Water and Energy Cycle

NASA Science Mission Directorate

Jared Entin – email: Jared.K.Entin@nasa.gov
Sun-Earth System Science

Sun-Earth Connection

Climate Variability and Change

Earth Surface and Interior

Weather

Carbon Cycle and Ecosystems

Atmospheric Composition

Water & Energy Cycle
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

- River discharge monitored globally; Snow water equivalent observations
- Global precipitation measurements (GPM)
- Global Soil Moisture (HYDROS)
- EOS/in-situ observations of land surface state variables
- Improved precipitation forecasts that support: Water supply Decision Support System with 7-10 day lead time & seasonal water supply forecasting ability
- 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

GOAL: Models capable of predicting the water cycle, including floods and droughts, down to 10s of kms


- Cloud parameterization and precipitation/water-vapor assimilation enabling more reliable short-term precipitation forecasts and accurate role of clouds in climate predictions
- 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)

Unfunded Partnership = field campaign

T= Technology development required

- Reservoirs and tropical rainfall well quantified
- Difficulty balancing the water budget on any scale
- Inability to observe and predict precipitation globally
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.
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

Terrestrial water balance:

\[ ET = P \ - \ Q \ - \ \Delta S \]

- Evapotranspiration (ET) estimated as residual of a terrestrial water budget
- GRACE provides previously unavailable input: terrestrial water storage change (\( \Delta S \))
- 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

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

From Rodell et al., GRL, 2004

Matthew.Rodell@nasa.gov
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.

**FORCING DATA**
- Precipitation
- Temperature
- Radiation
- Other variables

**PARAMETERS**
- Vegetation Types
- Soil Classes
- Elevation
- Other data

**LDAS**
- North American LDAS
- Global LDAS

**Assimilation**

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

M. Rodell and P. Houser / 974
**Objective:** A high performance, high resolution (1km), near-real-time (<1 day/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.

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

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

Milestone achieved: LIS can now run approx. 3 days/day
Impacts: Improved Representation of Land-Atm Energy Exchange

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)

<table>
<thead>
<tr>
<th></th>
<th>RMS W/m²</th>
<th>Bias W/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR</td>
<td>62</td>
<td>14</td>
</tr>
<tr>
<td>MODIS</td>
<td>50</td>
<td>-5</td>
</tr>
</tbody>
</table>

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.
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


**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

Snow Water Storage - National Snow Analyses (NSA)

Total Volume of Water Stored: 274 km$^3$

11% of U.S. Annual Renewable Water Resources (2478 km$^3$)
59% of the total fresh water withdrawal in U.S. (467 km$^3$)
47% of the total annual flow of the Mississippi River (580 km$^3$)

Economic benefits of snow: Winter tourism (8); Snowpack water storage (up to 348)
Economic costs of snow: Snow removal (2), Effects of Road closures (10), Flooding (4), Damage to Utilities (2/event)
Number are estimates of billions of dollars per year

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.”
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.

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

- Algorithms
- Technology
  - Water Cycle
  - Validation

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)
Initiated in 2003


Roses element closed in Nov. 2005 – 4-6 proposal sought to fill gaps.

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**

**Phase 2 Deliverables:**
- Fix model problems
- New measurement approaches
- End-to-end prediction system

**Prediction**

**Phase 3 Deliverables:**
- Dataset gaps filled and extended
- Intensive prediction system testing
- Prediction system delivery

**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

**APPLICATION:**
- Improved water & energy cycle forecasts for use in decision support systems

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

ANALYSIS & PREDICTION:
- Understand variability in stores and fluxes
- 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

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

Focus Area Linkages

= Carbon
C = Climate variability
V = Atmospheric composition
A = Weather
W = Surface & interior
S = Technology development
< = Field campaign
F = Funded
U = Unfunded
Thank you!