Towards Improved High-Resolution Land Data Assimilation Systems Using a Physically-Based Land Surface Hydrologic Model and Data Assimilation

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Land Data Assimilation Systems

"The *Noah and Mosaic models* are useful only for about 10% of the 961 small basins, the *SAC-SMA and VIC models* are useful for about 30% of the 961 small basins" from 1 Oct 1979 to 30 Sep 2007 (Xia et al. 2012)
Towards Improved LDASs

Modeling Technique
Incorporate physics-based hydrologic component

Data Assimilation Technique
Fully utilize reanalyses, remotely-sensed and in situ data
Automated parameter and state optimization

Improved land surface and hydrologic data assimilation systems
Physically-Based Land Surface Hydrologic Model: Flux-PIHM

Shi et al. 2013 Journal of Hydrometeorology
Shale Hills Watershed

SSHCZO: Susquehanna/Shale Hills Critical Zone Observatory

Area: 0.08 km$^2$
Testing Flux-PIHM at Shale Hills

Shi et al. 2013 Journal of Hydrometeorology
Flux-PIHM EnKF System

Initial conditions → Perturbation → Ensemble members → Flux-PIHM

Forecast → Flux-PIHM

Constrained analysis → Observations

Analysis → EnKF → Quality control
Synthetic Experiment Design

- **Site:** Shale Hills Watershed
- **Experiment period:** 10 Feb to 1 Aug 2009
- **Number of ensemble members:** 30
- **Assimilation interval:** 3 days
- **Observations:**
  - Outlet discharge
  - Average water table depth at three wells
  - Average soil water content at three wells
  - Watershed average land surface temperature
  - Watershed average sensible heat flux
  - Watershed average latent heat flux
  - Watershed average canopy transpiration

Shi et al. 2014 Water Resources Research
What parameters are the most important to simulate the variables?

- Hydrologic parameters
  - Effective Porosity $\Theta_e$
  - van Genuchten soil parameter $\alpha$
  - van Genuchten soil parameter $\beta$

- Land surface parameters
  - Zilitinkevich parameter $C_{zil}$
  - Minimum canopy stomatal resistance $R_{cmin}$
  - Maximum canopy interception storage $S$

Shi et al. 2014 Journal of Hydrometeorology
Can EnKF system provide accurate estimates of parameter values?
What if we use real observations?

- **Real observations:** outlet discharge, water table depth, soil water content, and sensible and latent heat fluxes
- **Assimilation interval:** 7 days
How about model performances?

- Forecasts using manually calibrated parameters and EnKF estimated parameters are similar
- Time cost:
  - EnKF: 6.5 hours (parallel runs)
  - Manual: Days—weeks
What observations do we need to constrain the parameters?

Control: Discharge, WTD, SWC, LST, sensible and latent heat fluxes, transpiration

QST: Discharge, WTD, SWC, LST, sensible and latent heat fluxes, transpiration
What about spatial patterns?

10-cm soil moisture pattern on Aug 23, 2009

Calibrated only using outlet discharge and SWC and WTD at one location, and driven by spatially uniform forcing data

Shi et al. 2015 Hydrological Processes
Flux-PIHM EnKF System

- High fidelity land surface hydrologic model with physics-based hydrologic component
- Resolves high resolution land surface heterogeneity ($10^1 \sim 10^2$ m/hourly resolution)
- Performs multivariate data assimilation for dual state-parameter optimization
- Only requires discharge, soil water content, and land surface temperature to constrain model parameters
Towards Large Scale High-Resolution Land Surface Hydrologic Data Assimilation System

Flux-PIHM Data Assimilation System

Hourly meteorological forcing at 1/8° resolution

SMAP soil moisture (3—9 km)
MODIS LST (1 km)
MODIS LAI (1 km)

Sub-daily river discharge over 10,000 stations

NED
SSURGO
NLCD

WaterWatch
USGS
Coupled Biogeochemistry Modules

Flux-PIHM-BGC

RT-Flux-PIHM
Chloride concentration

Unit: µmol/L

(Courtesy of Chen Bao)
Coupled Biogeochemistry Data Assimilation

Flux-PIHM Data Assimilation System

Geochemical Box Model
WITCH

Mineral dissolution / Precipitation
Adsorption Ion Exchange
Advection Diffusion/Dispersion
Reactive Transport Module

Forest Ecosystem Model
Biome-BGC

Crop Ecosystem Model
Cycles
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Assimilation Interval

Shi et al. 2014 Water Resources Research
Evolution of Model Variables

(a) $Q$ (m$^3$ d$^{-1}$)

(b) $T_{sfc}$ (°C)

Shi et al. 2014 Water Resources Research
What about the spatial patterns?

Calibrated only using outlet discharge and SWC and WTD at one location, and driven by spatially uniform forcing data.

Shi et al. submitted B