DEVELOPING A HIGH-RESOLUTION LAND DATA ASSIMILATION AND FORECAST SYSTEM FOR AGRICULTURAL DECISION SUPPORT

Fei Chen, Michael Barlage, David Gochis, and William Mahoney

Research Applications Laboratory

National Center for Atmospheric Research

Boulder, CO 80301

Email: feichen@ucar.edu

1. INTRODUCTION

Despite technological improvements that increase crop yields, extreme weather events have caused significant yield reductions in some years. According to the United Nations Food and Agriculture Organization, 70% increase in agricultural productivity will be required by 2050 to meet the growing food demand. Climate Changes - rising temperature, increasing CO_2 level, and altered precipitation patterns – have affected the water resources and agriculture productivity in U.S. and worldwide. The United Nations Framework Convention on Climate Change (Frankhauser et al. 2010) estimated that about US$14 billion will be needed annually by 2030 to cope with the adverse impacts of climate change, though this figure could be two or three times greater.

The National Center for Atmospheric Research, Research Applications Laboratory (NCAR/RAL) has been engaged with the research and end-user communities to develop numerous observing (see Fig. 1), modeling, and prediction capability for assessing interactions between weather, climate, crop growth, and hydrology, and for agricultural applications.

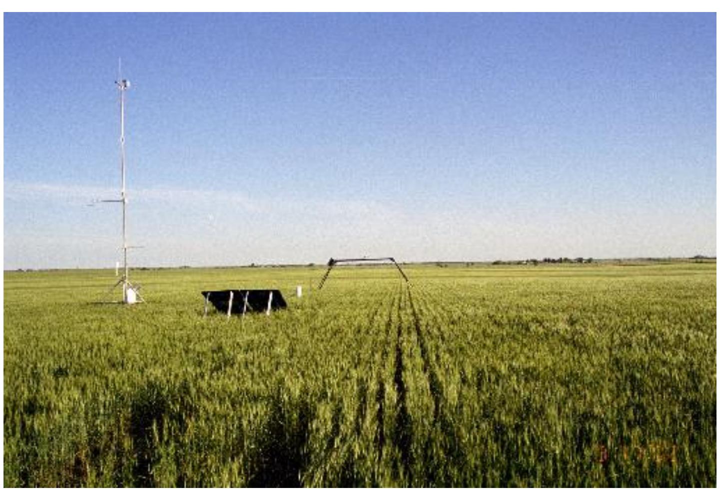

Fig. 1: Observing crop-atmosphere interactions at a winter-wheat site in Kansas during the International H_2O Project (IHOP-02) field campaign. Details see LeMone et al. (2007).

2. SOIL CONDITION PREDICTION

A High-Resolution Land-Data Assimilation System (HRLDAS, Chen et al. 2007) was developed at NCAR/RAL to provide analysis and prediction of high-resolution soil and vegetation conditions from 10-day to seasonal time scales. The advantage of HRLDAS is its use of 1-km-resolution land-cover, soil-texture maps and terrain heights, and 4-km rainfall data. Because of this fine-scale aptitude, it can capture fine-scale heterogeneity of moisture and temperature at the surface and in the crop root zones up to 2-meter below the ground surface. NCAR/RAL has been collaborating with industry sectors to develop agricultural decision-support capabilities that optimize the timing of pesticide application and irrigation. These projects typically utilize advanced weather and land-surface models and an intelligent data-fusion technology that continuously optimizes the weather and soil predictions.

This research has led to improvements in HRLDAS, Dynamic, Integrated Forecast System (DICast®), and the Noah land-surface model (Chen et al. 1996). This research is instrumental in providing critical input to the weather and land-surface modeling, and satellite communities, and comprises a cross-disciplinary effort. Continued work in this area will lead to more precise prediction of weather and soil condition and more efficient and profitable agricultural operations. Figure 2 shows a snap shot of 4-km scale prediction of volumetric soil moisture at 5-cm below the ground surface.

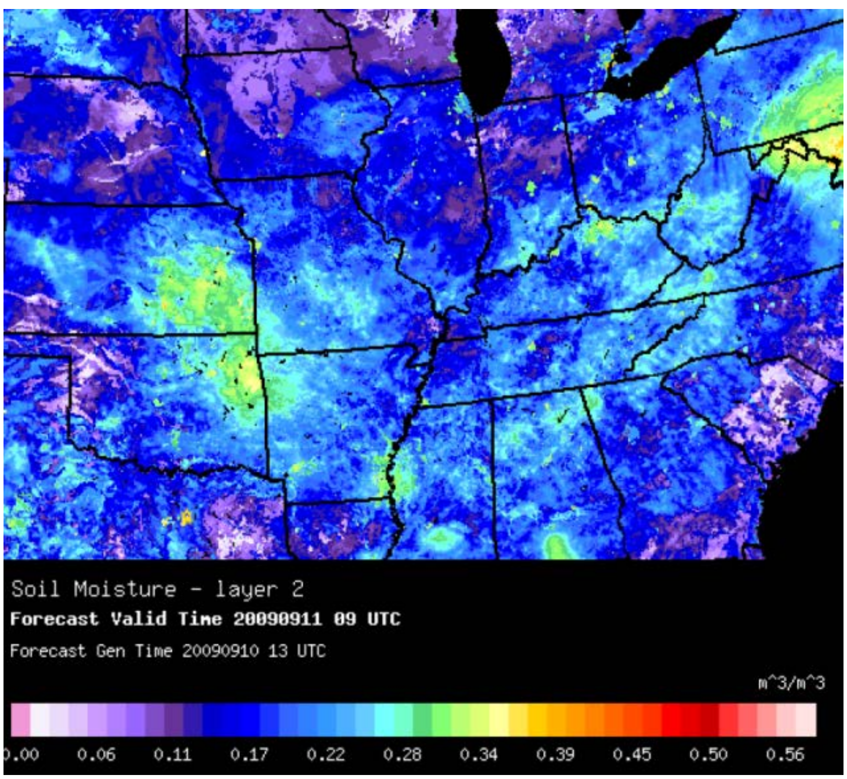

Fig. 2: Prediction of volumetric soil moisture at 5-cm below the ground surface. This is an example from a 10-day prediction of soil conditions for 2009.

3. INTEGRATED WRF-CROP MODELING SYSTEM

The field of climate change assessment and agriculture adaption and mitigation has grown considerably in the past few decades. It is critical to quantify complex climate–soil-crop interactions, which is essential for supporting precision agriculture and agricultural management strategies and policy decisions at multiple scales, from global, to continental, and farm scales. The Weather Research and Forecasting (WRF) model is a widely used numerical prediction and regional climate modeling system. However, current WRF research considers only the effect of climate on crop production, and neglects multi-scale (both in time and space) interactions and feedbacks of crop growth on weather, climate and hydrology.

The overarching project goal is to develop an integrated WRF-Crop modeling system that captures such effects, incorporating both modeling and data assimilation components. This will establish a much-needed WRF-Crop regional climate modeling system to: 1) provide a tool to understand emerging science themes such as the role of land-cover change and agriculture practice in regional climate variability, 2) study the sensitivity of crop growth and pest emergence under a variety of weather and soil conditions during the growing season, and 3) allow the research community and stakeholders to address food safety issues under extreme weather and future climate change in different regions of the world.

Weather, climate, and hydrology are already simulated in the WRF-Hydro coupled modeling system. Ongoing efforts focus on establishing the crop modeling capability in the new-generation Noah-MP (MP: Multiple Parameterization) land-surface model in WRF-Hydro by: 1) coupling the Noah-MP photosynthesis and soil hydrology components with crop-growth models, and 2) developing crop-specific parameters required by crop-growth models.

The crop-growth models under development in this project are intended to simulate phenological development, growth and yield formation from emergence until maturity using crop genetic properties, weather, and soil conditions following methods developed and adapted in the agriculture communities. The photosynthesis-based dynamic-vegetation model in the community Noah-MP land model (Niu et al. 2011) is extended to parameterize crop yield, which allocates carbon to leaves, stems, roots and wood as well as fast and slow soil carbon pools. For a whole suite of crop growth modules (rice, corn, wheat, sorghum, soybean, etc), simulated processes include phenological development rate, CO2 assimilation, maintenance respiration, dry matter partitioning for biomass accumulation, growth and senescence of leaves and extension of roots. Observations of crop phenology and yield at agriculture sites are used to determine these parameters from an iterative process. The WRF-Crop modeling system incorporates the following crop characteristics per species:

- Emergence: sow date, temperature threshold from sowing to emergence, initial crop dry weight, leaf area index at emergence.
- CO2 assimilation characteristics of a single leaf: initial light efficiency, rate of net or gross CO2 assimilation at light saturation, respiration in the dark.

- Conversion efficiency of the sugars produced in the assimilation process into leaves, stems, roots, and grains.
- Seasonal partitioning of newly formed dry mass into leaves, stems, roots, and grains. Note that the fraction of total dry matter to various plant parts depends on plant development stages.
- Maintenance respiration rate.
- Specific leaf area as function of development stage.
- Initial rooting depth and maximum rooting depth.
- Death rate of leaves, roots, and stems.

Figure 3 shows an example of simulated seasonal variation of the leaf area index (LAI) by the Noah-MP land surface model. While the preliminary results are encouraging, the model needs to be refined to improve its physical representation of spring crop emergence, summer crop growth, and yields.

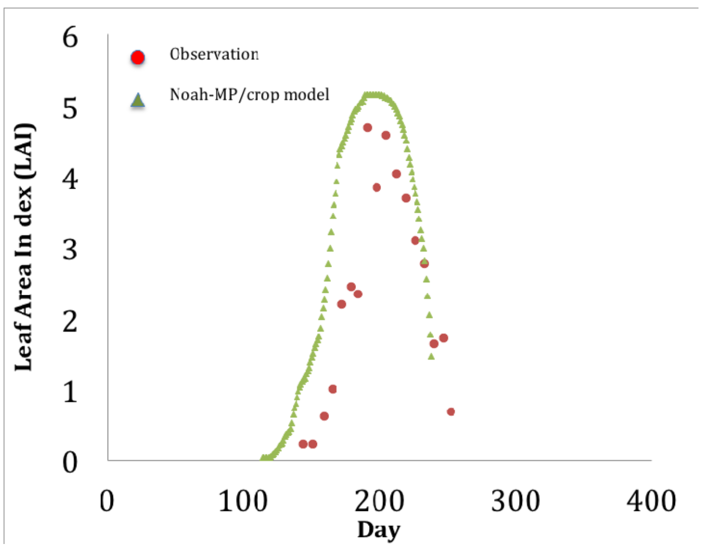

Fig. 3: Predicted crop leaf area index (LAI) for an Illinois (corn and soybean rotation) site by the Noah-MP land-surface/hydrology model.

4. REFERENCES

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