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ASSIMILATION OF AMSR-E SOIL MOISTURE INTO THE USDA GLOBAL CROP PRODUCTION DECISION SUPPORT SYSTEM

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1. INTRODUCTION

The monitoring of global food supplies performed by the U. S. Department of Agriculture (USDA) Production Estimates and Crop Assessment Division (PECAD) is essential for early warning of food shortages, and providing greater economic security within the agriculture sector. Monthly crop yield and forecasting is calculated by PECAD through a combination of climatic and land surface data integrated into land surface models within the Crop Assessment Data Retrieval and Evaluation (CADRE) Decision Support System (DSS). The accuracy of this system is highly dependent on the data sources used; particularly the accuracy, consistency, and spatial and temporal coverage of the land and climatic data input into the models.

Soil moisture is a fundamental data source used in crop growth stage and crop stress models. Currently, the PECAD DSS utilizes a modification of the Palmer two-layer soil moisture model to estimate surface soil moisture. This model uses a simplified water balance scheme by calculating the amount of water withdrawn by evapotranspiration and replenished by precipitation. Inputs into the model include soil parameter values of soil water holding capacity, daily precipitation and temperature estimates provided by weather data from the Air Force Weather Agency (AFWA) and precipitation observations from the world Meteorological Organization (WMO). These sources provide secondary estimates of soil moisture and may be improved by the addition of direct observations of soil moisture.

This study aims at improving the soil moisture estimates used by the PECAD by integrating soil moisture observations from the NASA EOS Advanced Microwave Scanning Radiometer (AMSR-E) into the USDA DSS. Launched in 2002, the AMSR-E instrument is capable of providing a full global coverage soil moisture product over lightly vegetated areas every 2-3 days. The improved spatial and temporal resolution of AMSR-E upon the current AFWA and WMO data will be beneficial particularly in areas where the AFWA and WMO data are sparse. Therefore, the integration of the AMSR-E soil moisture product into the PECAD FAS DSS is envisaged to provide a better characterization of surface wetness conditions at the regional scale and enable more accurate monitoring of boundary condition changes in key agricultural areas.

2. METHODS

2.1 USDA Global Crop Production Decision Support System

Global agricultural monitoring is provided by the PECAD Crop Assessment Data Retrieval and Evaluation (CADRE) Data Base Management System (DBMS) which combines past (~20 years) and present meteorological, remote sensing, crop model and soil moisture model data. Historical data

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is used by the system to track growing season evolution and trends relative to mean conditions for specific regions; however, accurate monitoring of recent land and climate conditions is fundamental to the system. A timely, objective and accurate assessment of global agricultural production is essential for proper commodity marketing and trade strategy. In order to monitor crop conditions of a specific region, remotely sensed vegetation and other climate conditions are used.

PECAD synergistically applies daily agro-meterological and weather data provided by approximately seven thousand ground stations and multiple remote sensing sensors including the Advanced Very High Resolution Radiometer (AVHRR). Climatic data is also provided by the AFWA Agricultural Meteorology modeling system (AGRMET), e.g., Cochrane (1981). The main climate data output products used for agricultural assessment include estimated precipitation and temperature, and top- and sub-layer soil moisture at a 47 km horizontal grid spacing.

The PECAD DBMS utilizes a modification of the Palmer two-layer soil moisture model as described by Palmer (1965) to calculate surface and subsurface soil moisture content from daily precipitation and temperature records. The modified Palmer model applies the Penman-Monteith equation (Allen et al. 1998) to compute daily potential evapotranspiration (PET) from station latitude, longitude, elevation and daily temperature extremes. Moisture loss from the soil is determined by initial moisture content, PET, and soil water-holding capacity. Soil water-holding capacity (Reynolds et al. 2000) was calculated for each grid location by soil type and soil depth from the Food and Agriculture Organization (FAO) Digitized Soil Map of the World (DSMW) 1996. The top-layer soil moisture is assumed to hold a maximum of 25 mm of available water, and the sub-layer soil moisture is dependent on the soil's water-holding capacity. The first model layer is filled completely by precipitation before the second is increased to soil water-holding capacity. When the soil water-holding capacity of both layers is reached, excess precipitation is treated as runoff and is lost from the model; no lateral movement of water is assumed. The model extraction function allows moisture to be depleted from the lower layer before the surface is completely dry. A maximum root depth of one meter or less was assumed for calculating the water holding capacity, and impermeable soil layers were considered. From these assumptions, water holding capacity for both layers normally range from 127 to 203 mm/m of water depending on soil texture (ranging from sand to clay) and soil depth. The CADRE outputs of surface layer soil moisture for the United States from 04/11/06 to 04/20/06 are shown in Figure 1.

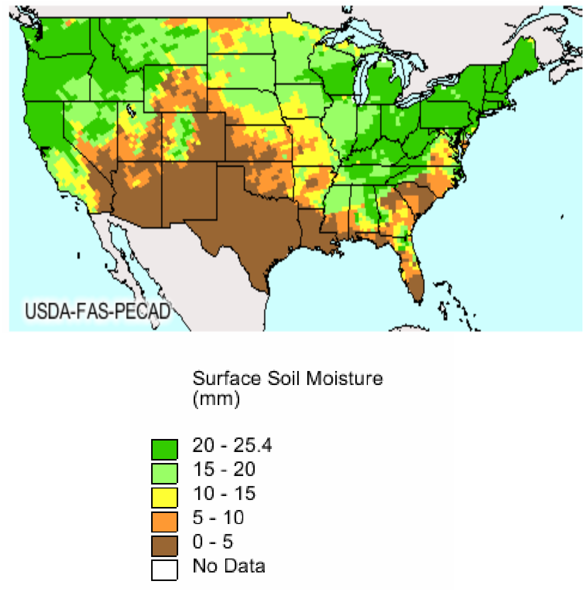

Figure 1. AFWA Surface Soil Moisture 04/11/06 - 04/20/06.

2.2 Advanced Microwave Scanning Radiometer

Recent advances in satellite remote sensing have made possible efficient estimates of soil moisture over large areas. Performing most notably over areas of light vegetation, satellite remote sensing enables frequent observations of surface soil wetness in areas where point measurements are sparse or infrequently collected. Principal to this study is the NASA EOS Advanced Microwave Scanning Radiometer (AMSR-E), which was launched in 2002 aboard the National Aeronautics and Space Administration (NASA) Aqua satellite. For over three years this instrument has provided a daily global soil moisture product (Kawanishi et al. 2003; Njoku et al. 2003).

Aqua follows a sun-synchronous orbit with a descending equatorial crossing at approximately 1330 Local Standard Time. The instrument measures brightness temperatures at six frequencies: 6.92, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz, with vertical and horizontal polarizations at each frequency. At a fixed incidence angle of 54.8° and an altitude of 705 km, AMSR-E provides a conically scanning footprint pattern with a swath width of 1445 km. The mean footprint diameter ranges from 56 km at 6.92 GHz to 5 km at 89 GHz.

The AMSR-E data used in this study will consist of daily soil moisture estimates from the AMSR-E Level-3 land surface product (Njoku 2004). The Level-3 product is a gridded data product using a global cylindrical 25 km Equal-Area Scalable Earth Grid (EASE-Grid) cell spacing. The AMSR-E soil moisture algorithm uses Polarization Ratios (PR) of 10.7 GHz and 18.7 GHz, plus three empirical coefficients to compute a vegetation/roughness parameter for each grid cell. Deviations from a 18.7 GHZ PR baseline value for each grid cell are used to calculate daily soil moisture estimates for each grid cell. These soil moisture estimates represent a soil depth comparable to the first layer soil moisture used by the PECAD DBMS.

Figure 2 illustrates a three day composite (04/11/06 – 04/13/06) of the AMSR-E soil moisture product at ¼ degree latitude and longitude grids. The relation between observed surface volumetric soil moisture and AMSR-E soil moisture product has been validated in numerous large-scale soil moisture experiments (Njoku et al. 2004).

Frequent regional characterization of soil moisture is crucial to the crop yield forecast. Temporal resolution is particularly vital in order to adequately characterize surface wetting and drying between precipitation events. AMSR-E revisit coverage is on ~3 days at the equator and more frequently at higher latitudes. The integration of the AMSR-E data into the PECAD soil moisture algorithm is envisaged to provide better characterization of surface wetness conditions at the regional scale and enable more accurate monitoring of boundary condition changes in key agricultural areas.

2.3 Integration Scheme

Preliminary analyses of the current AMSR-E product have shown that there are some potential bias and sensitivity issues with the product. Before model initialization using AMSR-E derived soil moisture can be accomplished, the modified two-layer Palmer soil moisture model used by PECAD and observed AMSR-E data must be scaled to a common climatology to reduce the time-invariant errors. Previous studies have demonstrated that biases can be removed by transforming each dataset into standard normal deviates and their representative deviations from local mean values (Reichle and Koster 2004). By computing the long-term climatological soil moisture statistics of both datasets, an unbiased inter-comparison of the dataset anomalies is possible. A bias removal method similar to that presented by Crow et al. (2005) will be followed here.

An Ensemble Kalman Filter (EnKF) will be used in a soil moisture assimilation strategy to efficiently combine the satellite-, ground observed-, and modeled soil moisture. The application of the 1-Dimensional EnKF will be used to assimilate a three-year dataset of AMSR-E observations in crop production regions into the modified Palmer soil moisture model. Data assimilation via the EnKF is based on an ensemble of randomly generated model trajectories from conditional error/covariance statistics. Data assimilation using the EnKF has been evaluated for land surface data applications (e.g., Reichle et al. 2002) and was found to give satisfactory estimates at moderate ensemble sizes. Ground observations from various field experiments and other available data sets will also be used to provide an assessment of the assimilated soil moisture product.

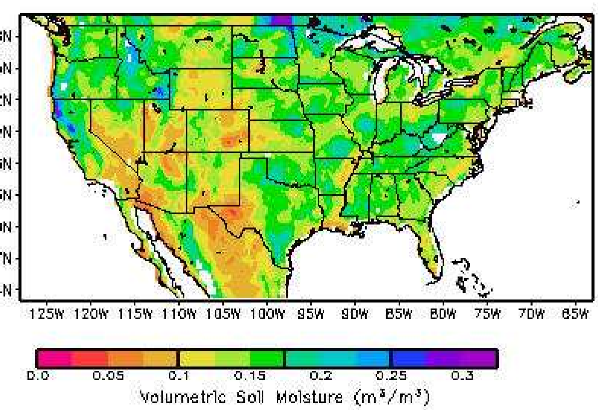

Figure 2. AMSR-E Surface Soil Moisture 04/11/06 – 04/13/06.

3. ANTICIPATED RESULTS

Initial comparisons of the modified Palmer and AMSR-E surface soil moisture estimates were made over the Walnut Gulch Watershed, AZ. This area was the focus of a rigorous soil moisture validation experiment in 2004 (SMEX04) and provided a large amount of soil moisture validation data concurrent with AMSR-E overpasses. More information on SMEX04 can be found at: http://hydrolab.arsusda.gov/smex04/. The climatologically rescaled AMSR-E data will then be applied to the EnKF using sequential observations of AMSR-E and AFWA agrometeorological input data. A summary of the integration scheme is illustrated in Figure 3.

The integration of direct measurements from microwave satellite data is envisaged to correct for poor precipitation estimates currently derived from satellite imagery. These additional soil moisture observations should provide better spatial coverage and finer resolution than the stand-alone modified Palmer soil moisture estimates used by the PECAD. Comparison between the modified Palmer soil moisture model output and EnKF assimilated soil moisture will be presented.

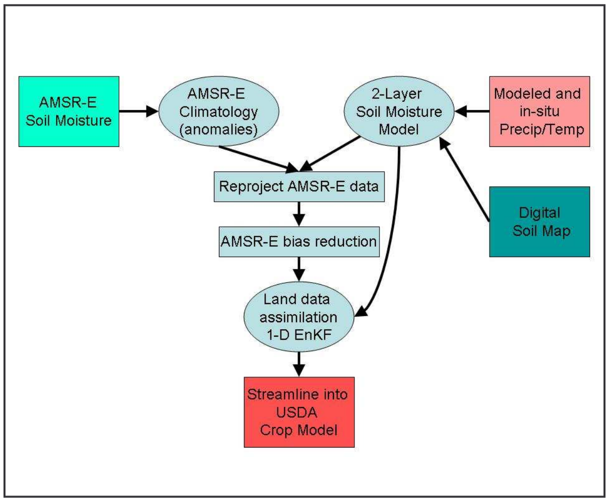

Figure 3. Integration flowchart

ACKNOWLEDGMENT

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