411

Results from Assimilating AMSR-E Soil Moisture Estimates into a Land Surface Model using an Ensemble Kalman Filter in the Land Information System (LIS)

Clay B. Blankenship[1], William L. Crosson[1], Jonathan L. Case[2], and Robert Hale[3]

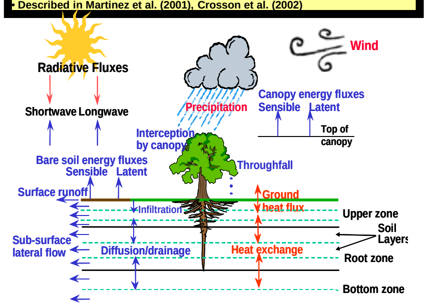
[1]USRA, Huntsville, AL [2]ENSCO, Inc., Huntsville, AL [3]Cooperative Institute for Research in the Atmosphere, Ft. Collins, CO

Objectives of Project

- Improve simulations of soil moisture/temperature, and consequently boundary layer states and processes, by assimilating AMSR-E soil moisture estimates into a coupled land surface-mesoscale model
- Provide a new land surface model as an option in the Land Information System (LIS)

SHEELS – Simulator for Hydrology and Energy Exchange at the Land Surface

- Distributed land surface hydrology model
- Heritage: 1980's Biosphere-Atmosphere Transfer Scheme (BATS)
- Can run off-line or coupled with meteorological model
- Flexible vertical layer configuration designed to facilitate microwave data assimilation
- Contains radiative transfer model for microwave applications
- Described in Martinez et al. (2001), Crosson et al. (2002)



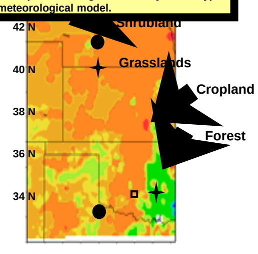
SHEELS Integration in LIS

- We have integrated SHEELS into LIS (Kumar et al., 2006), a software framework for running land surface models.
- We have performed off-line simulations over a Great Plains domain in LIS to provide initial conditions to future WRF-SHEELS coupled simulations.
- SHEELS 'spin up' has been performed off-line, forced with North American Land Data Assimilation System (NLDAS) data from 1/1/2002 through 6/9/2003

Features of LIS

- Highly customizable at run-time, facilitating modeling experiments & intercomparisons
- Modular structure allows user to specify:
  - Land Surface Model
  - Base forcing (meteorological fields)
  - Supplemental forcing (e.g. precipitation)
  - Parameters including land cover, soil type, greenness fraction, topography
- Domains of input variables may be independent.
- Allows several tiles per grid cell to represent subgrid variability of soil type.
- Can run coupled with the WRF meteorological model.

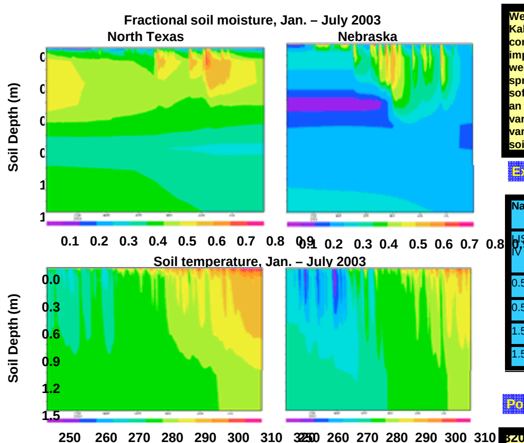
U.S. Great Plains Model Domain



Land cover classes used in SHEELS land surface model.

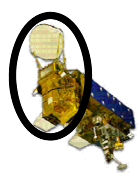
Circles mark points used in time-depth cross sections, a rectangle marks the location of the Little Washita Micronet, and stars show points used in time series at right.

SHEELS Time-Depth Soil Moisture and Temperature Results

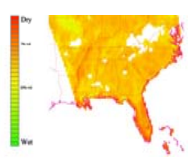


AMSR-E Soil Moisture

- Conically scanning passive microwave radiometer
- Measures brightness temperatures at 6 frequencies from 6.9 to 89.0 GHz
- Horizontally and vertically polarized radiation are measured separately at each frequency
- Altitude of 705 km yields a swath 1445 km wide
- AMSR-E/Aqua global surface soil moisture and vegetation water content are generated from level 2A AMSR-E brightness temperatures spatially resampled to a nominal 25-km equal area earth grid.
- Algorithm minimizes differences between the observed brightness temperatures and those generated using a forward radiative transfer model.
- Due to extensive radio frequency interference in the 6.9 GHZ channel, 10.7 and 18.7 GHz observations are used for soil moisture estimation.



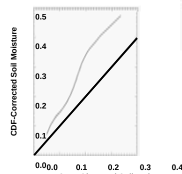
NASA Aqua satellite with AMSR-E instrument circled



AMSR-E retrieved soil moisture for August 2, 2008 over the SE US

AMSR-E Bias Correction

The dynamic range of AMSR-E observed soil moisture is small relative to that of the model.
A correction (right) is applied to convert the observation into a model-equivalent value.
A Cumulative Distribution Function (CDF)-matching technique is used here. This is similar in purpose to the bias corrections usually applied to satellite observations in NWP models.
Simulations made without the proper correction showed a pronounced dry bias.



Ensemble Kalman Filter Data Assimilation

We assimilate ASMR-E soil moisture observations using an Ensemble Kalman Filter (EnKF). Kalman filtering is a data assimilation method that combines a forecast (background) with observations to generate an improved estimate of a model variable. A Kalman Filter calculates an optimal weighting between the background and the observation. The EnKF uses the spread of the ensemble to represent the forecast error covariance. The LIS software includes the capability to perform EnKF data assimilation. We used an ensemble with 16 members generated using perturbations of 3 forcing variables (incident longwave and shortwave radiation, and rainfall), 14 state variables (14 layers of soil moisture), and 1 observation variable (AMSR-E soil moisture).

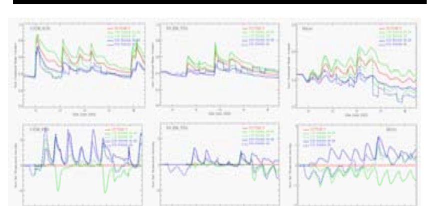
Experiments

Name	Data Assim.	Precip. Forcing	Purpose
LIS/Stage IV	No	Stage IV	"Truth" run for validation, since this is forced with the best available precipitation observations.
0.5x No DA	No	0.5 x Stage IV	Under-estimated rainfall for testing DA
0.5x DA	Yes	0.5 x Stage IV	
1.5x No DA	No	1.5 x Stage IV	Over-estimated rainfall for testing DA
1.5x DA	Yes	1.5 x Stage IV	

Point Validation Results

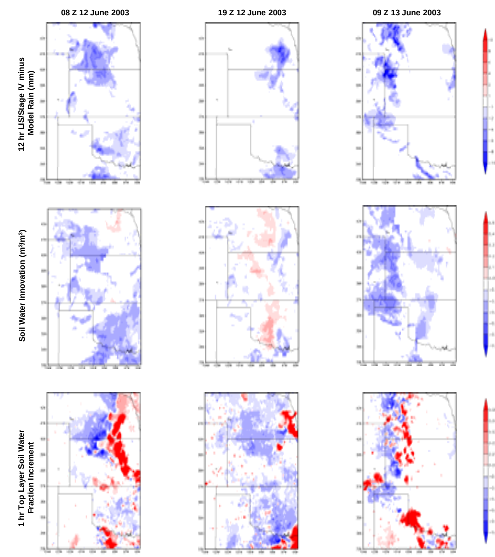
- The USDA Agricultural Research Service's (ARS) Grazinglands Research Laboratory has measured meteorological and hydrologic conditions in the Little Washita Experimental Watershed network ('ARS Micronet') in southwestern Oklahoma since 1961.
- In 1994, the ARS began monitoring the meteorological conditions in this watershed with a network called the ARS Micronet. The Micronet now consists of 20 core stations.
- Soil temperature and moisture are measured hourly at Micronet sites at 3 depths, including the 5 cm observations used here to validate model results.

- Time series of 5 cm soil water content at two ARS Micronet sites and the 12-site mean.
- Observations generally over-estimate soil moisture compared to the benchmark LIS/Stage IV simulation and the Micronet *in situ* observations.



- Time series of 5 cm soil water content and soil temperature (departure from LIS/Stage IV simulation) at two points, and for the average of all points south of 37N ("Mean").
- In some cases data assimilation improves the model variables relative to the LIS/Stage IV benchmark.
- The two data assimilation runs generally converge.
- Effects of assimilation on soil temperatures is consistent with soil moisture changes – lower soil moisture results in greater diurnal range of soil temperature.

Data Assimilation Results – Simulation using 1.5 x Stage IV rainfall



Top row: Benchmark (LIS/Stage IV) minus DA simulation of 12-hour rainfall accumulation, for three model time steps just after an AMSR-E overpass. Since the DA simulation has rain forcing set to 1.5x the Stage IV, this number is always <=0.
Middle row: Soil water innovation (AMSR-E observed minus model soil water) for the DA run. There is overall good correspondence between these values and top row.
Bottom row: Soil water 1-hr increment. This value includes the effect of data assimilation as well as precipitation and other physical processes during this time step. Dark red areas are predominantly areas of precipitation.

References

- Crosson, W.L., C.A. Laymon, R. Inguva and M. Schamschula, 2002: Assimilating remote sensing data in a surface flux-soil moisture model. *Hydrol. Proc.*, 16, 1645-1662.
- Kumar, S.V., C.D. Peters-Lidard, Y. Tian, P.R. Houser, J. Geiger, S. Olden, L. Lighty, J. L. Eastman, B. Doty, P. Dirmeyer, J. Adams, K. Mitchell, E.F. Wood and J. Sheffield, 2006: Land Information System - An interoperable framework for high resolution land surface modeling. *Environmental Modelling and Software*, 21, 1402-1415.
- Martinez, J.E., C.E. Duchon and W.L. Crosson, 2001: Effect of the number of soil layers on a modeled surface water budget. *Water Res. Research*, 37, 367-377.

Future Research

- Evaluate possible improvements to the CDF-matching adjustment by deriving separate curves for different vegetation types and times of day.
- Perform more extensive validation of soil moisture and temperature simulations.
- Run WRF-SHEELS coupled model in 12-hour forecast cycles for January and July, 2003.
- Evaluate value of AMSR-E DA in estimating boundary layer states (temperature, humidity, wind) and surface fluxes.
- Determine landscape and hydrometeorological conditions under which assimilation is most (and least) helpful.

Acknowledgments

The authors thank Sujay Kumar, Christa Peters-Lidard and Jim Geiger of Goddard Space Flight Center for their assistance with LIS integration.