Sensitivity of a Land Surface Model and Soil Moisture Assimilation System to Bias in the Hydrometeorological Forcing

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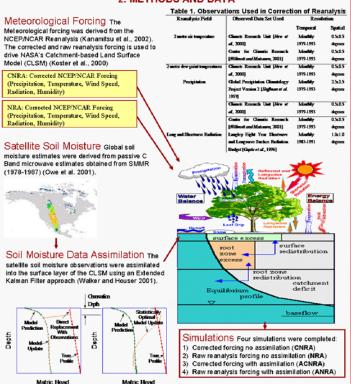
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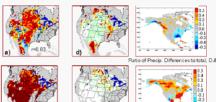
1. ABSTRACT

At regional to continental scales numerous studies have demonstrated the impact of realistic soil moisture initializations on the prediction of seasonal to sub-seasonal weather and climate, and streamflow. To develop realistic estimates of the soil moisture state researchers have focused on the development of appropriate land surface models (LSMs), on the development of suitable hydrometeorological forcing data sets for use in regional to continental LSMs, and on the development of methods for assimilating satellite soil moisture observations into land surface hydrological models. In this study we examine the sensitivity of a coupled LSM and data assimilation system to biases in the meteorological forcing for simulations of soil moisture and runoff over North America. Four simulations were completed as part of this study. In two simulations the LSM was driven with corrected and biased versions of the hydrometeorological forcing. These control simulations demonstrate impacts of bias in the forcing on LSM simulations of runoff and soil moisture. In the remaining two simulations, a data set of satellite derived soil moisture was assimilated into the LSM using an extended Kalman filter approach; identical to the control simulations, both corrected and biased versions of the hydrometeorological forcing were used for driving the LSM. Model errors and the sensitivity of the LSM/assimilation system to forcing bias are evaluated through comparisons of runoff and soil moisture between the four simulations. Further comparisons to observed runoff and soil moisture demonstrate the importance of the extended Kalman filter for reducing bias in the LSM.

2. METHODS AND DATA

Meteorological Forcing The Meteorological forcing was derived from the NCEP/NCAR Reanalysis (Kanamitsu et al., 2002). The corrected and raw reanalysis forcing is used to drive NASA's Catchment-based Land Surface Model (CLSM) (Koster et al., 2000).

CNRA: Corrected NCEP/NCAR Forcing (Precipitation, Temperature, Wind Speed, Radiation, Humidity)

NRA: Corrected NCEP/NCAR Forcing (Precipitation, Temperature, Wind Speed, Radiation, Humidity)

Satellite Soil Moisture Global soil moisture estimates were derived from passive C Band microwave estimates obtained from SMMR (1978-1987) (Owe et al. 2001).

Soil Moisture Data Assimilation The satellite soil moisture observations were assimilated into the surface layer of the CLSM using an Extended Kalman Filter approach (Walker and Houser 2001).

Table 1. Observations Used in Correction of Reanalysis

Reanalysis Field	Observed Data Set Used	Resolution Temporal	Resolution Spatial
2 meter air temperature	Climate Research Unit [New et al., 2000]	Monthly 1979-1993	0.5x0.5 degrees
	Center for Climatic Research [Willmot and Matsuura, 2001]	Monthly 1979-1993	4 degrees
2 meter dew point temperature	Climate Research Unit [New et al., 2000]	Monthly 1979-1993	0.5x0.5
Precipitation	Global Precipitation Climatology Project Version 2 [Huffman et al. 1997]	Monthly 1979-1993	2.5x2.5
	Climate Research Unit [New et al., 2000]	Monthly 1979-1993	0.5x0.5
	Center for Climatic Research [Willmot and Matsuura, 2001]	Monthly 1979-1993	0.5x0.5
Long and Shortwave Radiation	Langley Eight Year Shortwave and Longwave Surface Radiation Budget [Gupta et al., 1996]	Monthly 1983-1991	1.0x1.0 degrees

Simulations Four simulations were completed:
1) Corrected forcing no assimilation (CNRA)
2) Raw reanalysis forcing no assimilation (NRA)
3) Corrected forcing with assimilation (ACNRA)
4) Raw reanalysis forcing with assimilation (ANRA)

3. RESULTS

Assimilated Root Zone Soil Moisture and Comparisons

a) Correlation between the ACNRA and the ANRA simulations
b) Correlation between the ACNRA and the CNRA simulations
c) Correlation between the ACNRA and the NRA simulations
d) RMSE differences between the ACNRA and the ANRA simulations (RMSE / mean)
e) RMSE differences between the ACNRA and CNRA simulations (RMSE / mean)
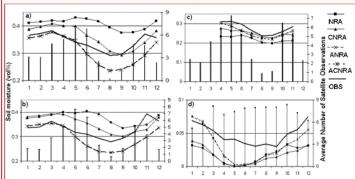f) RMSE differences between the ACNRA and NRA simulations (RMSE / mean)

The greatest differences between the ACNRA and ANRA simulations are observed in regions of high precipitation bias and low observation frequency.

Comparisons to Soil Moisture Observations
Model derived soil moisture from the four simulations were evaluated with observations from four locations. Southern and Northern Illinois, Iowa, and New Mexico.

Table 2. Correlations (anomaly correlation) and RMSE between simulated and observed soil moisture (*data is not significant at $p<0.05$)

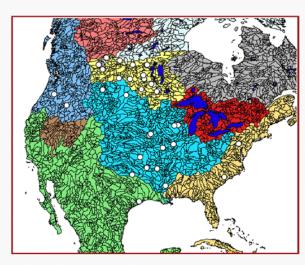| Location	Measure	ANRA	ACNRA	NRA	CNRA
Southern Illinois	RMSE	.058	.058	.081	.053
	Correlation	.69 (.46)	.69 (.45)	.53 (.37)	.64 (.42)
Northern Illinois	RMSE	.053	.053	0.079	0.059
	Correlation	.60 (.41)	.60 (.41)	.17* (.04)*	.42 (.18)*
Iowa	RMSE	.047	.047	.064	.048
	Correlation	.55 (.29)	.55 (.29)	.46 (.20)*	.46 (.30)
New Mexico	RMSE	.073	.073	.062	.060
	Correlation	.60 (.47)	.61 (.48)	.46 (.36)	.51 (.29)

Root zone soil moisture at: a) Southern Illinois, b) Northern Illinois, c) Iowa, and d) New Mexico compared with the four simulations using the corrected (CNRA) and raw (NRA) versions of the forcing product with (ACNRA and ANRA) and without data assimilation. Observations were obtained from the global soil moisture data bank GSMDB (Robock et al. 2000).
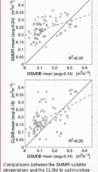
Runoff Comparisons
At 41 stream gauge locations across North America, average monthly discharge (1979-1987) was compared with modeled discharge from the CNRA, NRA, ACNRA, ANRA simulations. In Table 3, we present the percentage of stations where the soil moisture assimilation runs (ACNRA, ANRA) were in closer agreement to observations than the non-assimilation runs (CNRA, NRA). Particularly in the case of the ANRA vs. NRA simulations, the impact of the soil moisture assimilation reduced (increased) bias (correlation) across the majority of the gauging locations. The locations of the gauging locations are shown below.

Table 3. Percentage of gauging stations where simulations of runoff improved (higher correlation and lower RMSE) through implementation of the assimilation approach

ACNRA > CNRA Correlation (r)	ACNRA < CNRA RMSE	ANRA > NRA Correlation (r)	ANRA < NRA RMSE
46%	68%	71%	78%

4. Discussion and Conclusions

In Tables 2 and 3 we demonstrate that in general the soil moisture assimilation improves the simulation of soil moisture and runoff despite the presence of forcing biases. The improvements are especially evident in comparisons between the biased forcing simulations (NRA vs. ANRA), where the assimilated soil moisture simulation (ANRA) is closer to observations (for soil moisture and runoff) than the simulation completed with the raw NCEP/NCAR reanalysis forcing. Less improvement (to soil moisture and runoff) was observed in the assimilation run using the corrected forcing (ACNRA). This result may be anticipated based on the work of Reichle et al. (2004), which demonstrated that the NASA CLSM and the satellite soil moisture observations show considerable wet bias as compared to soil moisture observations from the GSMDB (illustrated on left). In this study, assimilation of soil moisture into the CLSM appears to remove some of the biases related to the forcing (ANRA vs. NRA comparisons), however, in the bias reduced forcing simulations (ACNRA vs. CNRA) errors in the SMMR soil moisture observations begin to impact the model results increasing model bias, particularly for the simulation of runoff.

Comparisons between the SMMR satellite observations and the CLSM to soil moisture observations (from Reichle et al. 2004)

5. REFERENCES

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