# Ensemble Kalman Filter Data Assimilation of AMSR-E Soil Moisture Estimates Into the LIS-WRF Coupled Land/Atmosphere Model

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

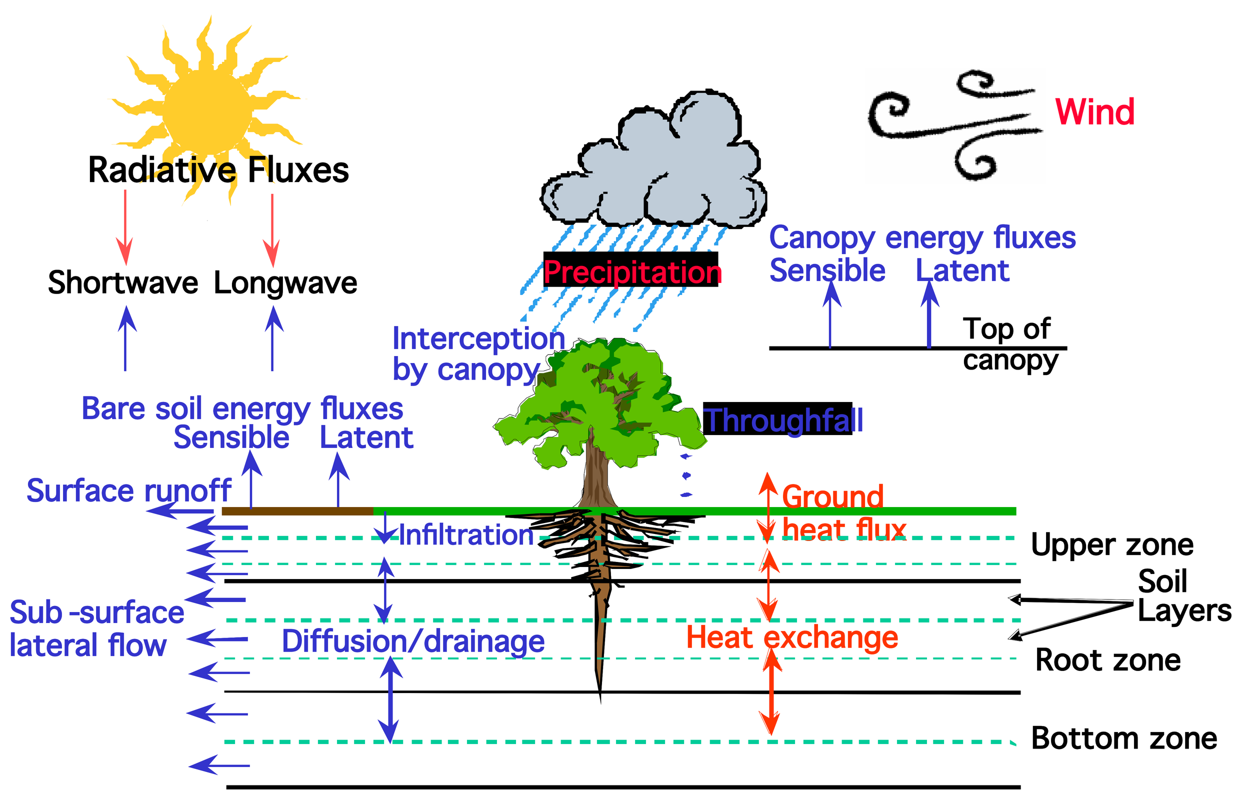
[1]USRA, Huntsville, AL [2]ENSCO, Inc., Huntsville, AL

## 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 (LIS-WRF)
- 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

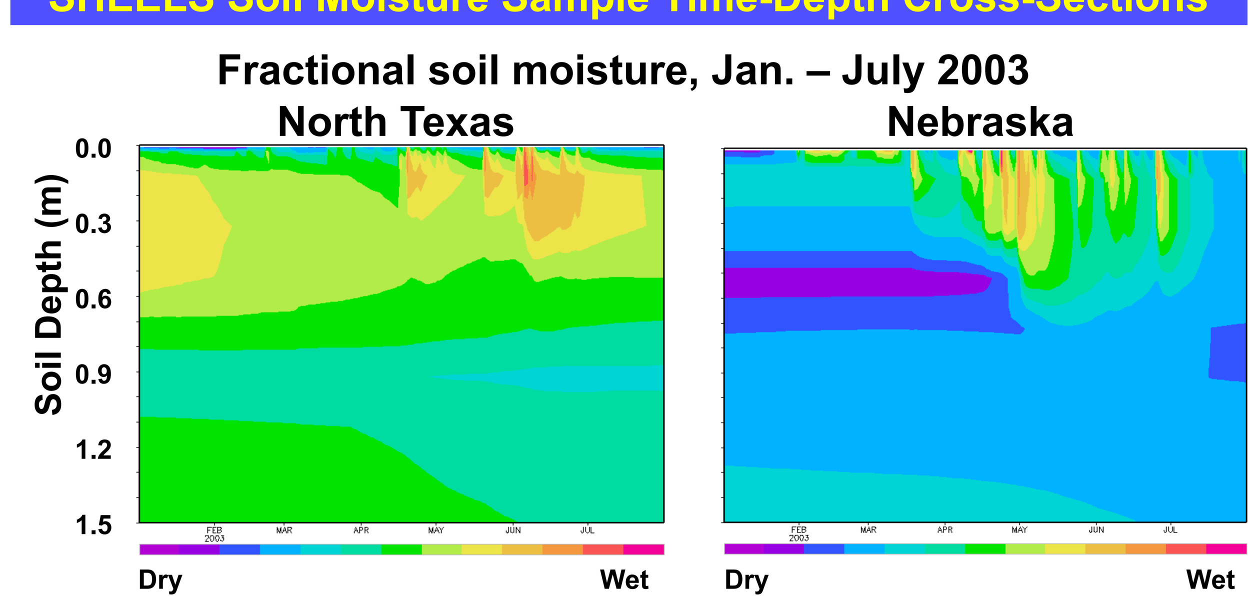
•Modular structure allows user to specify:
- Land Surface Model
- Base forcing (meteorological fields)
- Supplemental forcing (e.g. precipitation)
- Parameters include land cover, soil type, greenness fraction, topography

•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.

## SHEELS Soil Moisture Sample Time-Depth Cross-Sections

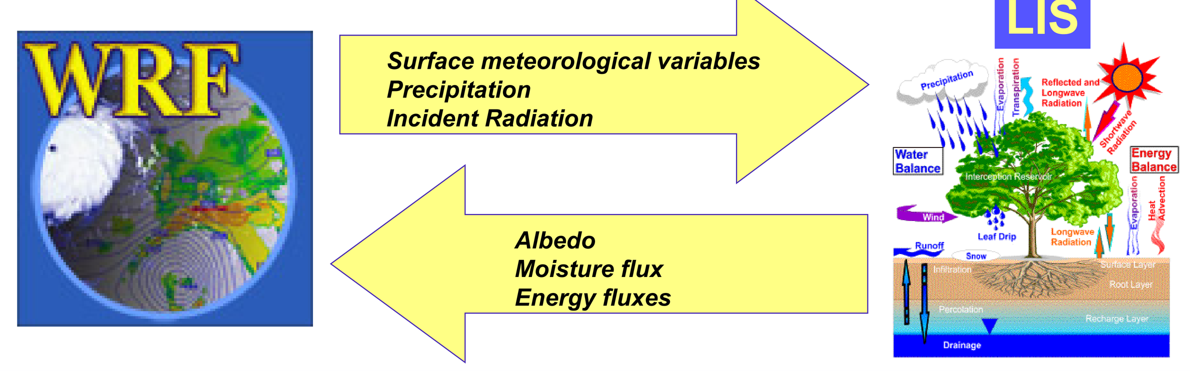



**Acknowledgement**

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

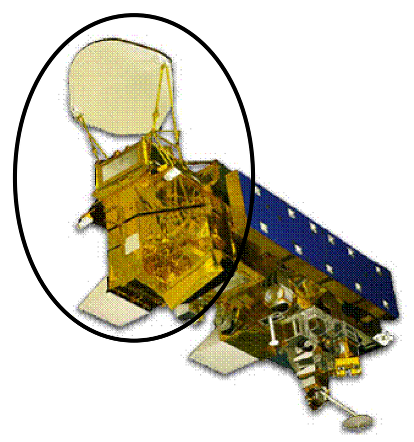
## LIS-WRF Coupling

•LIS can be run coupled with the WRF meteorological model.
•We are using ARW version 2.2 with LIS 5.0 and our SHEELS additions.

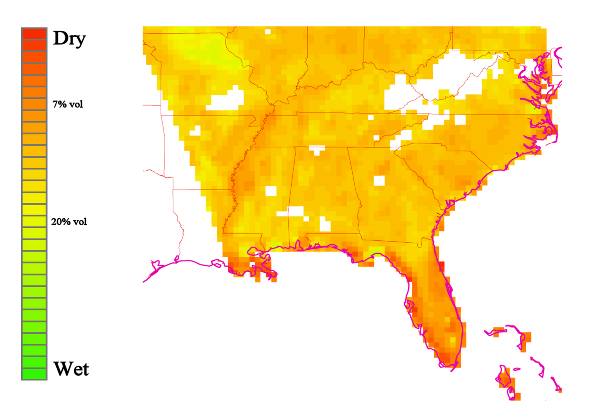



## AMSR-E Soil Moisture

- Conically scanning passive microwave radiometer
- Measures brightness temperatures at 6 frequencies, at H and V polarizations, from 6.9 to 89.0 GHz.
- Altitude of 705 km yields a swath 1445 km wide.
- 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.
- 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.



NASA Aqua satellite with AMSR-E instrument



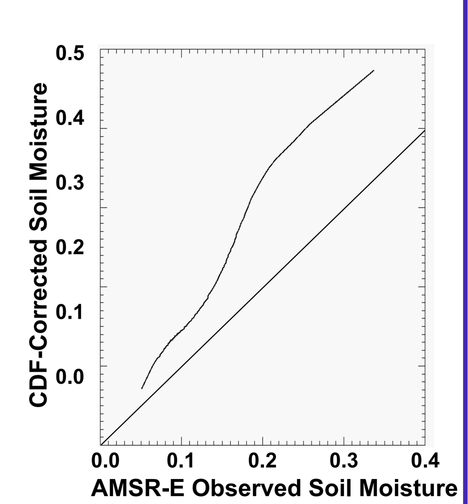

AMSR-E retrieved soil moisture for August 2, 2008 over the southeastern US

## Ensemble Kalman Filter Data Assimilation

Within the LIS system, 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 forecast error covariance. 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).

## 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.
- Issues remain--see discussion later.



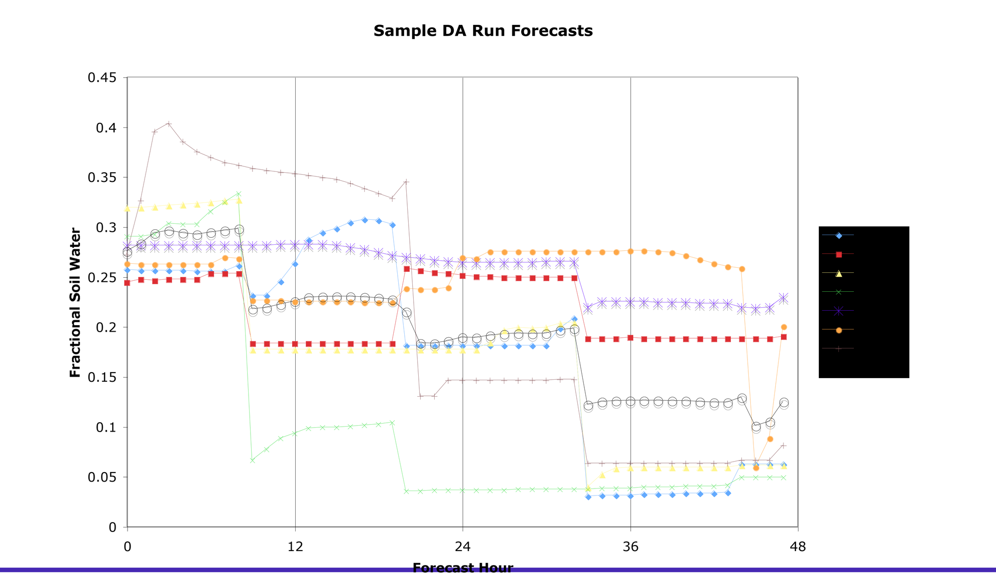

## Model Configuration

- We performed LIS-WRF coupled model runs with the SHEELS LSM, using ARW version 2.2 (Skamarock et al., 2005) along with LIS release 5.0 with modifications for the SHEELS LSM and AMSR-E soil moisture data assimilation.
- All model runs were made with State Soil Geographic Database (STATSGO) soil types, University of Maryland land use classification, Leaf Area Index from the Advanced Very High Resolution Radiometer (AVHRR) and greenness fraction from the National Centers for Environmental Prediction (NCEP).
- WRF runs used initial and boundary conditions from the NCEP Eta model.

- SHEELS model variables were initialized from a LIS 'spin up' simulation in uncoupled mode using NLDAS base forcing (surface meteorological variables and downwelling radiation) and Stage IV precipitation estimates (radar estimates adjusted with daily rain gauge totals) from January 2002 through June 2003.
- Experimental LIS-WRF coupled model runs were performed for each day in June 2003 at 0 and 12 UTC. For these 60 initial times, we made 48-hour forecasts for both a control run and an AMSR-E data assimilation run.
- Simulations were performed over a central U.S. domain extending from northern Texas to Nebraska.

## Bias Issue

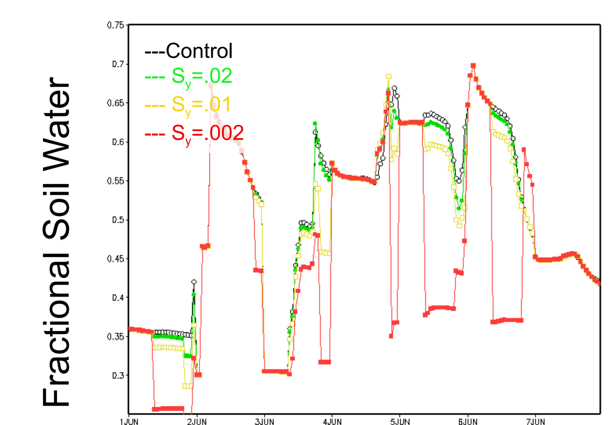
- We note a marked tendency for the data assimilation step to dry the soil. Satellite overpasses occur at roughly 8Z and 20Z for this domain. For points with satellite observations, drying usually happens at these times for the data assimilation run.
- Possible reasons:
  - •Initial condition from spinup run is too wet
  - •Bias in WRF climatology
  - •Poorly specified formula to convert model state into equivalent observations
- We plan to generate new CDF's and investigate the dependence of the bias on landcover type and time of day.



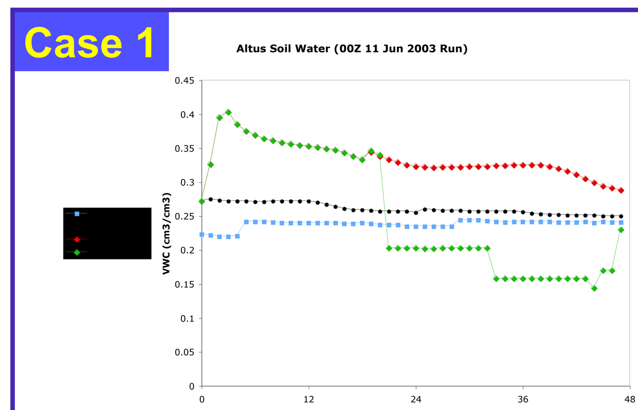

# Results

## Effect of Specified Observation Error

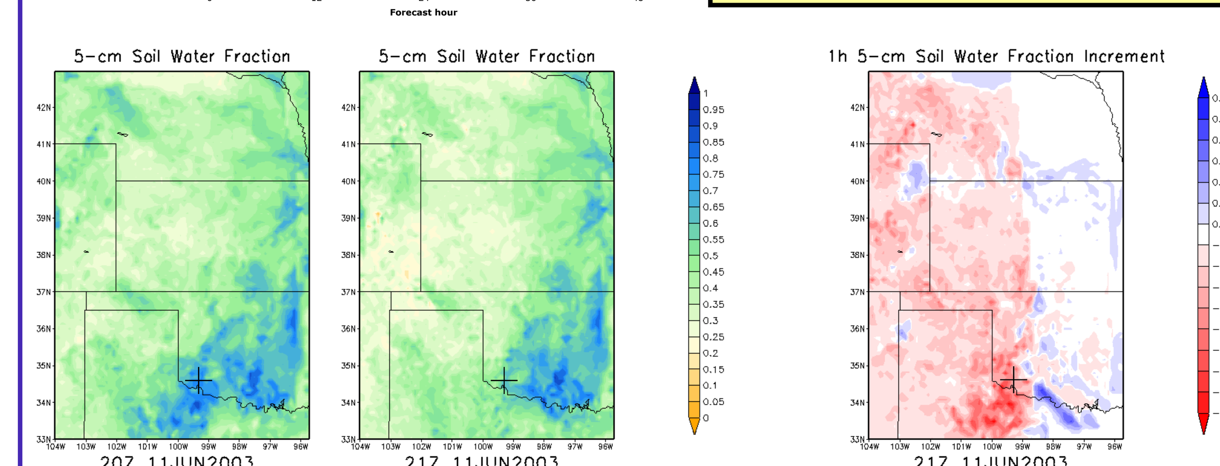
Time series for one sample point for four different settings of Observation Error ($S_y$) are shown. As the observation error decreases, the impact of the data assimilation increases as expected.
•These runs reset to Eta initial conditions every 24 hours.




## Case 1



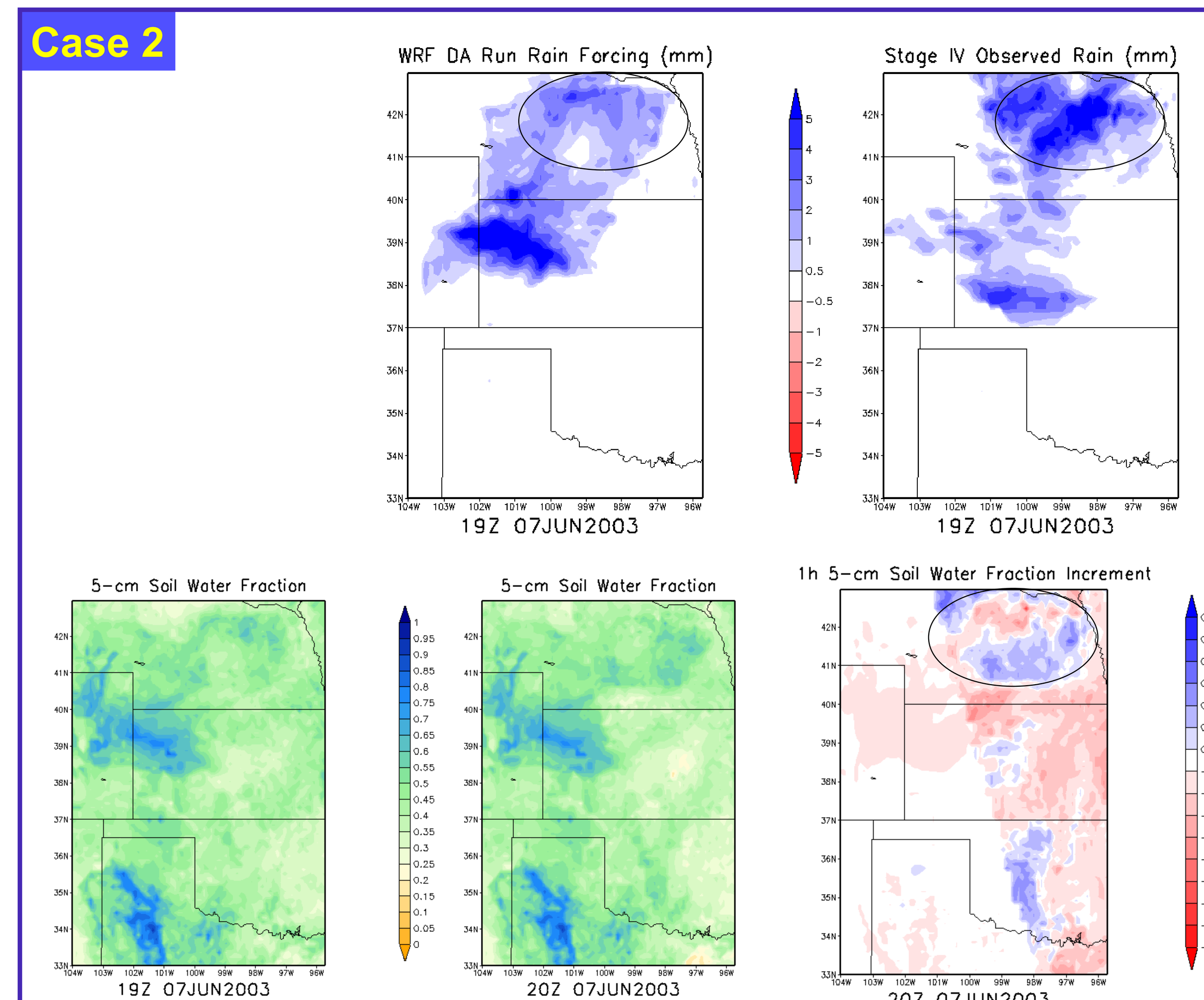

Mesonet: 5cm soil moisture derived from hourly Oklahoma Mesonet measurements at Altus.
Stage IV Run: LIS uncoupled run with observed (radar/rain gauge) Stage IV rainfall.
Control Run: LIS-WRF coupled run *without* data assimilation.
DA Run: LIS-WRF coupled run *with* data assimilation.




**Discussion**

- The control and DA runs experience rain in Altus for the initial 3 hours.
- The Altus Mesonet measurements (blue line) and the Stage IV run (black line) indicate no rain.
- The 20Z and 21Z model water plots show that the data assimilation correctly dries out the soil in SW Oklahoma and in nearby parts of Texas.

## Case 2




**Discussion**

- WRF model rain and Stage IV observations show a similar rainfall distribution, however WRF under-predicts the amount in Nebraska.
- DA correctly adds soil water in this region.
- This is a rare case where the current implementation of DA adds water--see discussion of bias above.

## Future Research

- Resolve bias problem, and evaluate possible improvements to the CDF-matching adjustment by deriving separate curves for different vegetation types and times of day.
- Run WRF-SHEELS coupled model in 12-hour forecast cycles for January and July, 2003.
- Perform additional validation, including near-surface air temperature and humidity against Mesonet measurements
- 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.

## 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, .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.

•Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers, 2005. A Description of the Advanced Research WRF Version 2. *NCAR Tech. Note, TN-468+STR, 88 pp.*, 2005. [Available from UCAR Communications, P.O. Box 3000, Boulder, CO 80307.]