Using High-Resolution Land Data Assimilation System to Improve Prediction of Soil Temperature and Moisture for Agriculture Application

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1. INTRODUCTION

Correctly predicting soil temperature and moisture at field scales is critical for agriculture applications, because, for instance, seed germination is largely controlled by soil temperature, and pest-life-stage development is dependent of soil condition. In this study, the high-resolution land data assimilation system (HRLDAS), developed by NCAR, is further enhanced to produce analysis and forecast of soil temperature and moisture as input to agricultural decision support systems (Myers et al., 2008). Various observations and high-resolution land-use and soil texture fields are used to drive HRLDAS so that the evolution of soil moisture and temperature in HRLDAS are constrained by observations (e.g., precipitation, etc). HRLDAS is set up with a 4-km grid-spacing covering major agricultural states in the US for a retrospective spin-up period (2005-2006) and for real-time forecast. The forecast of soil temperature and moisture from March to August 2006 is evaluated against the observations from the Soil Climate Analysis Network (SCAN), which has more than 116 stations located in 39 states and provides hourly soil temperature and moisture at different soil depths. A series of numerical experiments are designed to investigate the sensitivity of this soil prediction system to data sources and model physics. One important goal is assess the degree to which the use of NASA MODIS vegetation data in HRLDAS can improve the forecast of soil temperature and moisture.

2. HRLDAS RESULTS and DISCUSSION

2.1. Performance of 4-layer HRLDAS

The HRLDAS system is traditionally set up with four soil layers, in which the predictive level of soil temperature and moisture are at 5 cm, 25 cm, 70 cm, and 150 cm, respectively (Chen et al., 2007). The domain size is 543 X 350 with 4 km grid-spacing. Atmospheric forcing conditions are collected from **(1)** 4-km hourly NCEP Stage-IV rainfall analyses based on raingage-calibrated WSR-88D radar rainfall estimates, **(2)** 0.5-degree hourly downward solar radiation derived from Geostationary Operational Environmental Satellite (GOES) satellites, **(3)** 3-hourly atmospheric analyses from the NCEP Eta model-based Data Assimilation System (EDAS).

HRLDAS runs are initialized with the soil conditions of EDAS on 2 January 2005, to perform a continuous, hourly soil simulation until 31 December 2006. The HRLDAS soil temperature and moisture from March to August 2006, after a reasonable spin-up time, are verified against 42 SCAN observation sites located in the HRLDAS domain, which, for the purpose of verification, is divided into four sub domains, namely: northwest (NW), northeast (NE), southwest (SW), and southeast (SE) according to climatology conditions (Fig 1).

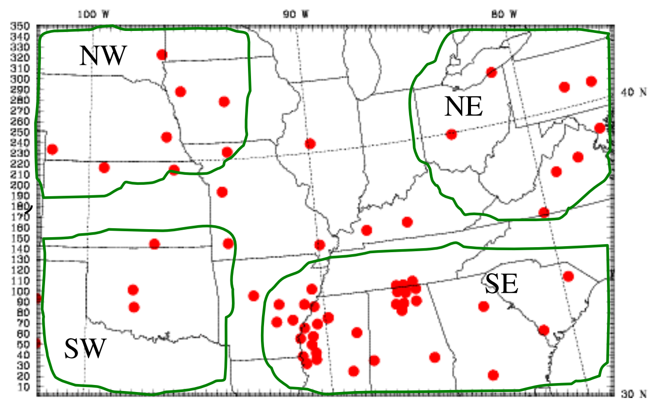

Figure 1. 4-km HRLDAS domain and location of SCAN sites.

	RMSE		BIAS	
	ST1	**ST2**	**ST1**	**ST2**
Northwest	2.92	1.94	1.14	-1.10
Northeast	2.62	3.32	-0.71	-2.68
Southwest	2.83	2.32	0.73	-1.28
Southeast	2.27	2.34	-0.65	-1.83

Table1. Root mean square error and mean difference of soil temperature (in K) between HRLDAS and SCAN during spring (ST1: 5cm, ST2: 20cm)

Table 1 shows the root mean square error (RMSE) and mean difference (BIAS) of soil temperature between the HRLDAS control run and SCAN observations during spring (from March to May) of 2006 in four sub-domains. These verification statistics are calculated form hourly data for each station and then averaged for the season and finally averaged for all stations within the same sun-domain. In general, the RMSEs are less than 3K, and biases are about 1.5K. Note that HRLDAS forecasted soil temperature are generally lower the observations. HRLDAS captures the observed diurnal cycle of 5-cm soil temperature reasonably well (Fig2a), but produces larger amplitude for 5-cm soil temperature and smaller amplitude for 20-cm soil temperature (Fig. 2b).

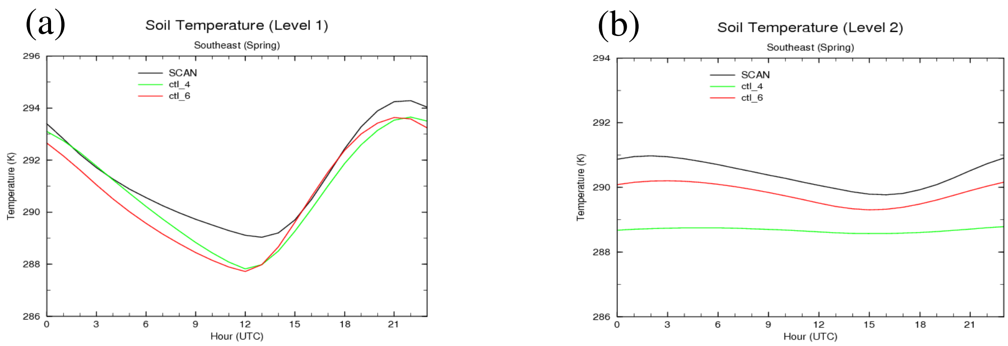

Figure 2. Averaged soil-temperature diurnal cycle over 25 SCAN sites in southeast domain: (a) 5cm soil layer depth, and (b) 20cm soil layer depth. Green lines are results using HRLDAS with four soil layers and red lines represent results using HRLDAS with six vertical layers.

2.2. 6-Layer HRLDAS Run

In this experiment, HRLDAS is re-configured with six vertical layers, in order to improve the performance by better capturing the soil temperature gradient near the surface, because the SCAN data clearly revealed the diurnal cycle of 20-cm soil temperature, which is missed by 4-layer HRLDAS but captured by 6-layer HRLDAS (red line in Fig. 2b). However, only slight changes are found for the diurnal cycle of 5-cm soil temperature (Fig 2a). Moreover, Figure 3 shows that 6-layer HRLDAS captures the observed vertical structure of soil temperature better than 4-layer HRLDAS, as expected. The soil temperature profiles in 6-layer HRLDAS run (red line), are closer to SCAN data than 4-layer run (green line) for both midday and midnight.

2.3 The Control of Surface Layer Parameterization on Soil Temperature Prediction

In both 4-layer and 6-layer HRLDAS runs, the averaged diurnal cycle of 5-cm temperature is larger and warmer than SCAN observations in the west domain, but cooler in the east domain. That seems to imply that the land surface is less coupled to the atmosphere, and as a result, too much heat is transferred to soil. In HRLDAS, the surface exchange coefficient for heat C_h, which is related to the roughness length for heat Z_{0t}, may be too small in the west domain and too large in the east domain. In HRLDAS, we use the following formulation proposed by Zilitinkevich to calculate Z_{0t} (Chen et al., 1997),

$$\frac{z_{0m}}{z_{0t}} = \exp(\kappa C \sqrt{\mathrm{Re}^*}), \qquad (1)$$

where C is an empirical constant. In the default 4-layer and 6-layer HRLDAS runs, we used a global constant of C=0.1. We now use different values of C for different vegetation types in this experiment. In Equation (1), smaller (larger) C increases (decreases) Z_{0t}, which in turn increases (decreases) C_h (Fig. 4a,b). Figure 5 shows the averaged 5-cm soil temperature diurnal cycle. In the west domain during springtime, the vegetation height is generally low.

Reducing C value produces a smaller diurnal cycle (green line in Fig. 5a), which is closer to SCAN observation. While vegetation is growing taller in summer, increasing C value in the east domain produces a larger diurnal cycle (green line in Fig. 5b).

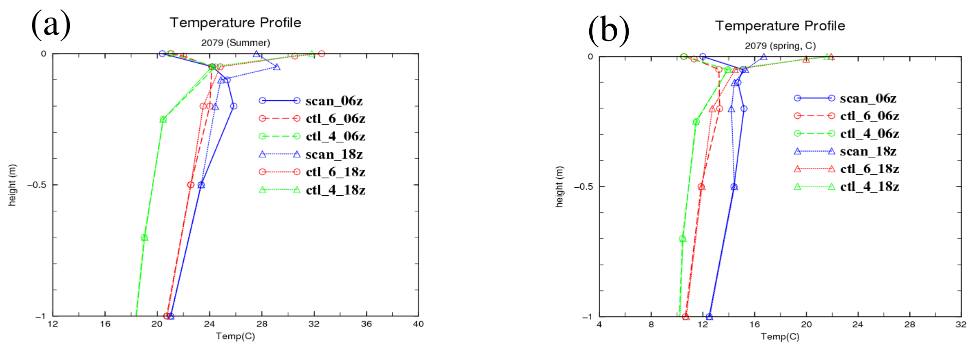

Figure 3. Averaged soil temperature profiles at midday (18Z) and midnight (06Z), (a) spring and (b) summer.

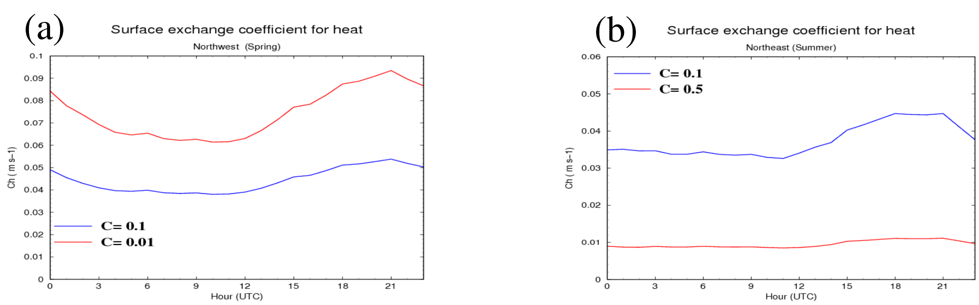

Figure 4. Averaged C_h diurnal cycle: (a) northwest domain and (b) northeast domain.

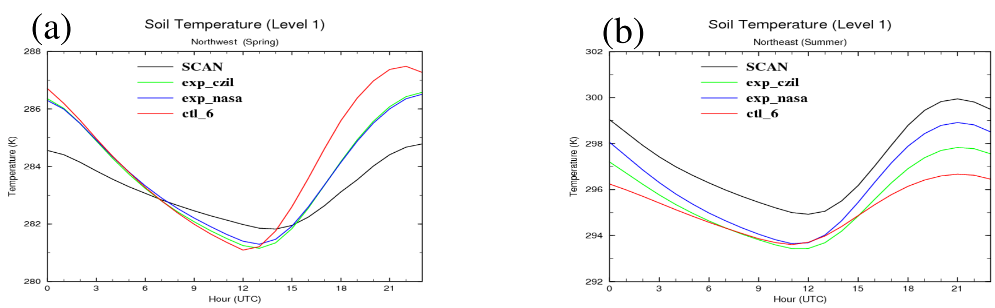

Figure 5. Averaged soil temperature diurnal cycle in 5cm soil layer depth: (a) northwest domain and (b) northeast domain.

2.4 Impact of NASA MODIS vegetation Data in HRLDAS

Many HRLDAS vegetation parameters are based on climatological data sets. NASA

MODIS leaf area index (LAI) and green vegetation fraction (FPAR) data provide much better spatial (1-km) and temporal (8-day) resolution than the default HRLDAS climatology data. The 1-km MODIS LAI and FPAR data are interpolated to the HRLDAS 4-km domain. Figure 5 shows the comparison of LAI between MODIS and climatology AVHRR-based in the HRLDAS domain. In this experiment, MODIS LAI and FPAR were used to drive 6-layer HRLDAS with different C constant. The results indicate that MODIS data further improve the soil temperature diurnal cycle (blue line in Fig. 4). The amplitude of diurnal cycle in the west domain is slightly decreased, and its amplitude in the east domain is significantly increased.

(a) (b)

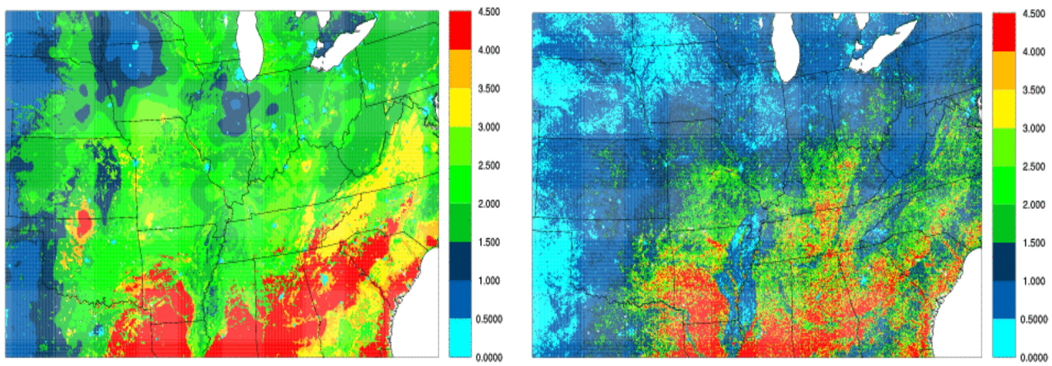

Figure 6. Leaf area index valid around 22 April 2006: (a) HRLDAS climatological data, and (b) NASA MODIS data.

3. SUMMARY

In this project, the high-resolution land data assimilation system (HRLDAS) is implemented to produce analysis and prediction of soil temperature and moisture, which are used as input to agricultural decision support systems. Preliminary verifications against SCAN observations show promising potential for adopting HRLDAS for agricultural applications:

- HRLDAS can capture the observed seasonal, weekly, and daily soil-temperature variations and vertical structure. The averaged diurnal cycle of HRLDAS soil temperature is in good agreement with SCAN observations.
- The forecast of soil temperature is sensitive to the treatment of atmospheric surface layer, and specifically to the C coefficient in HRLDAS. Defining C as function of vegetation type seems to improve soil temperature forecast.
- Using NASA-MODIS vegetation phenology data result in a significant improvement of soil temperature prediction.

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