Assimilation of remote sensing data in a hydrologic model to improve estimates of spatially distributed soil moisture

Bill Crosson, Charles Laymon

Global Hydrology and Climate Center
National Space Science and Technology Center
Huntsville, Alabama

Wael Khairy, Marius Schamschula, Tom Coleman

Center for Hydrology, Soil Climatology and Remote Sensing
Alabama A&M University
Normal, Alabama

Rama Inguva

East-West Enterprises
Huntsville, Alabama

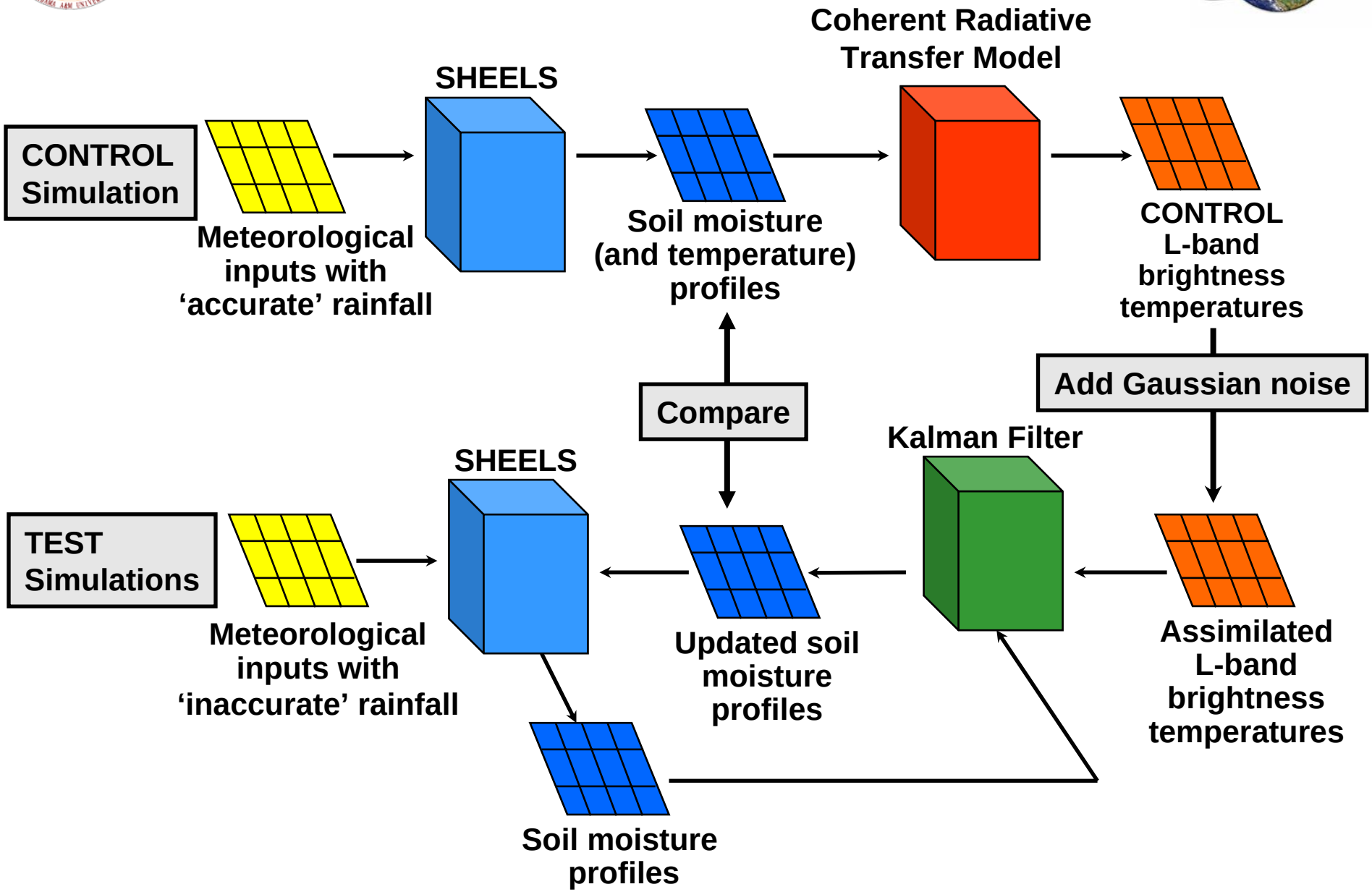
Objective

To examine the sensitivity of land surface model performance to the temporal frequency of microwave observation assimilation

Approach

- Use a coupled land surface-radiative transfer-Kalman filter model to simulate the soil moisture profile.
- Perform CONTROL simulation using best available rainfall data with no data assimilation.
- Perform TEST simulations using inaccurate rainfall data, assimilating data at various regular intervals produced by the CONTROL simulation. All simulations use identical initial conditions and meteorological forcing except for rainfall.
- Statistically compare TEST simulations with CONTROL case for each assimilation interval.

Assimilation Procedure



Approach Caveats

- Model-simulated data serve as a proxy for microwave measurements from aircraft or satellite-borne sensors.

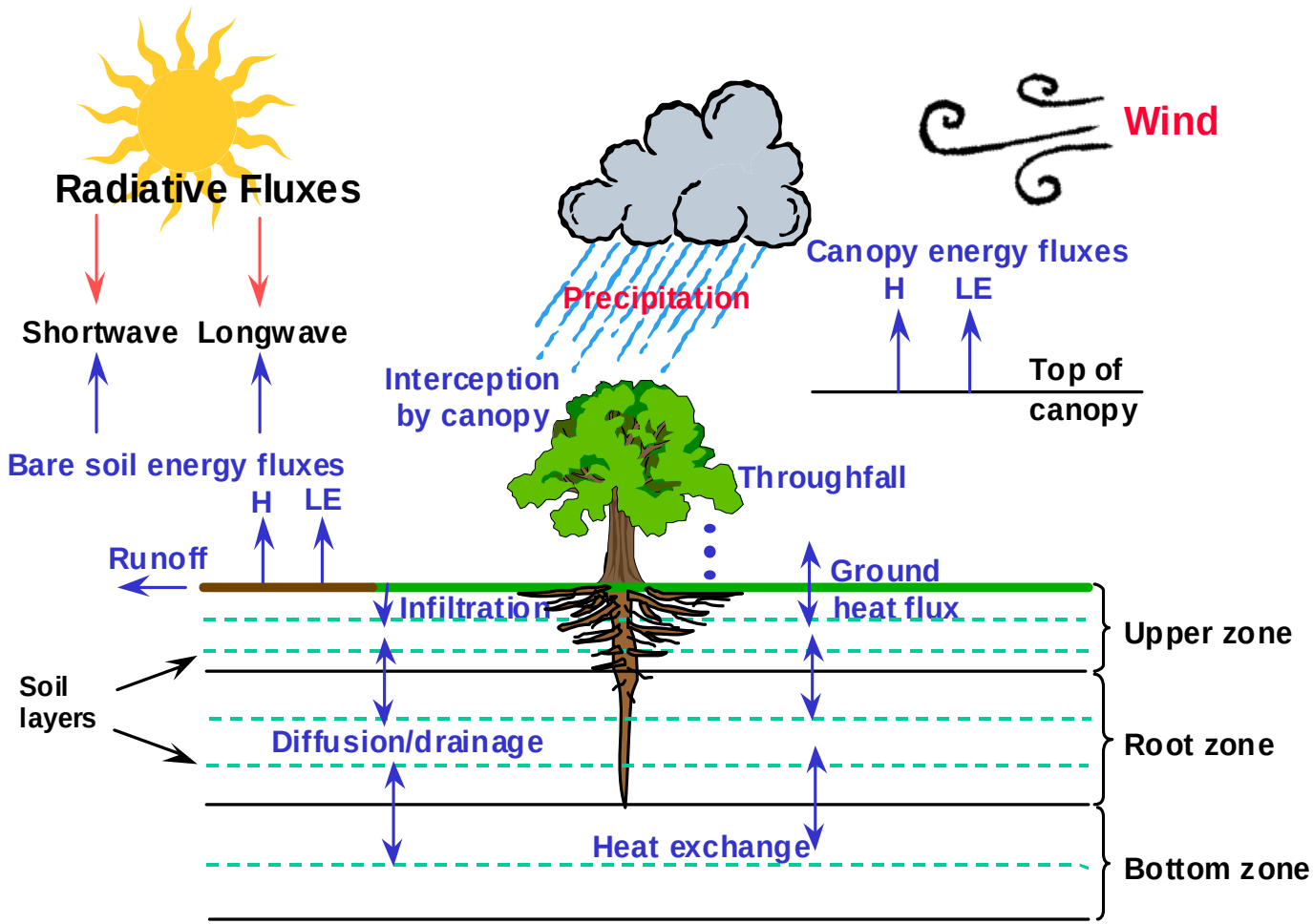
- This approach assumes that the CONTROL simulation is perfect:
  - Model physics are perfect
  - Meteorological data are perfect
  - Simulated brightness temperatures are perfect

- This experiment is designed to examine the relationship between assimilation frequency and model performance.

- Because the CONTROL simulation is not perfect, the resulting performance measures are relative, not absolute.

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

- Accommodates any number of soil layers
- Explicit diffusion schemes for sub-surface moisture and heat fluxes
- Simulates overland runoff
- Linked to radiative transfer model to estimate microwave brightness temperature and emissivity



Njoku and Kong Radiative Transfer Model

Forward coherent wave radiative transfer model of Njoku and Kong, 1977

- **Determines microwave brightness temperatures at given frequencies based on soil moisture and temperature profiles**
- **Incorporates effects of surface roughness and vegetation**
- **Uses Dobson dielectric mixing model**

Kalman Filter

Basic principles:

- Assimilates intermittent remotely-sensed estimates
- Nudges surface soil moisture toward remotely-sensed estimate
- Model and remote estimates weighted according to relative uncertainties
- Profile soil moisture adjusted based on vertical covariance structure

Specifics related to our implementation:

- Can utilize single- or multiple-frequency microwave brightness temperatures (used only L-band in this study) or soil moisture derived from remote sensing or other sources
- Contains parameterization for emitting depth that depends on wavelength and soil moisture content
- Observation error std deviation assumed constant 3 K or ~ 2% VWC
- Initial model state error covariance matrix must be specified; inter-layer error covariances may be set to zero or estimated
- Several options exist for temporal covariance propagation

Model study area and data sets

Model domain -- Little Washita River Basin, OK (600 km^2)

Model grid spacing -- 800 m

Terrain slope -- USDA/ARS 30 m DEM, aggregated to 800 m

Hydrography -- USGS DLG's

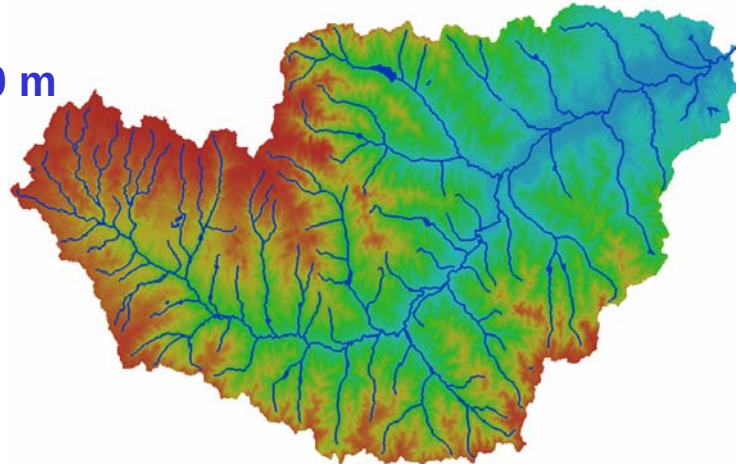
Vegetation parameters -- SGP'97 30 m Land Cover, aggregated to 800 m

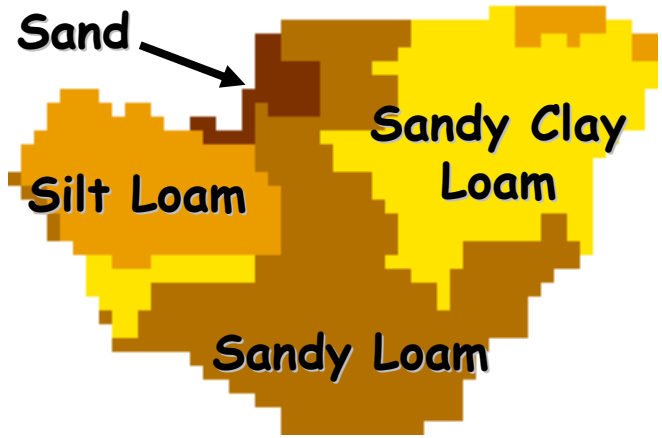
Soil properties -- CONUS 1 km multi-layer soil characteristics data set, resampled to 800 m

L band T_B -- SGP'97 ESTAR

- Surface roughness
- Soil moisture
- Soil bulk density
- Percent sand
- Percent clay
- Vegetation water content
- Vegetation b parameter

} ESTAR-associated data sets





Meteorological data -- Oklahoma Mesonet, USDA/ARS Micronet, SGP'97 soil profile stations

Precipitation --

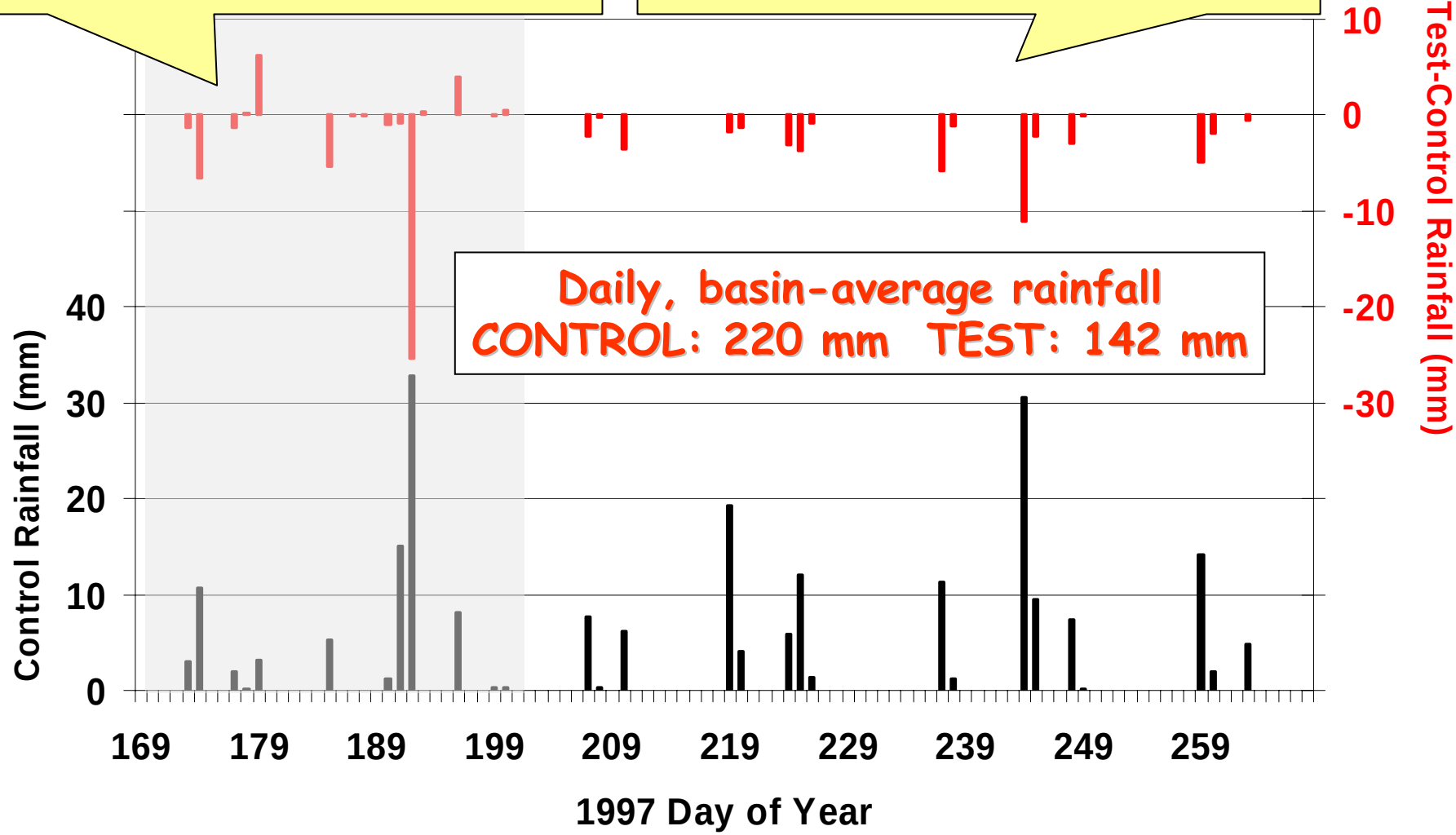
'Accurate': USDA Micronet rain gage network gridded at 800 m using Thiessen polygons

'Inaccurate': NOAA Stage IV 4 km rainfall estimates resampled to 800 m

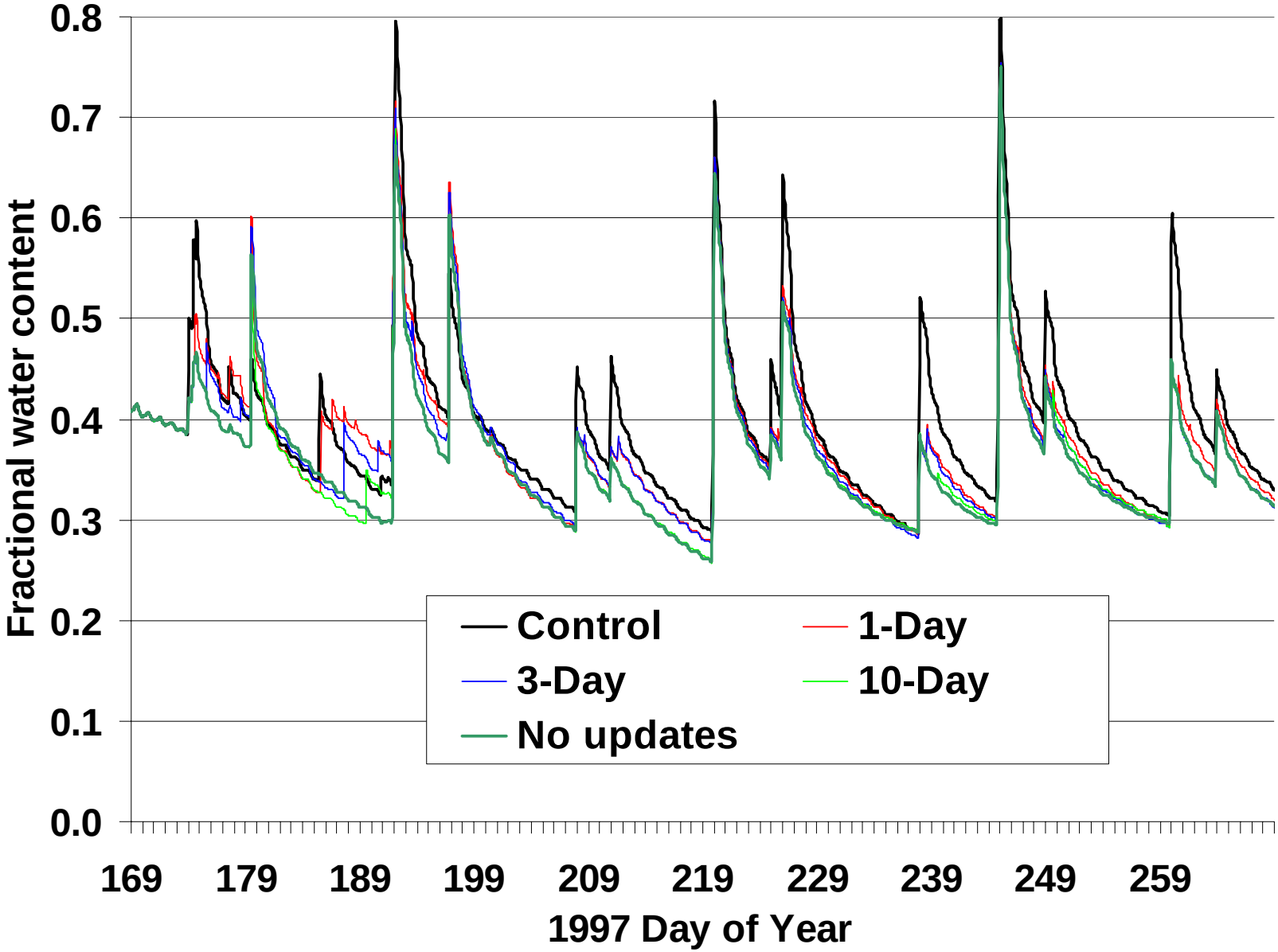
CONTROL and TEST rainfall inputs

First 34 days (169-202)
CONTROL: Gridded gage observations
TEST: NOAA Stage IV 4 km

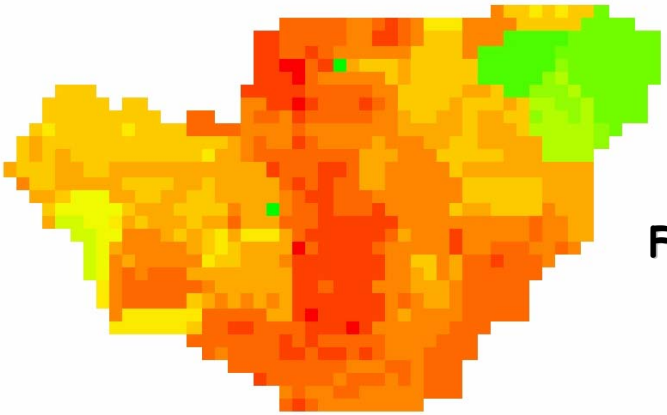
Next 66 days (203-268)
CONTROL: Simulated climatology
TEST: CONTROL + noise – 30% bias



Upper zone (0-10 cm) soil moisture TEST simulations vs. CONTROL



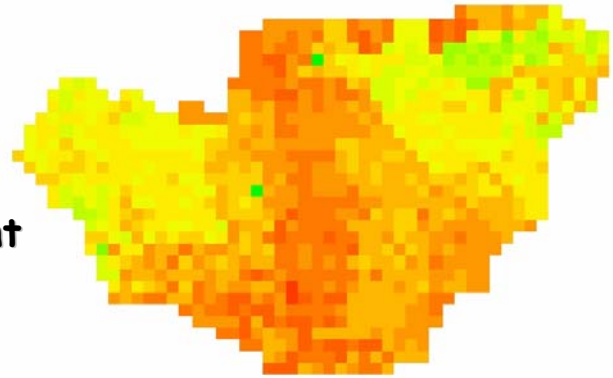
Upper zone (0-10 cm) soil moisture TEST simulations vs. CONTROL Day 185 (July 4) 9:00 LST



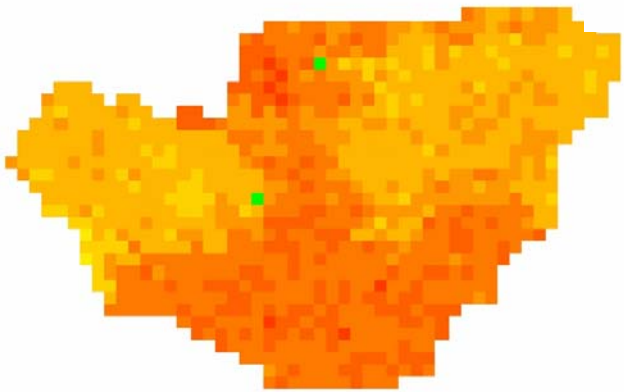
CONTROL

Fractional water content

0.24 - 0.28	0.52 - 0.56
0.28 - 0.32	0.56 - 0.60
0.32 - 0.36	0.60 - 0.64
0.36 - 0.40	0.64 - 0.68
0.40 - 0.44	0.65 - 0.72
0.44 - 0.48	0.72 - 0.76
0.48 - 0.52	0.76 - 1.0

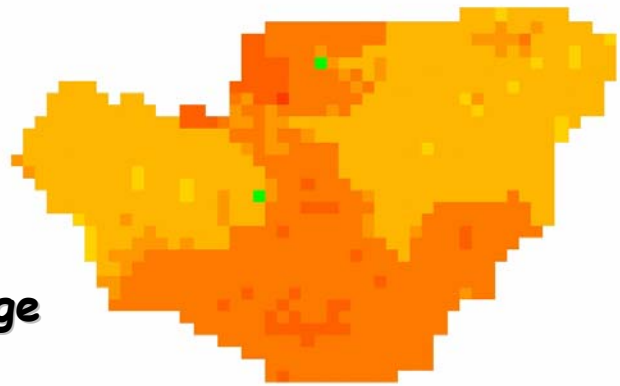


1-day updates



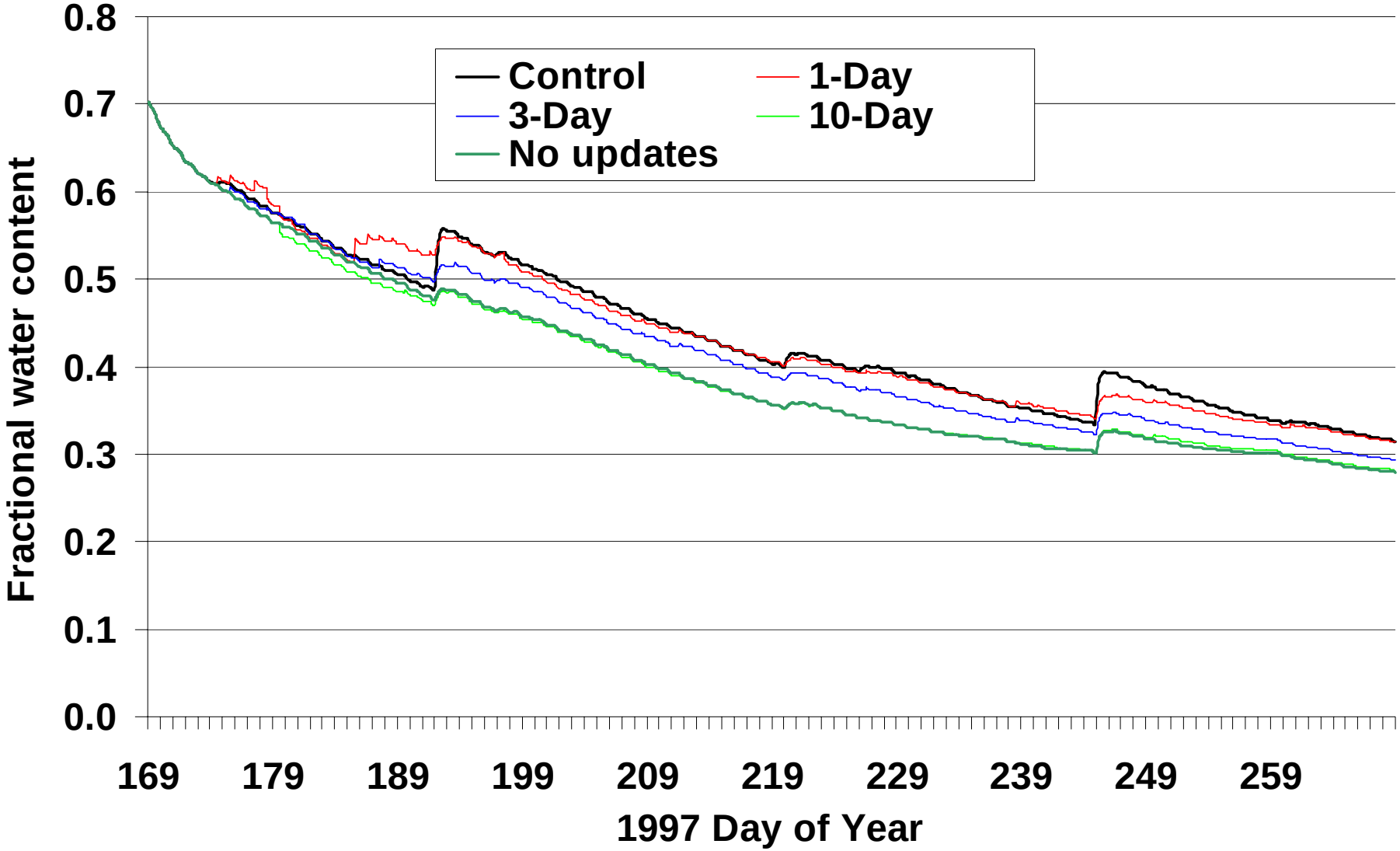
3-day updates

Note: Rainfall earlier this day is absent in the Stage IV rainfall data

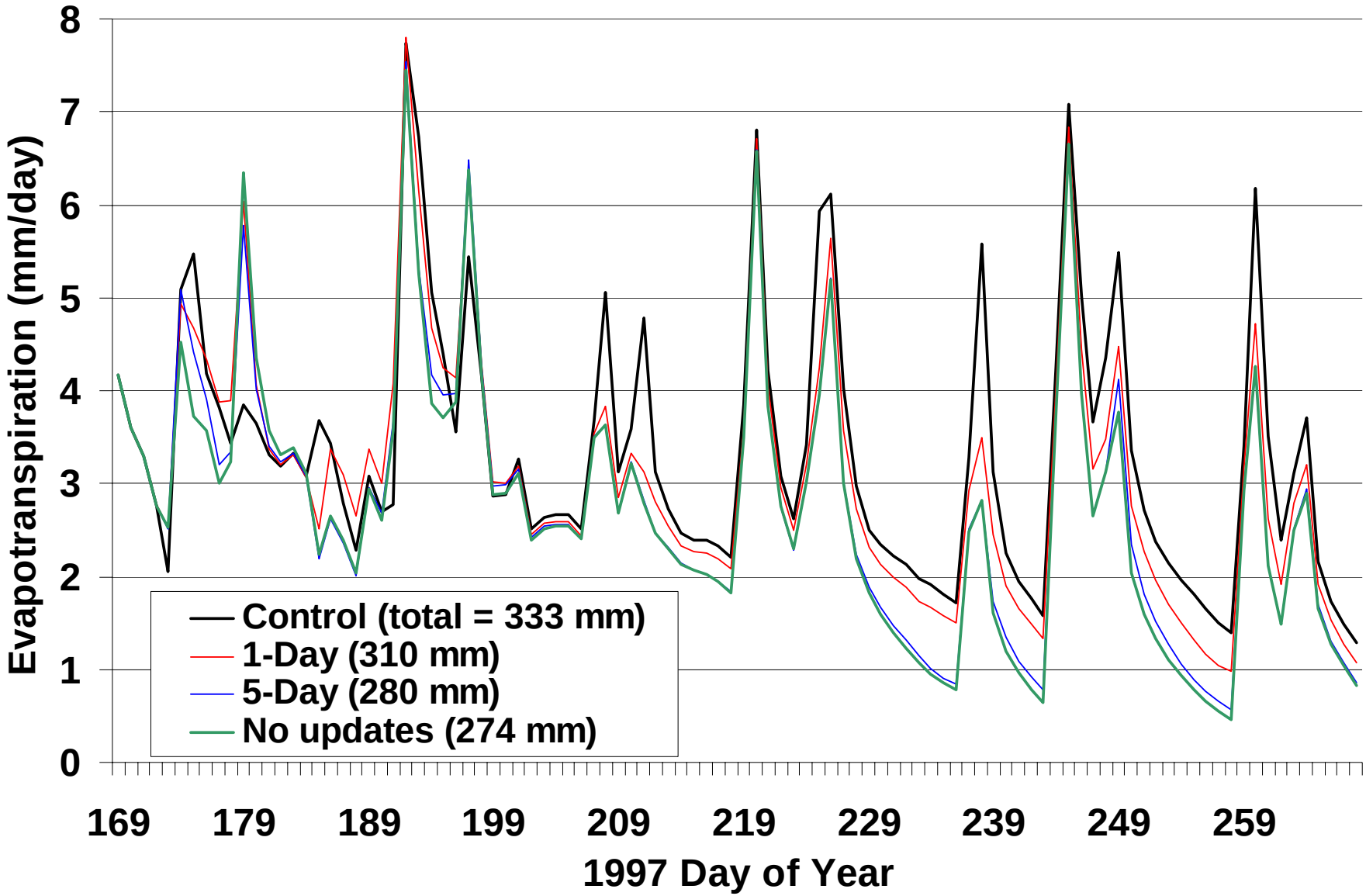


No updates

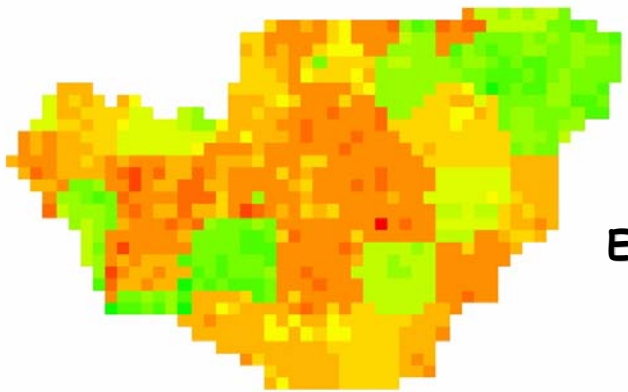
Root zone (10-100 cm) soil moisture TEST simulations vs. CONTROL



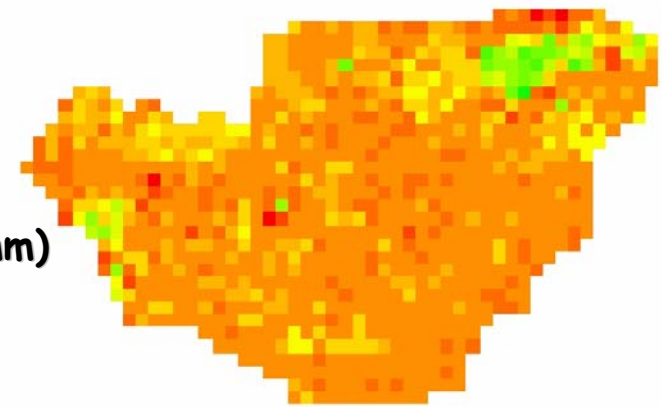
Daily evapotranspiration
TEST simulations vs. CONTROL



Hourly evapotranspiration TEST simulations vs. CONTROL Day 185 (July 4) 9:00 LST



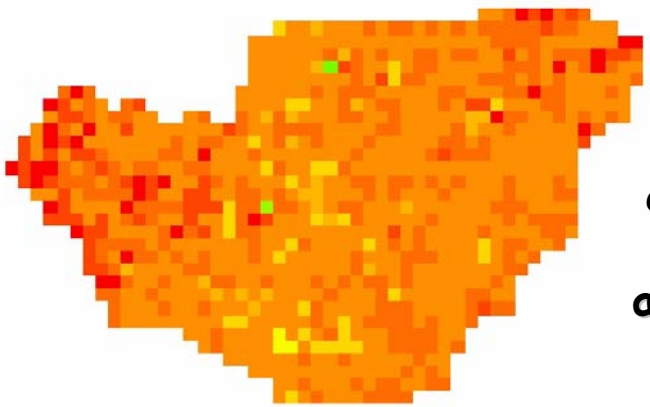
CONTROL



1-day updates

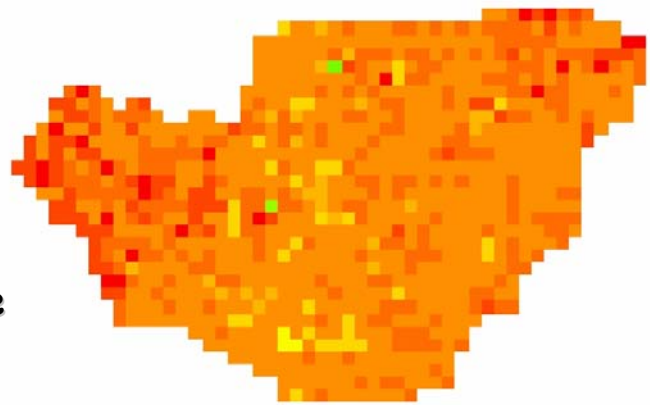
Evapotranspiration (mm)

0.00 - 0.10	0.30 - 0.35
0.10 - 0.14	0.35 - 0.40
0.14 - 0.18	0.40 - 0.45
0.18 - 0.22	0.45 - 0.50
0.22 - 0.26	0.50 - 0.55
0.26 - 0.30	0.55 - 0.60
	0.60 - 0.65



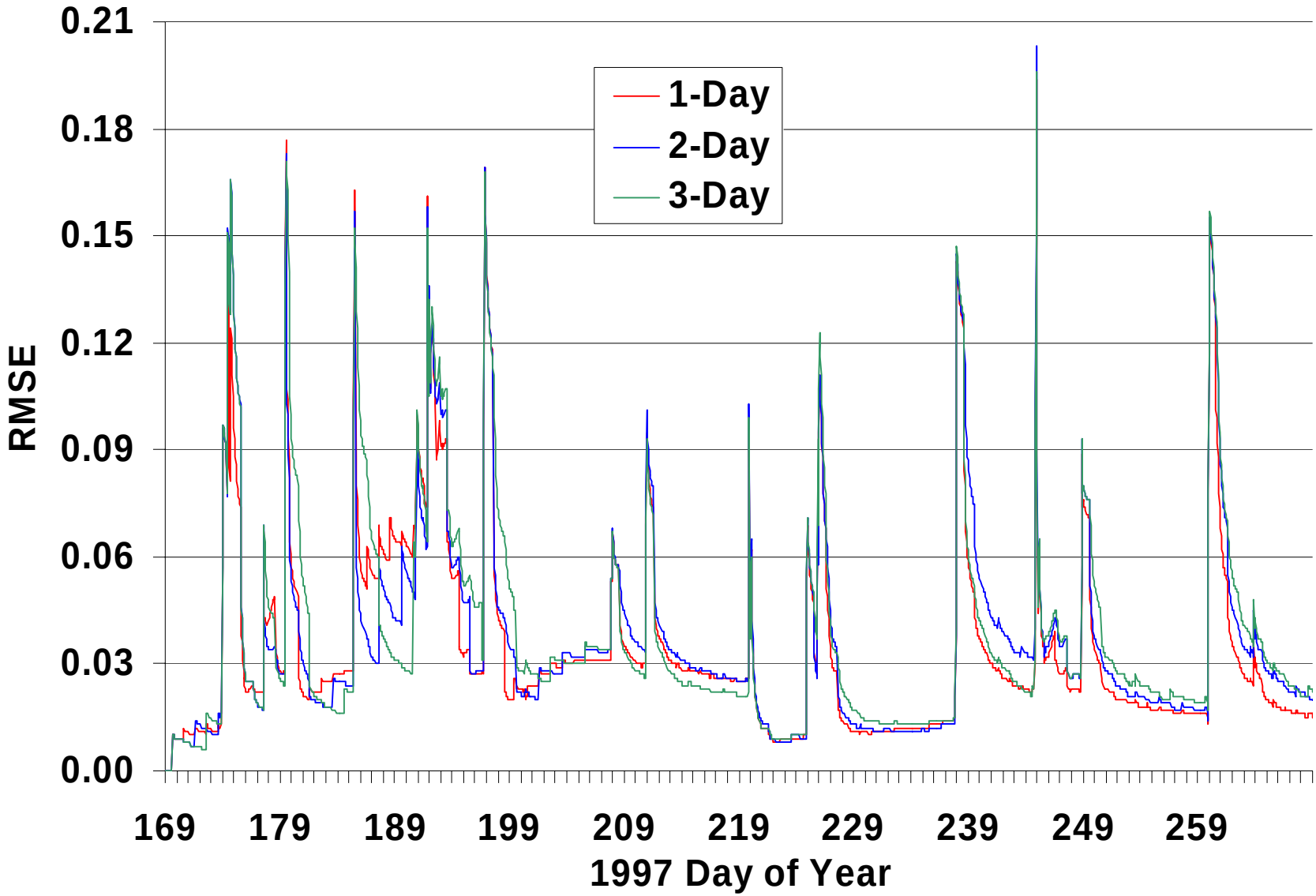
3-day updates

Note: Rainfall earlier on day 185 was completely absent in the Stage IV rainfall data product.

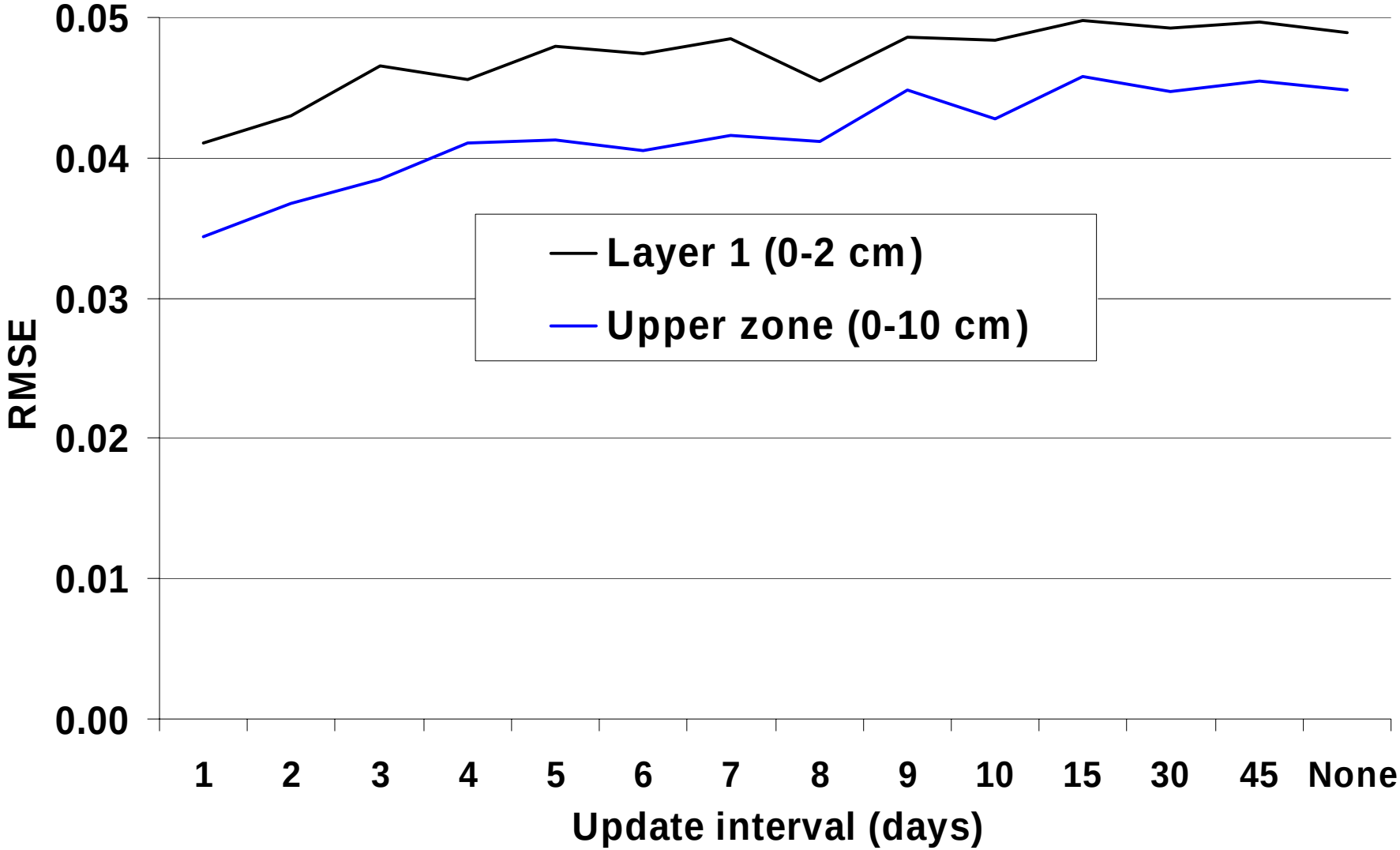


No updates

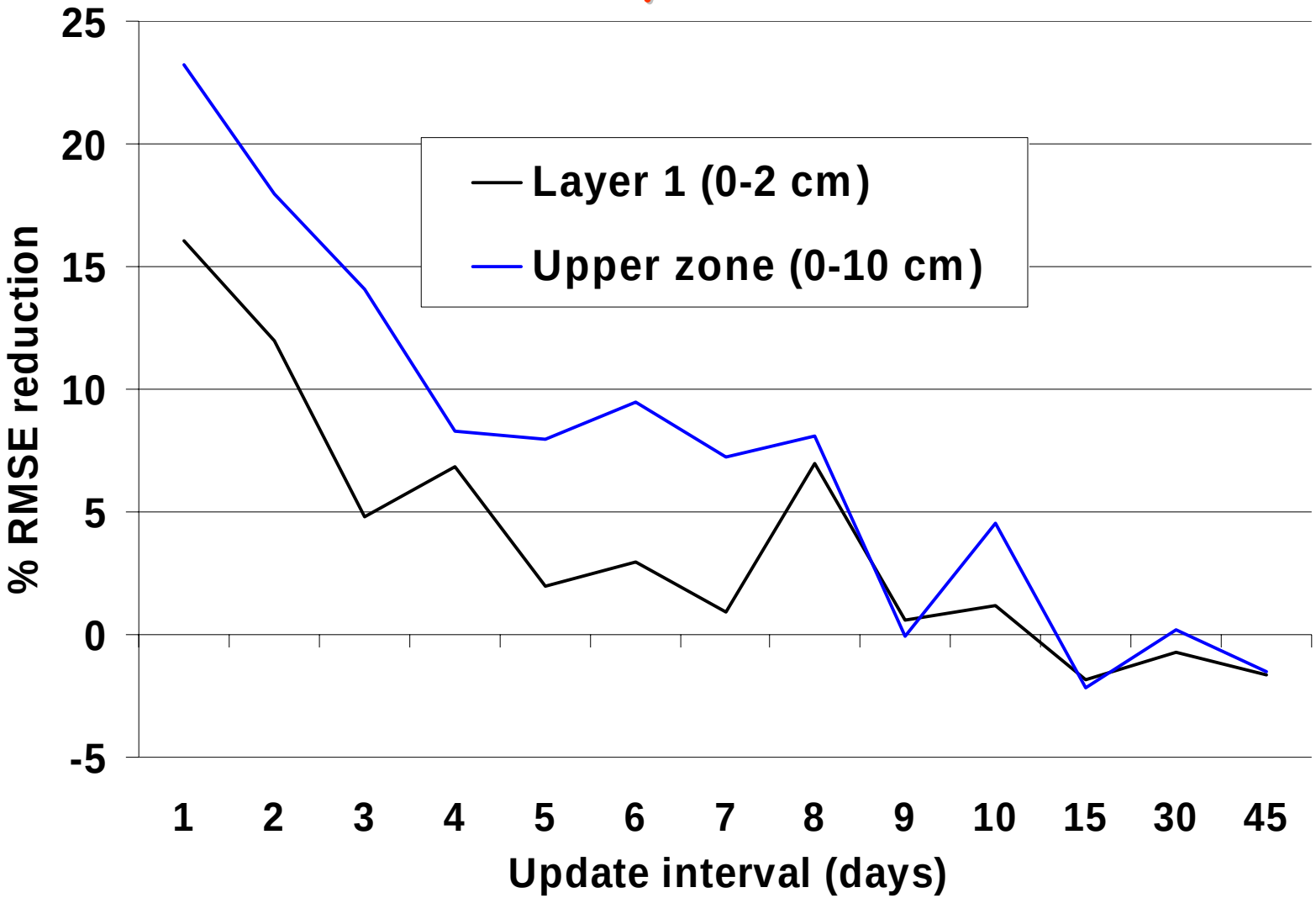
Root-Mean-Square Errors in upper zone soil moisture CONTROL vs. TEST simulations



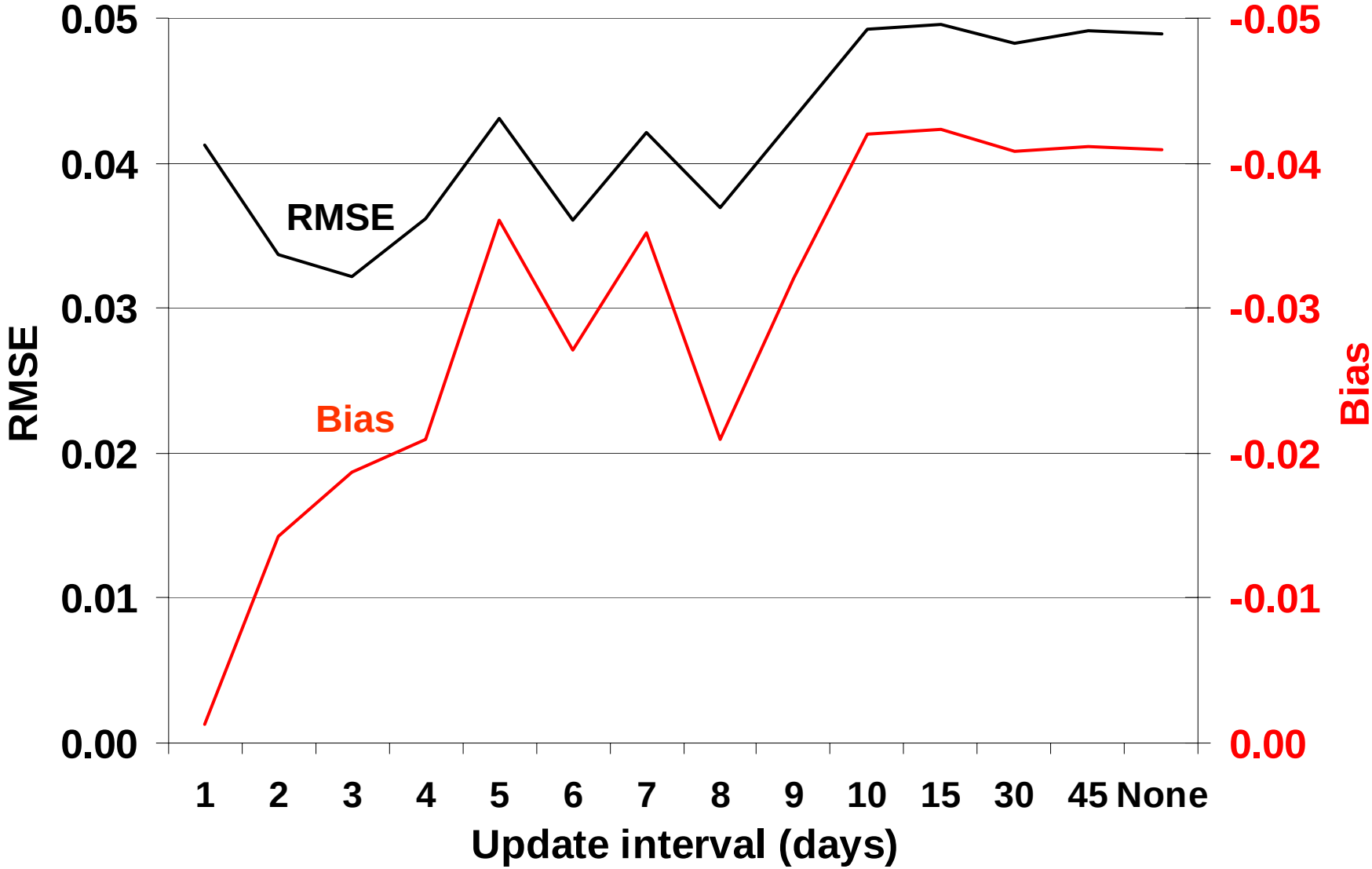
Root-Mean-Square soil moisture errors
CONTROL vs. TEST simulations
100-day means



Reduction in soil moisture RMSE compared with NO UPDATE simulation 100-day means



Root zone (10-100 cm) soil moisture RMSE and Bias with respect to CONTROL 100-day means



Conclusions

- Upper zone (0-10 cm) soil moisture is generally only moderately sensitive to temporal assimilation frequency; sensitivity can be much greater for brief periods following rainfall events.

- Root zone (10-100 cm) soil moisture and evapotranspiration are slightly more sensitive to assimilation frequency.

- Within the upper soil zone, RMS errors increase systematically with assimilation period from 1 day up to about 9 days.

- Assimilation at periods of 9 days or more appears to be of no value.

- With daily assimilation, upper zone soil moisture RMS errors were 23% lower than for the case with no assimilation. For the 0-2 cm layer, the improvement was 16%.

- For root zone soil moisture, RMS errors increase with assimilation period, but not systematically.