EVALUATION OF A SOIL MOISTURE DATA ASSIMILATION SYSTEM OVER WEST AFRICA

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1. INTRODUCTION

The U.S. Department of Agriculture (USDA) International Production Assessment Division (IPAD) is responsible for providing monthly global crop estimates that heavily influence global commodity market access. These estimates are derived from a merging of many data sources including satellite and ground observations, and more than 20 years of climatology and crop behavior data over key agricultural areas. The goal of IPAD is to provide timely and accurate estimates of global crop conditions for use in up-to-date commodity intelligence reports. A crucial requirement of these global crop yield forecasts is the regional characterization of surface and sub-surface soil moisture. However, due to the spatial heterogeneity and dynamic nature of precipitation events and soil wetness, accurate estimation of regional land surface-atmosphere interactions based sparse ground measurements is difficult [1]. Temporal resolution is particularly important for predicting adequate surface wetting and drying between precipitation events and is closely integrated with CADRE. We attempt to improve upon the existing system by applying an Ensemble Kalman filter (EnKF) data assimilation system to integrate surface soil moisture retrievals from the NASA Advanced Microwave Scanning Radiometer (AMSR-E) into the USDA soil moisture model. The improved temporal resolution and spatial coverage of the satellite-based EOS Advanced Microwave Scanning Radiometer (AMSR-E) is envisaged to provide a better characterization of root zone soil moisture at the regional scale and enable more accurate crop monitoring in key agricultural areas

This work aims at evaluating the utility of merging satellite-retrieved soil moisture estimates with the IPAD two-layer soil moisture model used within the DBMS. We present a quantitative analysis of the assimilated soil moisture product over West Africa (9°N-20°N; 20°W-20°E). This region contains many key agricultural areas and has a high agro-meteorological gradient from desert and semi-arid vegetation in the North, to grassland, trees and crops in the South, thus providing an ideal location for evaluating the assimilated soil moisture product over multiple land cover types and conditions. A data denial experimental approach is utilized to isolate the added utility of integrating remotely-sensed soil moisture by comparing assimilated soil moisture results obtained using (relatively) low-quality precipitation products obtained from real-time satellite imagery to baseline model runs forced with higher quality rainfall. An analysis of root-zone anomalies for each model simulation suggests that the assimilation of AMSR-E surface soil moisture retrievals can add significant value to USDA root-zone predictions derived from real-time satellite precipitation products.

2. METHODS

The IPAD DBMS combines many data sources including over 3000 ground observations from the World Meteorological Organization and agrometeorological estimates provided by the Air Force Weather Agency (AFWA). Daily estimates of minimum and maximum temperature and precipitation are applied to a modified Palmer two-layer soil moisture model which calculates the daily amount of soil moisture withdrawn by evapotranspiration and replenished by precipitation [6]. Estimates of soil moisture at each grid cell ($1/8^{th}$ mesh) are adjusted for total water holding capacity derived from the FAO Digital Soil Map of the World and dependent on the soil texture and depth of the soil column.

An integration of soil moisture observations from AMSR-E with the modified Palmer two-layer soil moisture model is accomplished by applying a 1-dimensional Ensemble Kalman filter (EnKF) at daily time-steps. The AMSR-E soil moisture observations used in this study are from the NASA AMSR-E L3 product [4]. The AMSR-E L3 soil moisture estimates are calculated from an empirical soil moisture model based on passive microwave brightness temperature observations at 10.7 GHz and 18.7 GHz [5]. The gridded ($\sim$25 km^2) L3 soil moisture product has full global coverage approximately every 2-3 days, providing improved spatial coverage relative to the IPAD soil moisture observations in data-poor regions of the globe. It is assumed for this study that the depth of the AMSR-E soil moisture product is approximately equal to the first layer of the Palmer model (2.54 cm).

The accuracy of remotely sensed observations vary greatly over different land cover types due to signal attenuation by vegetation and increased scattering over rough terrain [3]. At the wavelengths used by AMSR-E, the accuracy of observed soil moisture is significantly degraded over areas of vegetation water content greater than approximately 8-10 kg/m^2 [7]. We exploit this relation by adjusting the magnitude of the errors applied to the AMSR-E soil moisture in relation to vegetation water content. A diagnostic calibration of the filter is performed for many ranges of vegetation using filter innovation statistics.

A data denial framework is employed to test the system. An assessment of the filter performance is performed by comparing two model runs: one forcing the model with ‘bad’ error-prone precipitation, and another forced with ‘good’ benchmark precipitation. To demonstrate proof-of-concept, we show improved model performance by examining anomaly correlations of the benchmark forecasted product and AMSR-E assimilated model run for a five year duration over the West Africa domain.

Studies demonstrating the added benefit of using remotely sensed soil moisture observations as shown here are essential given the expected launch of several soil moisture-focused missions in the near future, including the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission in 2009 and the National Aeronautics and Space Administration (NASA) Soil Moisture Active/Passive (SMAP) mission scheduled for launch before 2013.

3. REFERENCES

[1] K.L. Brubaker and D. Entekhabi, “Analysis of feedback mechanisms in land-atmosphere interaction,” Water Resources Research, 325, 1343-1357, 1996.

[2] W. T. Crow, R.D. Koster, R.H. Reichle, H.O. Sharif, “Relevance of time-varying and time-invariant retrieval error sources on the utility of spaceborne soil moisture products,” Geoph. Res. Let., 32, L24405, 2005

[3] T.J. Jackson, and T.J. Schmugge, “Vegetation Effects on the Microwave Emission of Soils,” Remote Sensing of Environment, 363, 203-212, 1991.

[4] T. Kawanishi, T. Sezai, Y. Ito, K. Imaoka, T. Takeshima Y. Ishido, A. Shibata, M. Miura, H. Inahata, R. Spencer, “The Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), NASA's contribution to the EOS for global energy and water cycle studies,” IEEE Trans. on Geosci. and Rem. Sens. 41, 184-194, 2003.

[5] E.G. Njoku, T.J. Jackson, V. Lakshmi, T.K. Chan, and S.V. Nghiem, “Soil moisture retrieval from AMSR-E,” IEEE Trans. Geosci. Rem. Sens., 41, 2, 215-229, 2003.

[6] W.C. Palmer, “Meteorological drought” U.S. Weather Bureau Research Paper 45, 58 pp.,1965.

[7] R.H. Reichle, D.B. McLaughlin, D. Entekhabi,. “Hydrologic data assimilation with the Ensemble Kalman Filter”. Mon. Weat. Rev., 130, 103-114,2002.