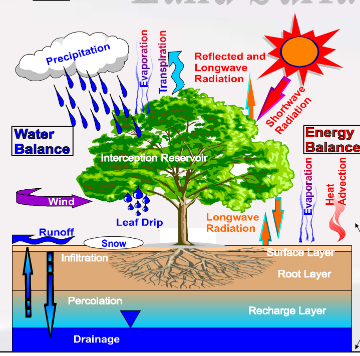
Assimilation

LDAS

North American LDAS

Global LDAS

Land Surface Models



Output

- Soil Moisture
- Evapotranspiration
- Energy fluxes
- River runoff
- Snowpack characteristics

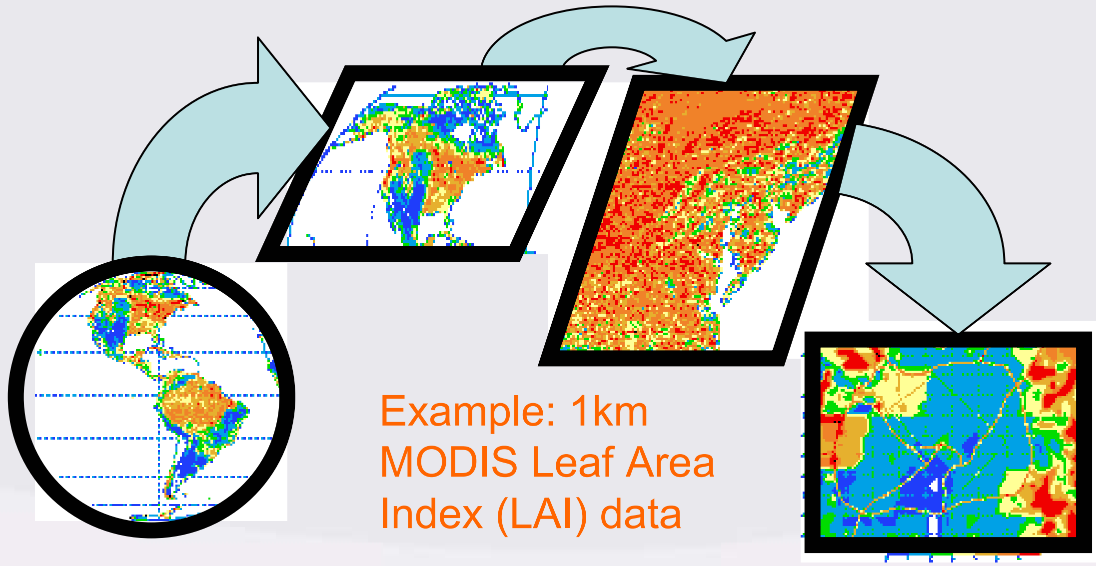
M. Rodell and P. Houser / 974

High Resolution Land Information System

LIS

Objective: A high performance, high resolution (1km), near-real-time (<1day/day execution time) global land modeling and assimilation system capable of demonstrating the impact of NASA observations on global water and energy cycles.

Applications: Weather and climate modeling, Flood and water resources forecasting, Precision agriculture, Mobility assessment, etc.

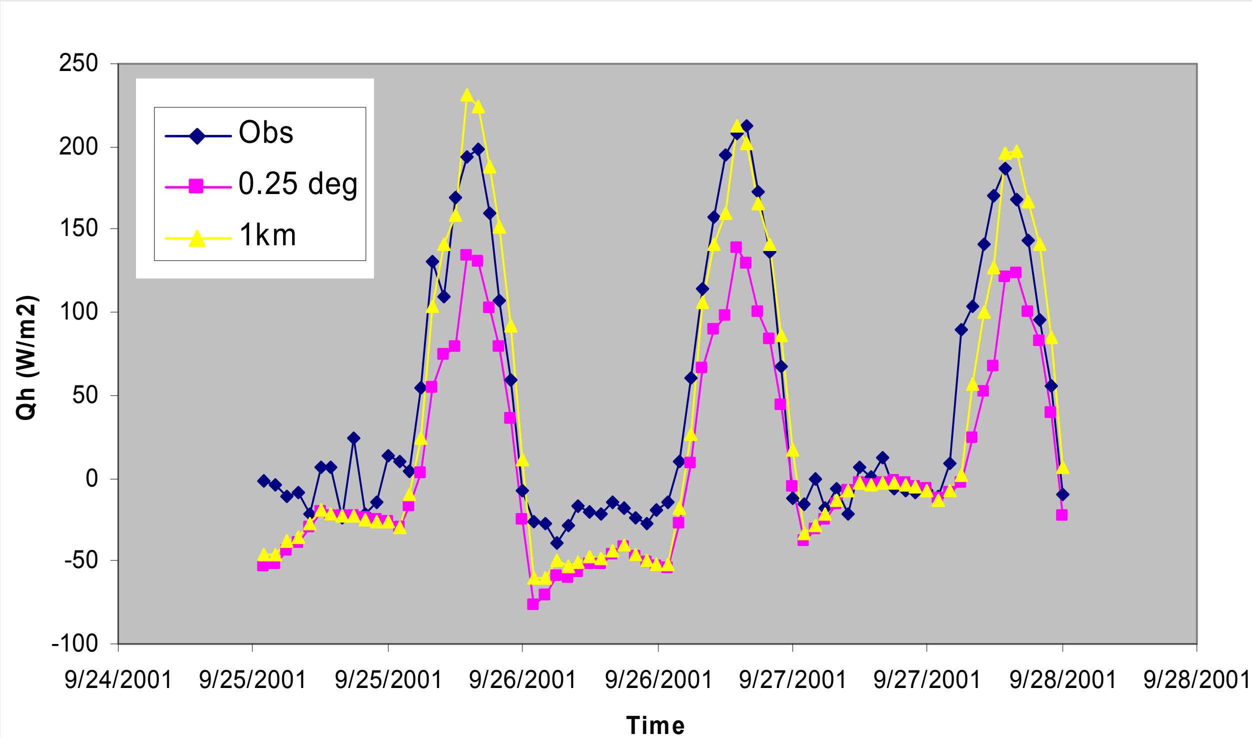


Example: 1km MODIS Leaf Area Index (LAI) data

	GLDAS		LIS
Resolution	1/4 deg	5 km	1 km
Land Grid Points	2.43E+05	5.73E+06	1.44E+08
Disk Space/Day (Gb)	1	28	694
Memory (Gb)	3	62	1561

Milestone achieved: LIS can now run approx. 3 days/day

Impacts: Improved Representation of Land-Atm Energy Exchange



LIS-predicted and observed sensible heat flux (Qh) at ¼ degree (~25 km) and 1km for three randomly selected days at Fort Peck, MT using the Noah land surface model.

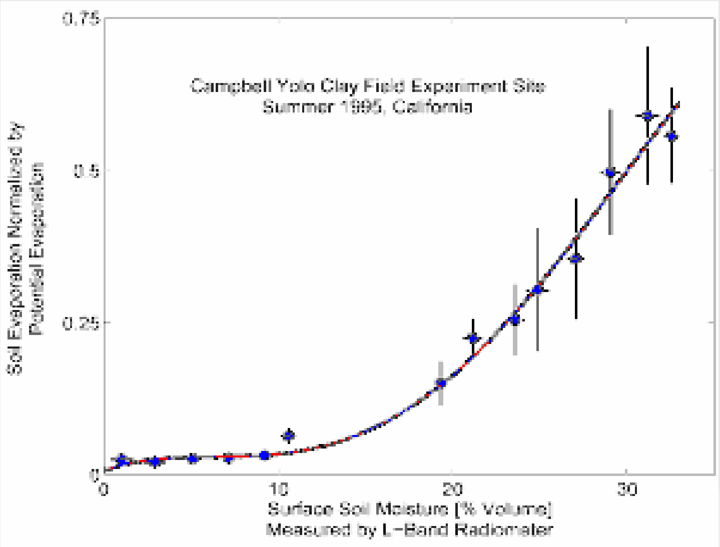
Impact of MODIS LAI (vs. AVHRR) on LIS-predicted latent heat flux (Qle) at Bondville, IL using the CLM land surface model. July-Sept 2001.
(Land cover type=croplands)

	RMS W/m^2	Bias W/m^2
AVHRR	62	14
MODIS	50	-5

Soil Moisture / Freeze-Thaw

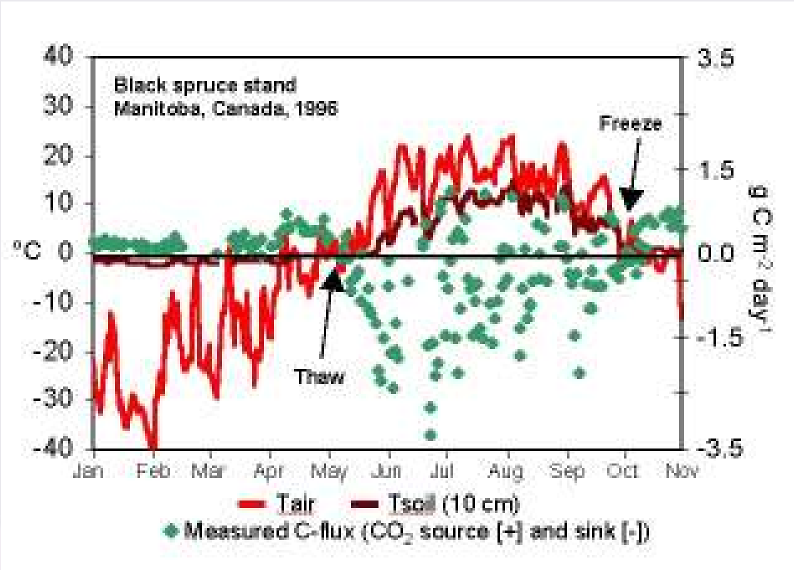
Soil Moisture a critical omission in observations suite (NASA, NOAA, USDA)

Water Cycle



Soil Moisture Strongly Influences Evaporation Rate and thus the Water and Energy Exchanges between Land & Atm.

Carbon Cycle

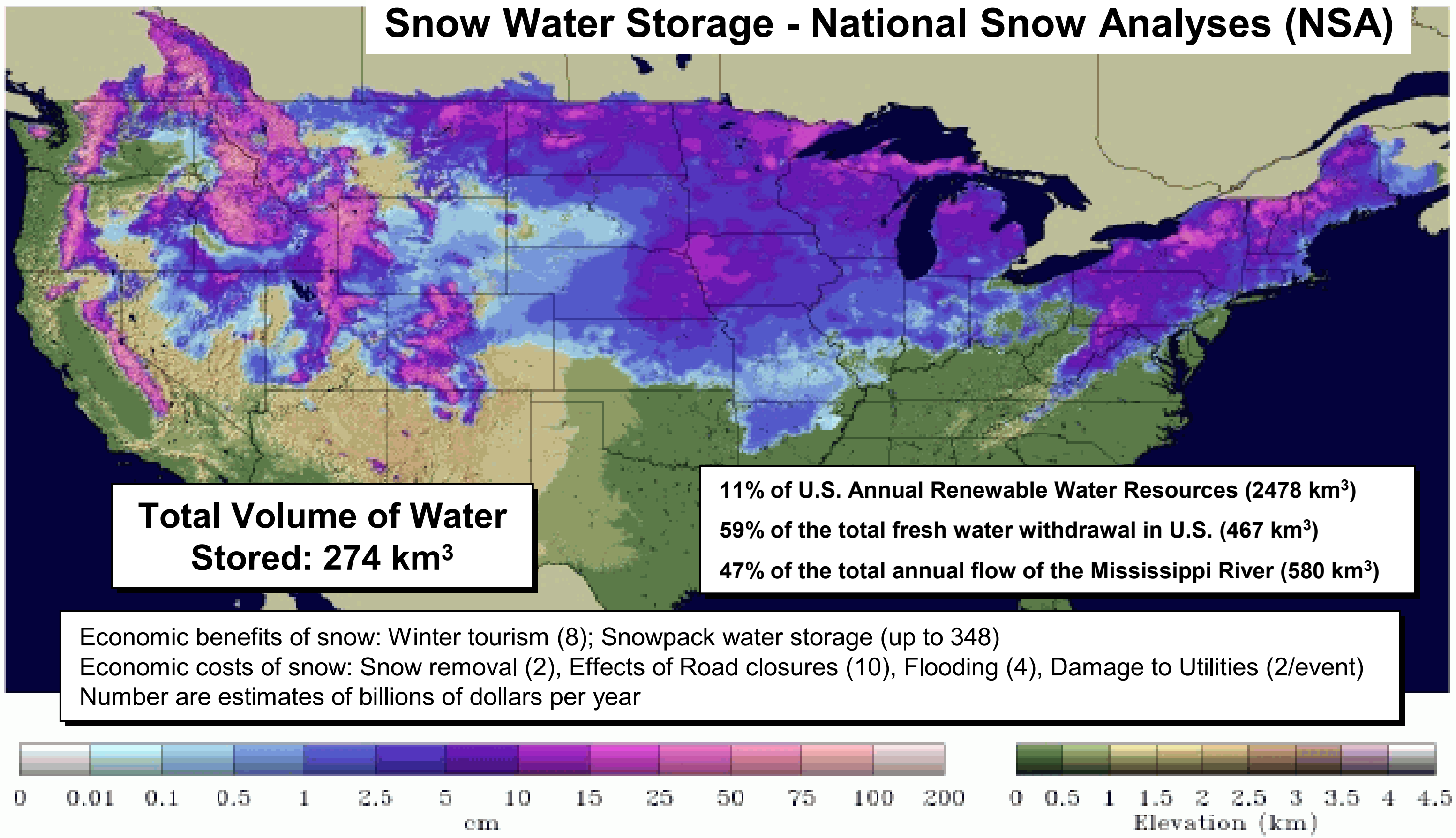


Freeze/Thaw Condition Influences Growing Season Length and thus the Carbon Balance.

Addresses Priority Soil Moisture Data Requirements Across Agencies

NASA: Monitor Process - Global Water, Energy, and Carbon Cycles
NOAA: Improve Weather and Climate Predictions: Flood and Drought
DoD: Applications in All Three Services (e.g. Terrain trafficability, Fog)
USDA: Agricultural Management, Drought Impact Mitigation

Snow – Liquid Water Equivalent



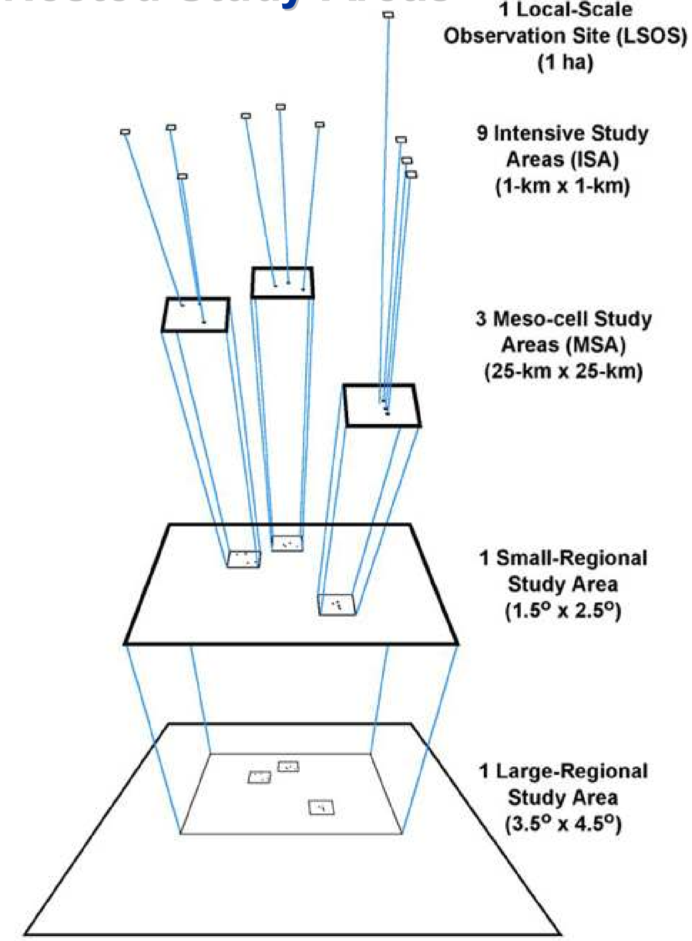
Preliminary information from “The Value of Snow and Snow Information Services” – Office of the chief economist (NOAA, 2004)

“..improved snow information and services have potential benefits greater than $1.3 billion annually.” “…investments that make only modest improvements in snow information will have substantial economic payoffs.”

Field Experiment

Cold Land Processes Experiment (CLPX) 2002-2003

Nested Study Areas



Multi-scale, multi-sensor approach to build comprehensive data set of satellite and airborne remotely sensed and in situ observations needed to meet NASA Earth Science objectives.


Shallow Snow Packs (~20 cm) in the North Park MSA


Moderate Snow Packs (~1 m) in the Fraser MSA

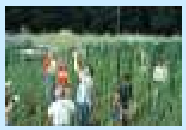

Deep Snow Packs (~2 m) in the Rabbit Ears MSA

The nested study areas in Colorado, USA provide a comprehensive range of snow and frozen soil characteristics.

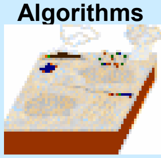
Soil Moisture Experiments (SMEX02, 03, 04, 05…)

Science

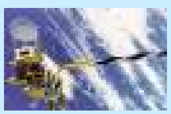
- Water Cycle

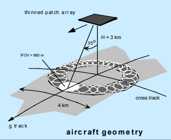


- Algorithms



- Validation
- Technology



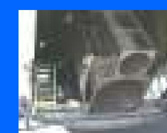


Satellite Instruments

- AMSR-E
- SSM/I
- TMI
- Envisat, ERS-2
- Radarsat, Quiksat
- MODIS, ASTER
- TM
- GOES, AVHRR

Aircraft Instruments

- PALS
- PSR
- ESTAR/2DSTAR
- GPS
- Aircraft flux
- VIS/IR

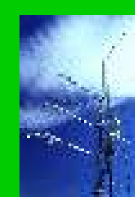


Sites (June-July)

- Iowa (Story Co.)
  - Algorithms
  - Water cycle
- SGP (LW and CF)
  - Validation
  - New Inst.
- Georgia (Little River)
  - Validation
- Alabama (NALMNET)
  - Validation

Ground Investigations

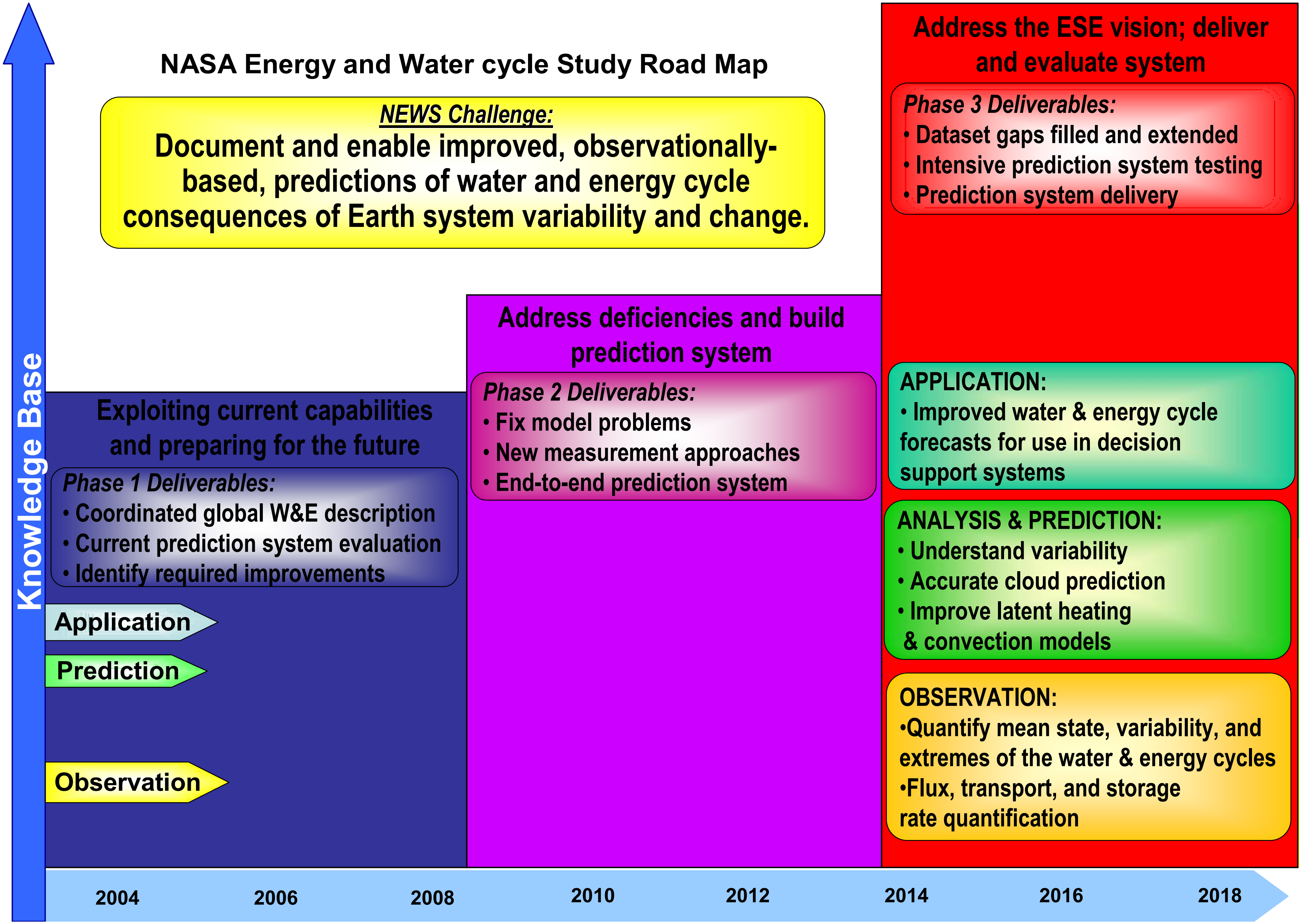
- Soil moisture
- Soil temperature
- Surface flux and atmospheric boundary layer
- Vegetation
- Surface roughness
- Ground based radiometry
- Insitu calibration
- Insitu scaling



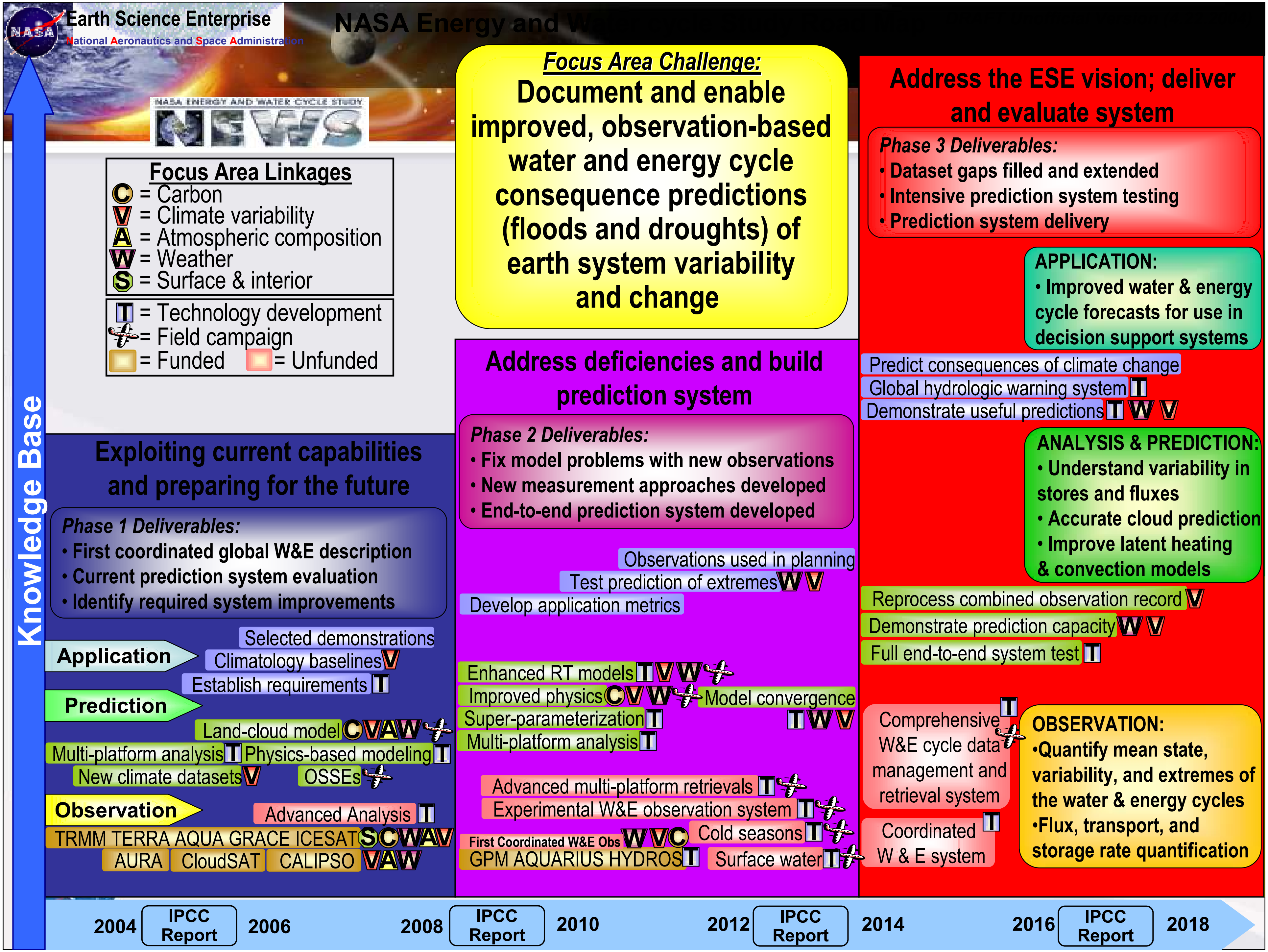
Contact: Tom Jackson (USDA Beltsville, Md)

NASA Energy & Water-cycle Study (NEWS)

- Initiated in 2003
- NRA released in 2004 – selection made in 2005.
- Roses element closed in Nov. 2005 – 4-6 proposal sought to fill gaps.
- More information available at http://wec.gsfc.nasa.gov

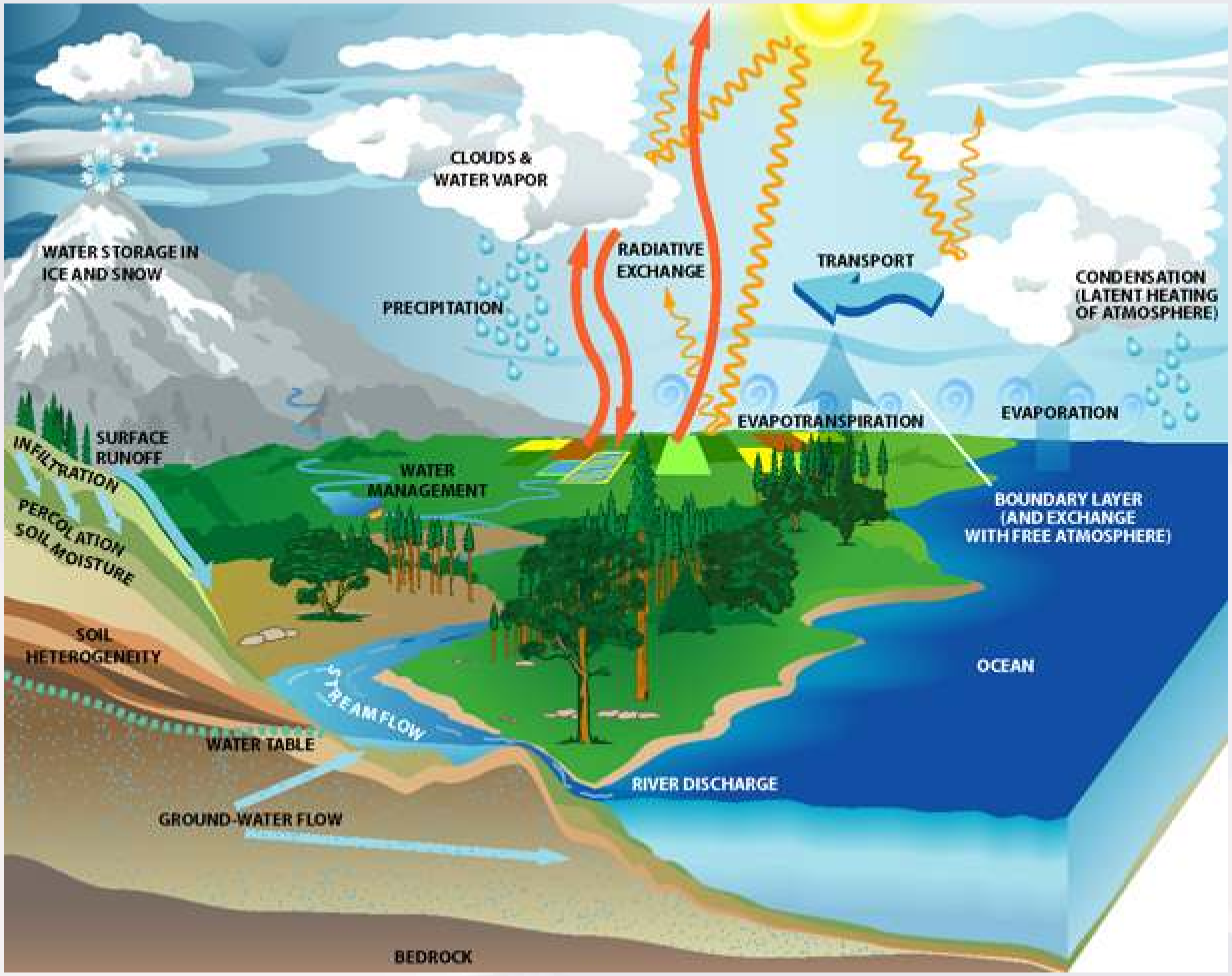


NASA Energy and Water cycle Study Road Map
NEWS Challenge:
Document and enable improved, observationally-based, predictions of water and energy cycle consequences of Earth system variability and change.
Knowledge Base
Exploiting current capabilities and preparing for the future
Phase 1 Deliverables:
• Coordinated global W&E description
• Current prediction system evaluation
• Identify required improvements
Application
Prediction
Observation
Address deficiencies and build prediction system
Phase 2 Deliverables:
• Fix model problems
• New measurement approaches
• End-to-end prediction system
Address the ESE vision; deliver and evaluate system
Phase 3 Deliverables:
• Dataset gaps filled and extended
• Intensive prediction system testing
• Prediction system delivery
APPLICATION:
• Improved water & energy cycle forecasts for use in decision support systems
ANALYSIS & PREDICTION:
• Understand variability
• Accurate cloud prediction
• Improve latent heating & convection models
OBSERVATION:
•Quantify mean state, variability, and extremes of the water & energy cycles
•Flux, transport, and storage rate quantification
2004
2006
2008
2010
2012
2014
2016
2018



Earth Science Enterprise
National Aeronautics and Space Administration
NASA Energy and W
NASA ENERGY AND WATER CYCLE STUDY
NEWS
Focus Area Linkages
C = Carbon
V = Climate variability
A = Atmospheric composition
W = Weather
S = Surface & interior
T = Technology development
= Field campaign
= Funded
= Unfunded
Focus Area Challenge:
Document and enable improved, observation-based water and energy cycle consequence predictions (floods and droughts) of earth system variability and change
Address the ESE vision; deliver and evaluate system
Phase 3 Deliverables:
• Dataset gaps filled and extended
• Intensive prediction system testing
• Prediction system delivery
APPLICATION:
• Improved water & energy cycle forecasts for use in decision support systems
Predict consequences of climate change
Global hydrologic warning system T
Demonstrate useful predictions T W V
ANALYSIS & PREDICTION:
• Understand variability in stores and fluxes
• Accurate cloud prediction
• Improve latent heating & convection models
Reprocess combined observation record V
Demonstrate prediction capacity W V
Full end-to-end system test T
Comprehensive W&E cycle data management and retrieval system T
Coordinated W & E system T
OBSERVATION:
•Quantify mean state, variability, and extremes of the water & energy cycles
•Flux, transport, and storage rate quantification
Address deficiencies and build prediction system
Phase 2 Deliverables:
• Fix model problems with new observations
• New measurement approaches developed
• End-to-end prediction system developed
Observations used in planning
Test prediction of extremes W V
Develop application metrics
Enhanced RT models T V W
Improved physics C V W
Model convergence T W V
Super-parameterization T
Multi-platform analysis T
Advanced multi-platform retrievals T
Experimental W&E observation system T
First Coordinated W&E Obs W V C
Cold seasons T
GPM AQUARIUS HYDROS T
Surface water T
Exploiting current capabilities and preparing for the future
Phase 1 Deliverables:
• First coordinated global W&E description
• Current prediction system evaluation
• Identify required system improvements
Application
Selected demonstrations
Climatology baselines V
Establish requirements T
Prediction
Land-cloud model C V A W
Multi-platform analysis T
Physics-based modeling T
New climate datasets V
OSSEs
Observation
Advanced Analysis T
TRMM TERRA AQUA GRACE ICESAT S C W A V
AURA CloudSAT CALIPSO V A W
Knowledge Base
2004
IPCC Report
2006
2008
IPCC Report
2010
2012
IPCC Report
2014
2016
IPCC Report
2018

Thank you!


CLOUDS &
WATER VAPOR
WATER STORAGE IN
ICE AND SNOW
RADIATIVE
EXCHANGE
TRANSPORT
PRECIPITATION
CONDENSATION
(LATENT HEATING
OF ATMOSPHERE)
SURFACE
RUNOFF
INFILTRATION
EVAPOTRANSPIRATION
EVAPORATION
WATER
MANAGEMENT
PERCOLATION
SOIL MOISTURE
BOUNDARY LAYER
(AND EXCHANGE
WITH FREE ATMOSPHERE)
SOIL
HETEROGENEITY
STREAM FLOW
OCEAN
WATER TABLE
RIVER DISCHARGE
GROUND-WATER FLOW
BEDROCK