

Hillslope scale soil moisture estimation through data assimilation: an emerging need for continued high resolution vegetation observations?

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Outline

- Importance of soil moisture
- Data assimilation approach
- Outline of data assimilation experiments
- Results and implications
- Ongoing and future work

Motivation



Sources: <http://gsl.erd.c.usace.army.mil/gl-history/images>, Matt Larsen (USGS)

Problem Statement

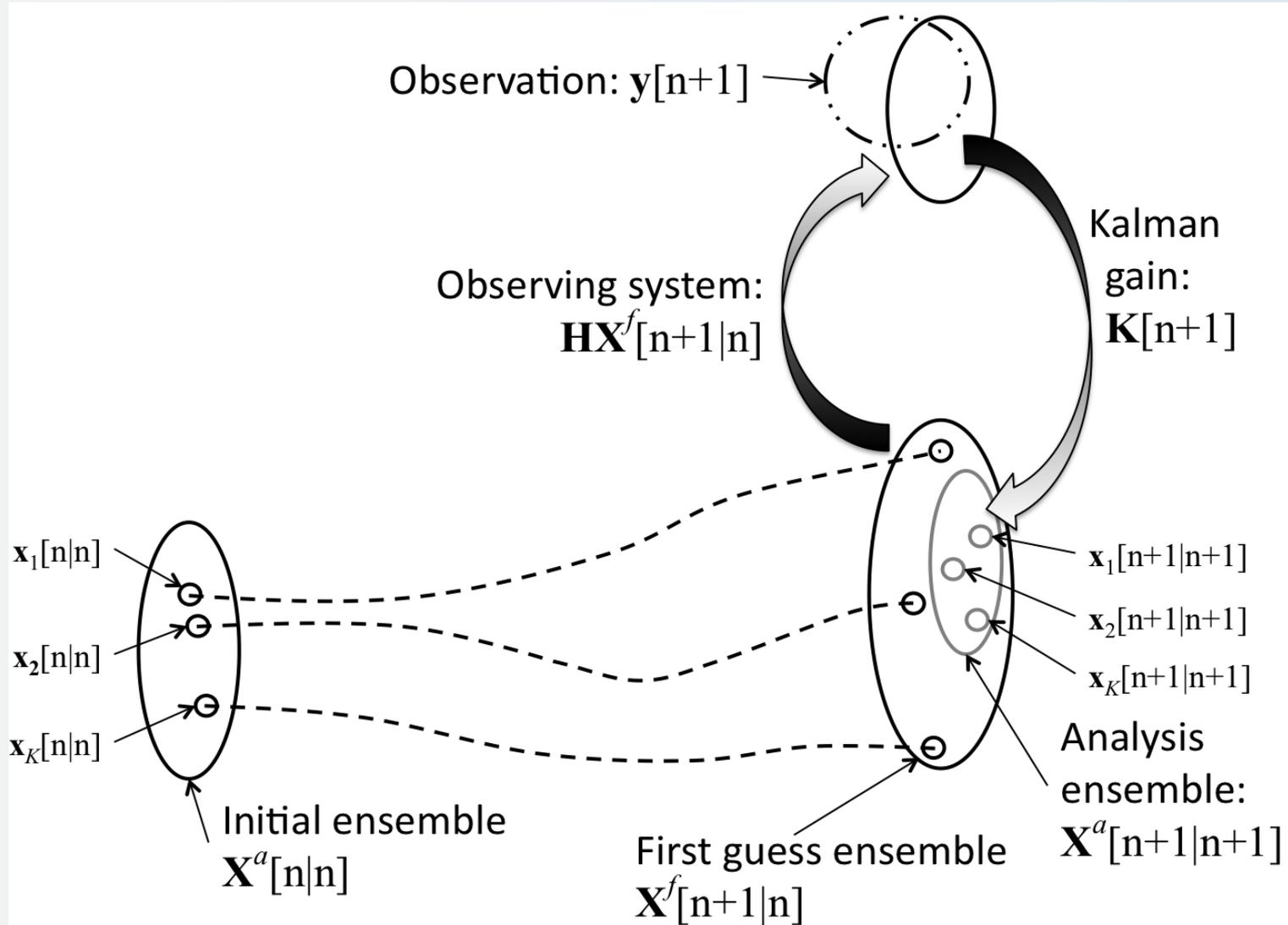
We require accurate soil moisture knowledge at hillslope scales. Potential data sources:

- Field-based observations
 - Advantages: Accurate, continuous, full profile
 - Drawbacks: Considerable spatial uncertainty
- Remote sensing measurements
 - Advantages: Global observation, high revisit
 - Drawbacks: Coarse spatial scale, requires inversion
- Physically-based modeling
 - Advantages: Continuous, fuses data sources, spatial resolution
 - Drawbacks: Model and input uncertainty

Data Assimilation

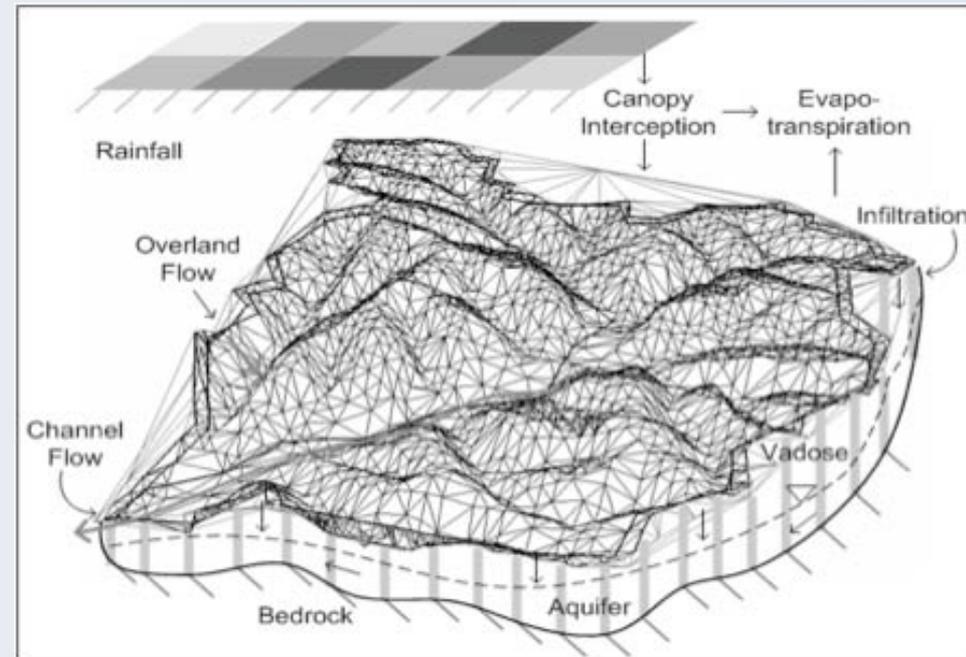
- Combines uncertain model estimates with noisy measurements
- Ensemble-based approaches:
 - Allow for nonlinear models and observing systems
 - Approximate uncertainty from an ensemble of Monte Carlo model simulations
 - Breadth in representing uncertainties in the model, its forcings and parameters
- Ensemble Kalman Filter (EnKF) “updates” states of a model based on noisy observations

Data Assimilation



The Model

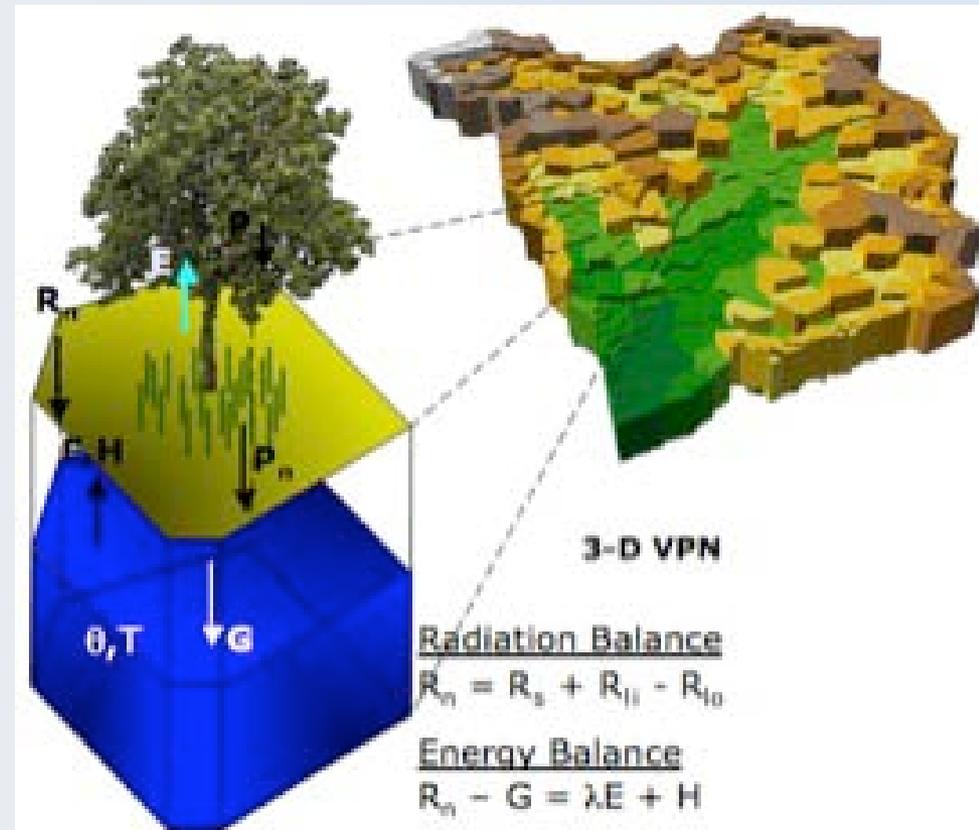
- TIN-based Realtime Integrated Basin Simulator and VEGetation Integrated Evolution model (tRIBS-VEGGIE)
- Triangulated Irregular Network (TIN) mesh
- Variable spatial resolution
- Static inputs:
 - Topography (SRTM)
 - Soils (SSURGO)
 - Land use/land cover (NLCD)
- Dynamic inputs (hourly):
 - Rainfall (e.g., NEXRAD)
 - Thermodynamic forcings (e.g., air temp., humidity, radiation) (weather station)



A conceptual diagram showing process representation embodied within tRIBS-VEGGIE [Vivoni, et al. 2005]

The Model (cont.)

- Water, energy, and carbon balance based on hourly met. forcings
- Energy balance computed separately for bare soil and canopy fractions
- Accounts for role of topography on incoming solar radiation
- Richards 1D infiltration with gravity dominated lateral redistribution
- Runon allows for downslope reinfiltration of runoff



tRIBS-VEGGIE solves moisture and energy balance at hillslope-scales based on the soil moisture state and meteorological forcings.

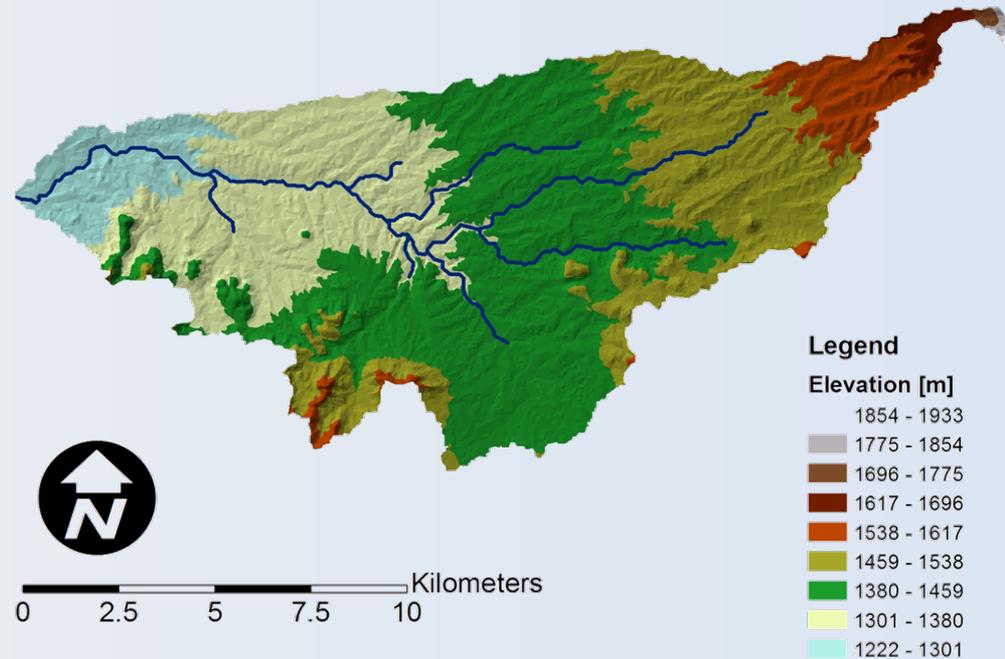
Sources of Uncertainty

Uncertainty in modeled soil moisture arises from:

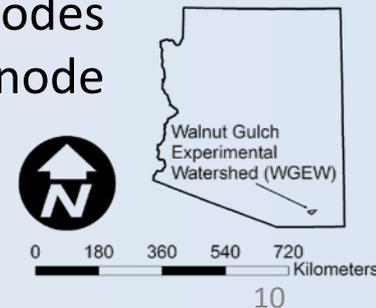
- Imperfect knowledge of soil hydraulic and thermal properties
 - Latin hypercube based approach that ensures low probability/high consequence soil parameters considered (**Flores, et al. 2010**)
- Uncertainty in rainfall forcings
 - Storm arrival and duration assumed well characterized, volume and spatial distribution uncertain
- Uncertainty in thermodynamic drivers (e.g., air temp., humidity, solar radiation, etc.)
 - Stochastic weather generator conditioned on precipitation

Experimental Setting

- Walnut Gulch Experimental Watershed (WGEW)
- Semiarid watershed in Southern Arizona
- Drainage area approx. 150 km²
- Mean annual precipitation 312 mm
- North American Monsoon System delivers approx. 60% of rainfall



TIN mesh:
19447 computational nodes
10 vertical soil layers per node



The Observations

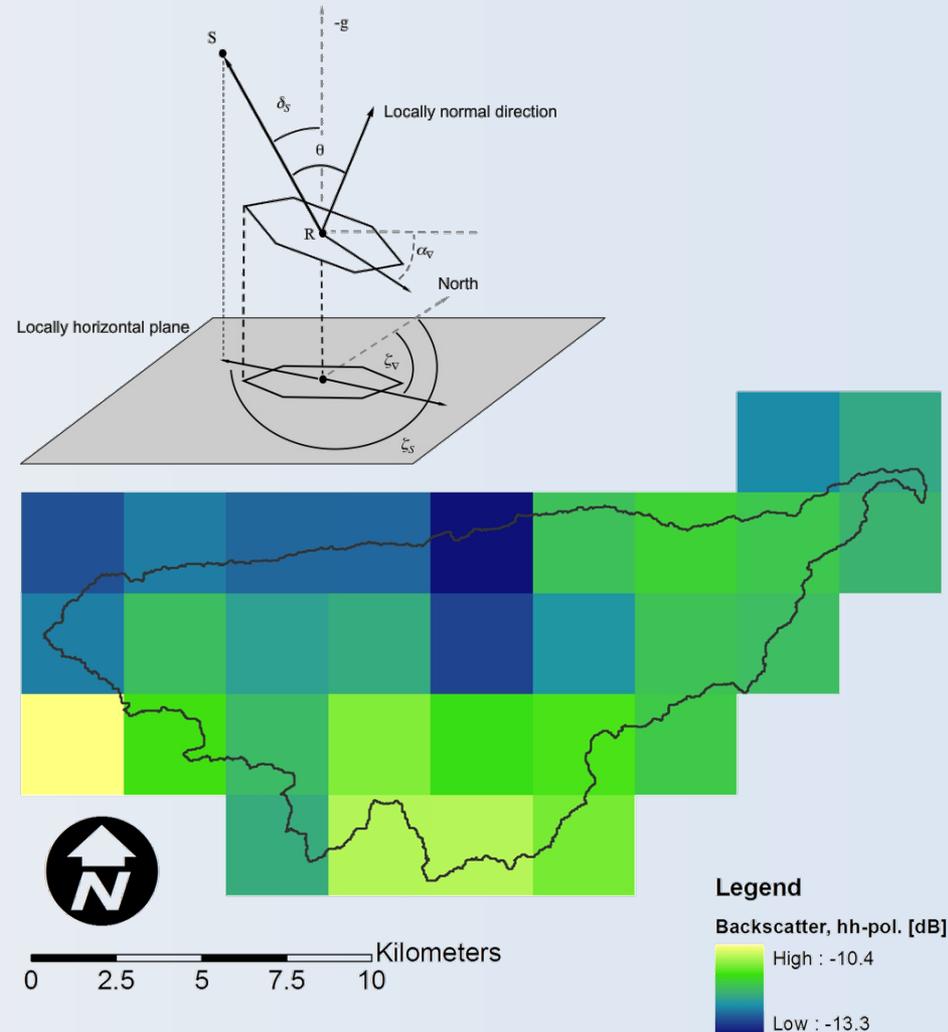
- NASA Soil Moisture Active-Passive (SMAP) satellite
- Key mission as identified by NRC decadal survey
- L-band microwave radiometer (1.41 GHz) and radar (1.26 GHz)
- Radiometer: 40 km
- **Radar: 3 km**
- Global coverage, 2-3 day revisit interval
- Launch between 2014-2015



From <http://smap.jpl.nasa.gov/mission/>

Observing System

- Integral equation model (IEM) [e.g., *Fung 1994*] simulates backscatter as a function of ***near surface (top 10 cm)*** hillslope-scale moisture
- Simulated backscatter in both horizontally- and vertically-copolarized states
- Stresses relationship between topography and sensor characteristics
- Aggregates hillslope-scale backscatter to 3 km grid
- Best suited for ***sparsely vegetated terrain/ bare soil***



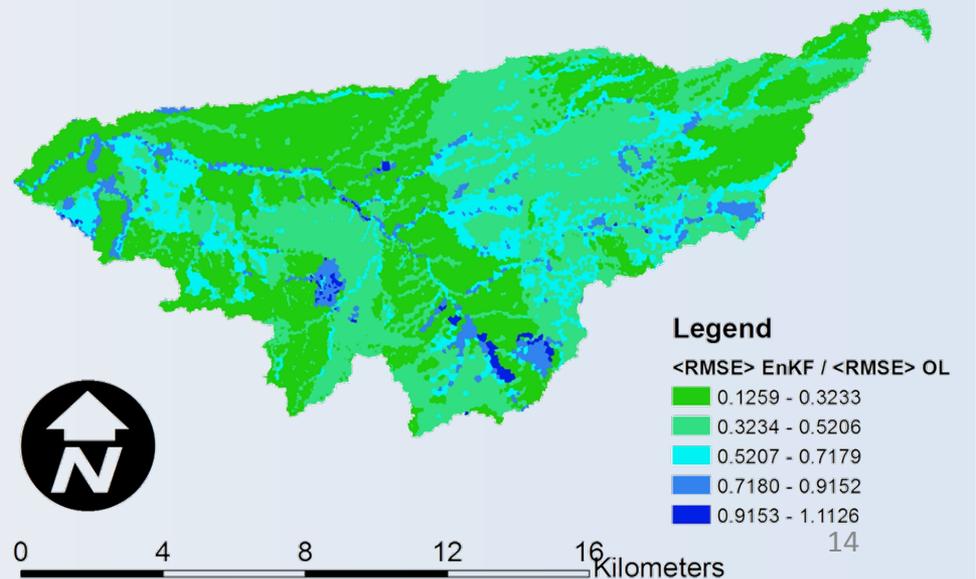
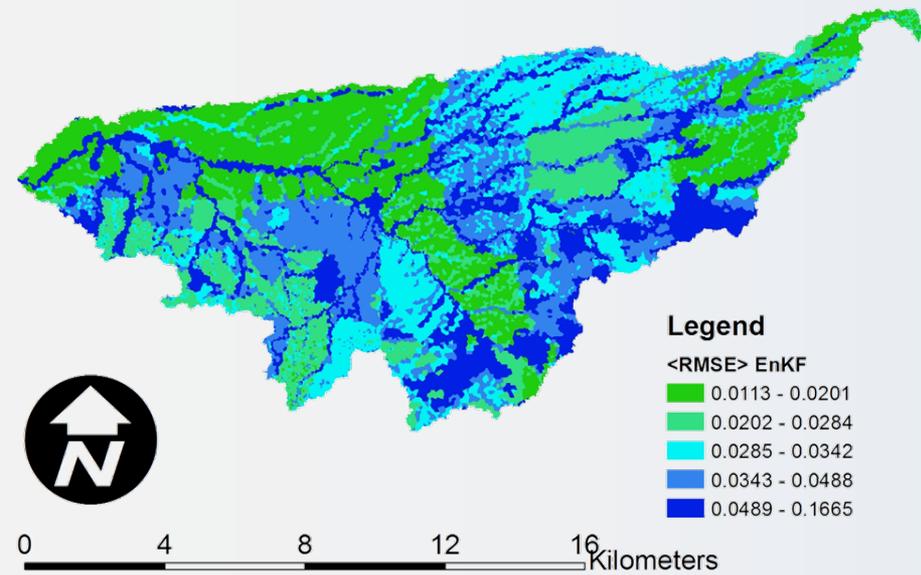
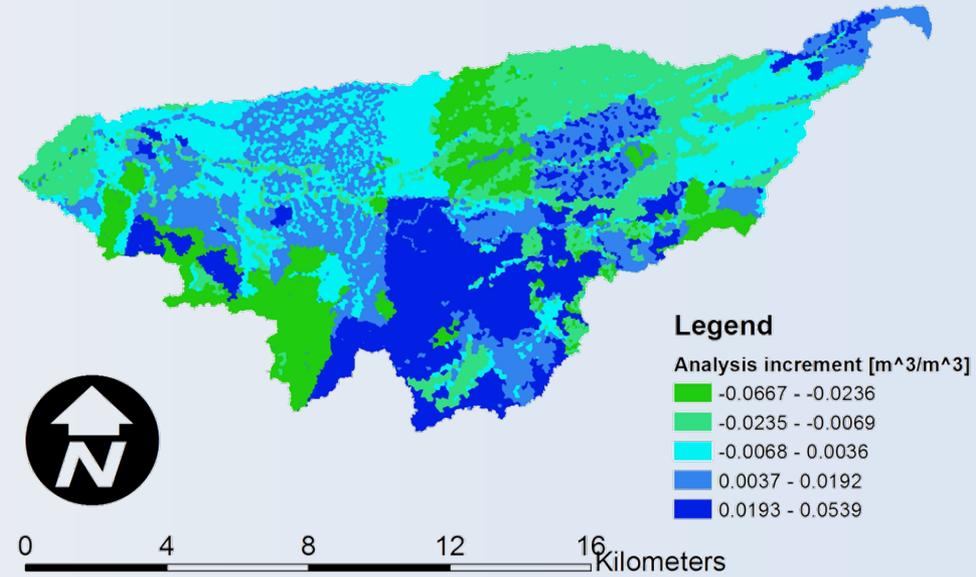
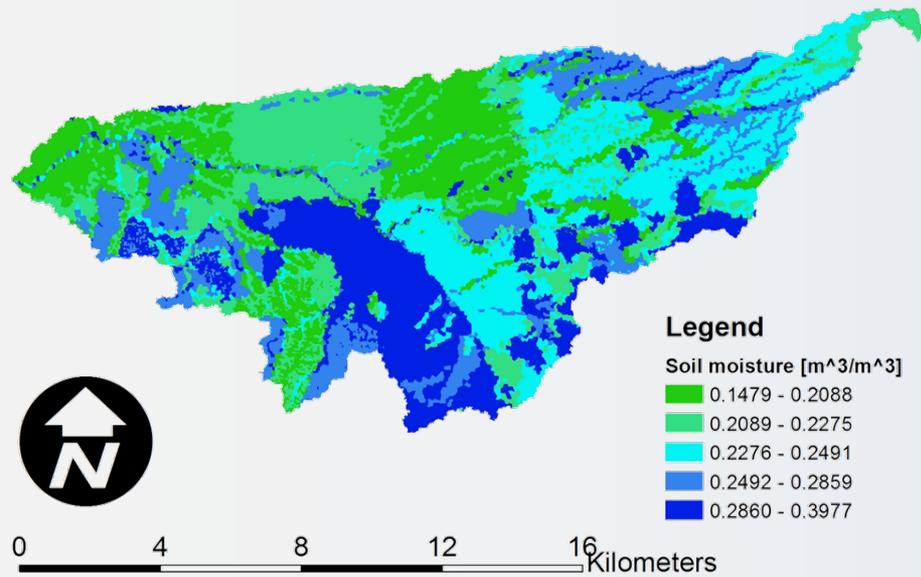
See *Flores et al.*, [2009] **IEEE TGRS**



Experimental Setup

- Observing System Simulated Experiment
 - tRIBS-VEGGIE model used to simulate ***multiple (four) potential true soil moisture realizations***
 - Observing system used to simulate L-band (1.26 GHz) radar observations ***at 3 km spatial resolution every 72 hrs*** at 0900 local time
 - Simulated observations perturbed with noise consistent with remote sensing instrument
- 27 day experiment during August: 4 sets of 9 observations to assimilate
- EnKF to assimilate synthetic backscatter observations with a 256-replicate ensemble
- Compare EnKF results to a 1024 replicate “open loop” experiment that simply propagates uncertainty

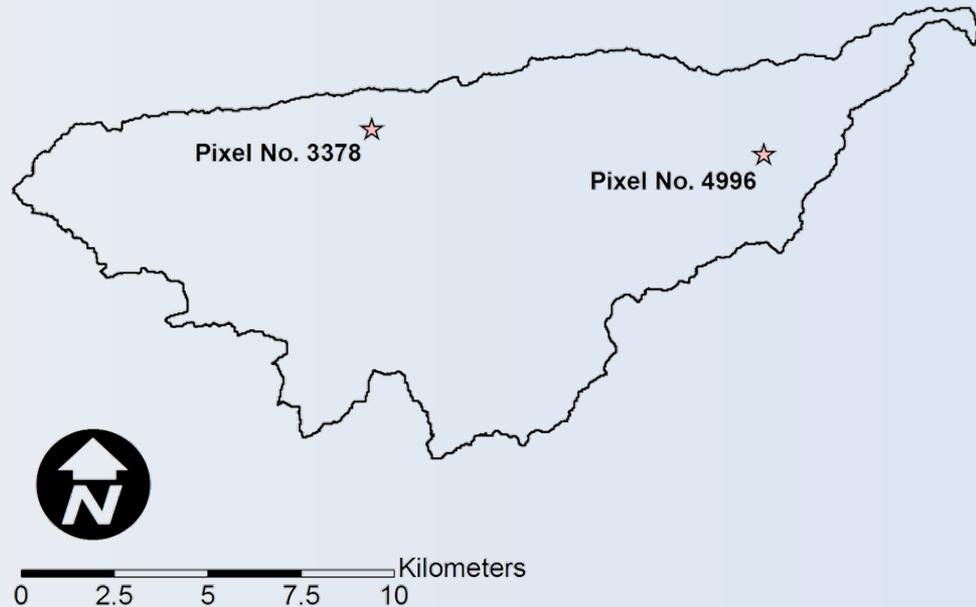
Results and Implications (216 hr)



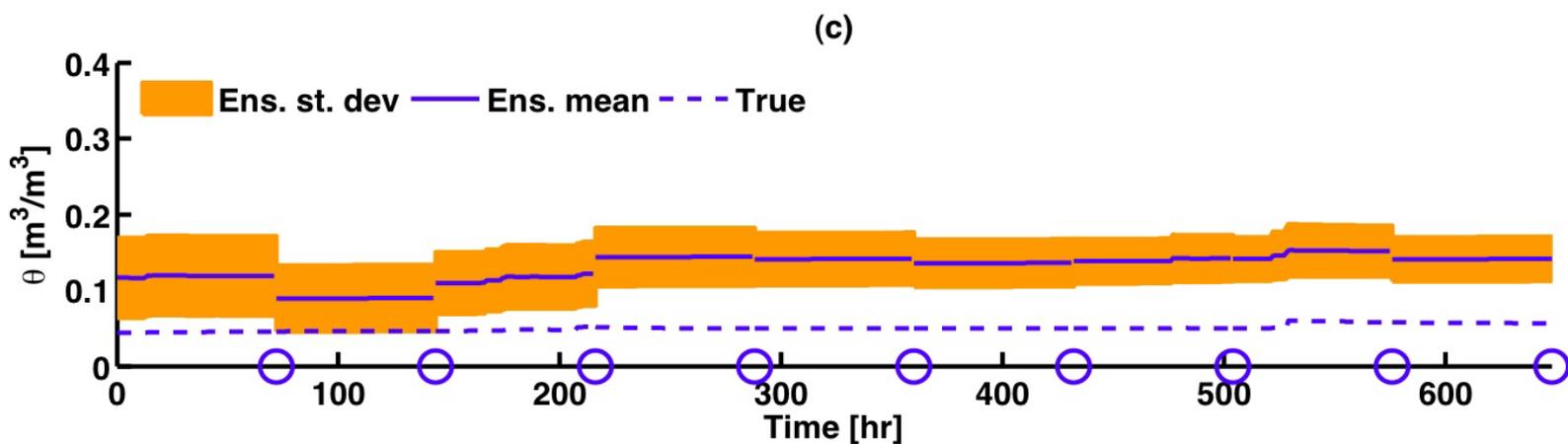
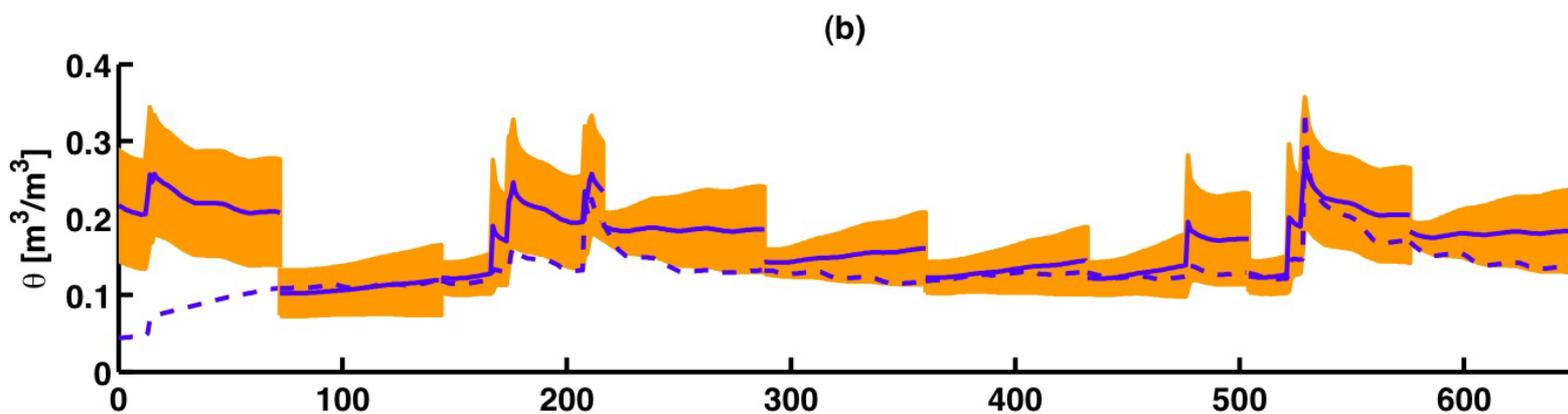
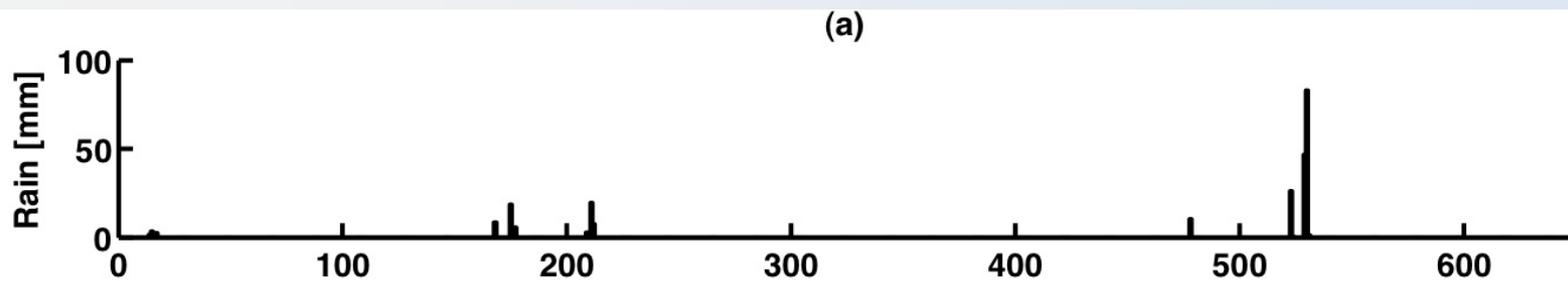
Pixel-scale Moisture Dynamics

Critical questions:

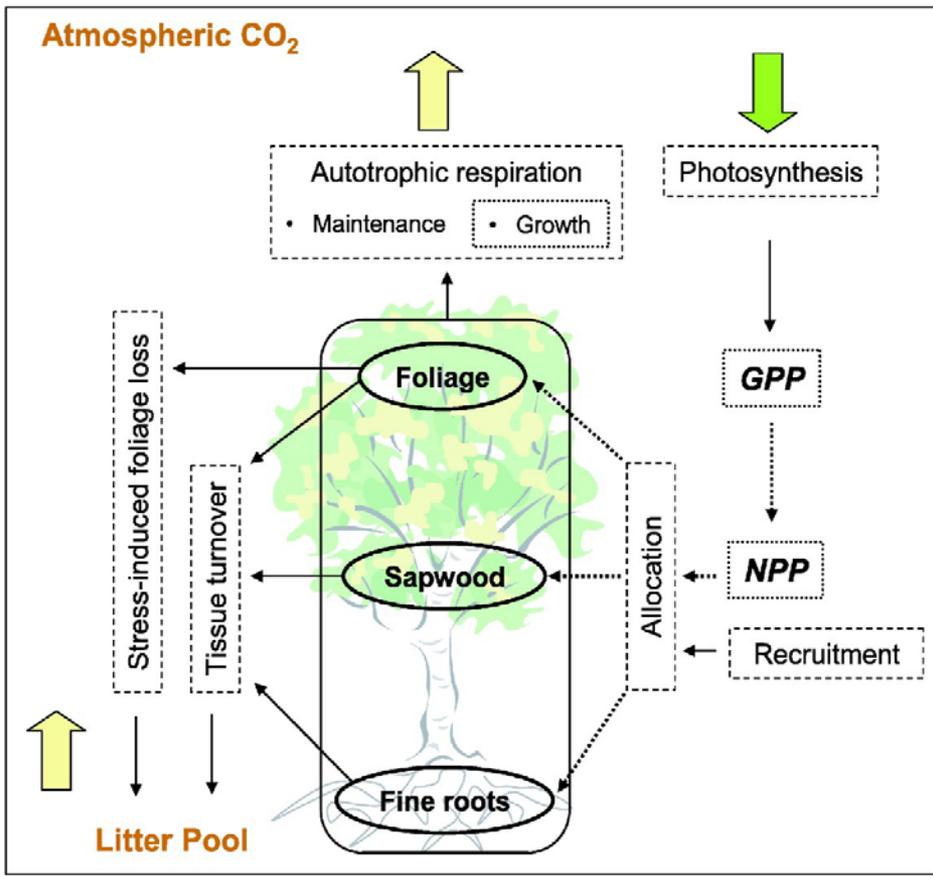
1. To what extent does assimilation improve local soil moisture knowledge?
2. Does update improve overall knowledge of moisture in column?
3. How quickly does improved knowledge degrade?



Two pixels were selected in order to monitor temporal soil moisture dynamics during the filtering experiments



Ongoing Related Research



VEGetation Growth and Integrated Evolution (VEGGIE) model component

- Vegetation is neither spatially homogenous nor temporally static
- We hypothesize that observable vegetation characteristics are informative regarding soil moisture
- VEGGIE captures temporal variability in vegetation states like LAI, canopy temp. and albedo
- Can LANDSAT/MODIS be used in a data assimilation framework to disaggregate SMAP radar observations to hillslope scales?

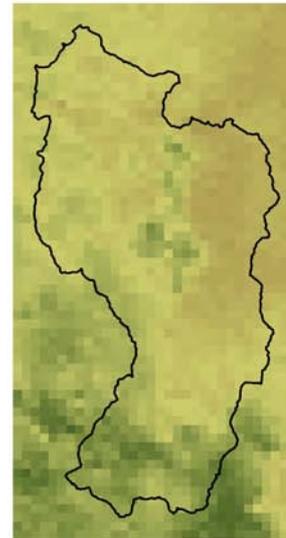
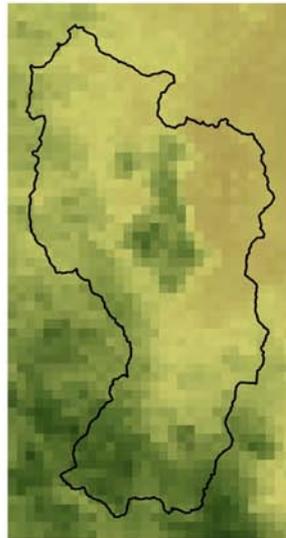
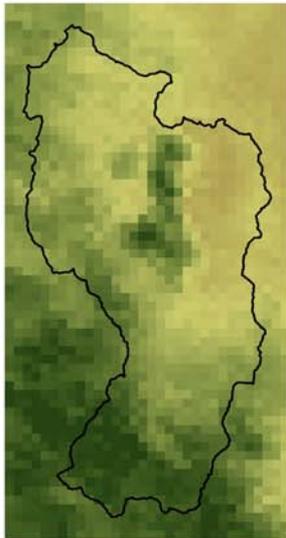
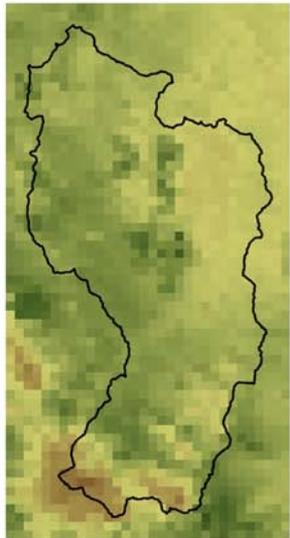
Ongoing Research

May 23, 2008

Jul. 26, 2008

Aug. 27, 2008

Oct. 14, 2008



NDVI
High : 0.7
Low : -0.2

0 2.5 5 7.5 10

