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DEVELOPMENT OF HIGH RESOLUTION LAND DATA ASSIMILATION SYSTEM AND ITS APPLICATION TO WRF

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1. INTRODUCTION

We describe in this paper a research and development effort with regards to develop a soil initialization technique to embrace the application of coupled modeling system such as Weather Research and Forecast (WRF) for high-resolution weather forecasts. Subjects to be discussed include the configuration of the system, its spin-up and sensitivity to atmospheric forcing conditions, and its verification against observed profile of soil moisture and temperature, surface heat fluxes, and natural streamflow.

Although the important role of soil moisture in deep-convection development has been recognized, there still are several fundamental issues concerning soil moisture measurement, its application at large scales, and soil moisture initialization for NWP models. Long-term and high-resolution soil moisture measurements do not exist at the regional and global scales. The heterogeneity in topography, soil, and vegetation characteristics further complicates the difficulty with interpretation of the traditional ``point'' measurement of soil moisture on the local scale and the understanding of its dynamics. On the other hand, increasingly improving remote sensing techniques hold the promise of monitoring the surface soil moisture at high resolution over a large domain up to global scale.

One approach is to utilize observed rainfall, satellite-derived surface solar insolation, and meteorological analysis to drive an off-line simulation of a LSM, so that the evolution of soil moisture does not suffer from the model biases in surface forcing fields. Studies using offline LSM at point and global scales show that with reasonable surface forcing, surface hydrological response, and soil moisture dynamics, stand-alone LSMs can adequately capture the evolution of soil moisture. Recently, a North-American Land Data Assimilation System (NLDAS) with 1/8 degree resolution is being developed at NCEP as experimental product. Nevertheless, using soil moisture from one land data assimilation system to initialize another coupled system, even with the same baseline land surface parameterization scheme, running with different domain configuration till raised concerns because of mis-match in terrtain, landuse, and soil texture used in these two different modeling systems.

Therefore, parallel to this NCEP effort, we developed a High-Resolution Land Data Assimilation System (HRLDAS) to specifically address its usefulness and evaluate the impacts of fine-scale soil moisture on mesoscale forecasts. HRLDAS can be configured with the same nested grid configuration used for mesoscale model domains, so that the HRLDAS soil conditions can be directly ingested into the coupled mesoscale models without interpolation. In this paper, we describe the general characteristics of HRLDAS. Issues concerning spin-up of this soil assimilation system are also addressed, and verification of this system against observations is presented.

2. HIGH-RESOLUTION LAND DATA ASSIMILATION SYSTEM CONFIGURATION

The motivation of developing HRLDAS is to mitigate errors introduced by interpolating land conditions (e.g., soil moisture and temperature) from one LDAS source to a coupled model grids because of the mis-match of terrain, landuse, and soil specification between these two systems. In this paper, as an example, HRLDAS is set up to run in the continental U.S. due to the readily available forcing data required by HRLDAS in this region (see Fig. 1).

Figure 1: Two nested grids used in HRLDAS for selected 1998 dryline deep convection cases simulation. The same configuration is also used for IHOP 2003 simulations

In HRLDAS, various types of observed and analyzed atmospheric forcing conditions are used to drive the Noah land surface model. These conditions are similar to those used in NLDAS (Mitchell et al 2003) that include:

1) 4-km hourly NCEP Stage-IV rainfall analysis;
2) 0.5 degree hourly downward solar radiation derived from GOES satellites, a product jointly developed by NESDIS/NOAA and University of Maryland;
3) near-surface temperature, humidity, wind, downward longwave radiation, and surface pressure from 3-hourly atmospheric analyses of NCEP EDAS;
4) 1-km USGS 24-category landuse map and 1-km STASGO 16-category soil texture map;
5) 0.15 degree monthly satellite-derived green vegetation fraction.

HRLDAS simulates the entire surface energy and water budgets including surface latent and sensible heat fluxes, soil moisture and temperature, surface runoff, and water table recharge.

To minimize the errors caused by interpolating soil moisture and temperature from HRLDAS to MM5/ or WRF/LSM coupled system, HRLDAS can be designed in a nested mode (for example, see the 4-km grid on Fig.1) to approximately overlap MM5 (or other nested mesoscale models) fine grids. It was run for the period from 1 January to August 1998 to determine the antecedent soil moisture and temperature conditions prior to our MM5 24-hour 180June-1998 dryline deep convection simulation. HRLDAS was also run for the year 2002 in preparation of our International Water Vapor Project (IHOP) 2002 (IHOP-02) convection initiation and quantitative forecast (QPF) study.

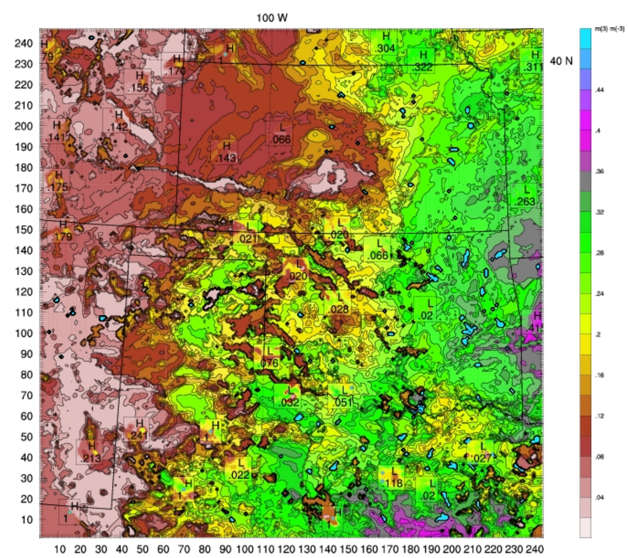

Figure 2. Volumetric soil moisture at 5-cm below the ground surface on a 4-km grid simulated by HRLDAS for the IHOP area; valid at 1200 UTC 31 May 2002.

The HRLDAS characterizes soil moisture/temperature and vegetation variability at small scales (~4km) over large areas in order to provide improved initial land and vegetation conditions for the MM5/LSM coupled model. As shown on Fig.2, HRLDAS soil moisture field captures not only the general west-east soil-moisture contrast across the general IHOP domain, but also fine-scale heterogeneity caused by small-scale convective rain, landuse types, soil texture, and vegetation characteristics.

3. RESULTS AND DISCUSSIONS

3.1 VERIFICATION OF HRLDAS

The NCAR nine flux-tower stations, established for the IHOP 2002 field experiment, provide a complete measurement of surface energy balance components, near-surface meteorological conditions, and soil moisture and temperature at several layers up to 90 cm below the surface. These stations were strategically along three boundary-layer-mission flight tracks flown by the University of Wyoming King Air (western, central, and eastern flight legs, as seen on Fig.3) and over various land-use types that include winter wheat (stations 5 and 6), grassland (2, 4, 7, 8, and 9), sparsely vegetated sagebrush (station 3), and bare ground (station 1), across the strong precipitation gradient between eastern Kansas and the Oklahoma Panhandle.

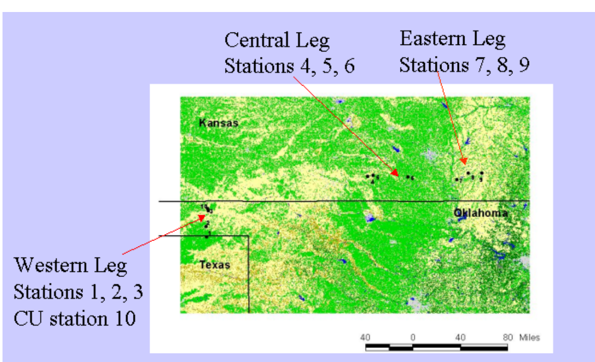

Figure 3. Location of HOP/NCAR/CU flux-tower stations

These data are used in this paper to verify HRLDAS. We have undertaken the following HRLDAS validation tasks:

- Verify various atmospheric forcing conditions used in HRLDAS against Mesonet and IHOP data, which include NCEP Stage-II rainfall analysis, NESDIS downward solar radiation, and model analyzed surface temperature, wind, and humidity
- Compare the 1-km USGS landuse and STATSGO soil texture used in HRLDAS with Mesonet and IHOP measurement
- Verify the HRLDAS simulated soil moisture, soil temperature, and surface heat fluxes with IHOP and Mesonet surface and soil data
- Verify HRLDAS simulated runoff with 'naturalized' stremflow for selected watersheds

Among the atmospheric forcing conditions used in HRLDAS, hourly precipitation and downward solar radiation may be the most important in that they are the primary energy and water input to drive the land modeling system and play a vital role in determining long-term evolution of soil moisture and temperature.

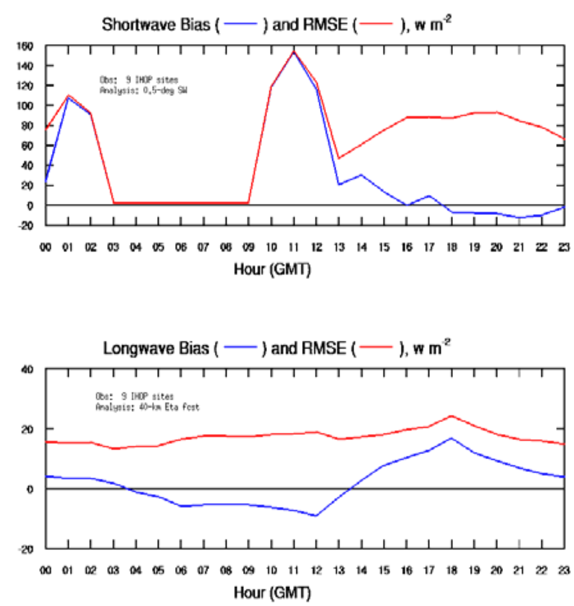

Figure 4: Bias and RMSE of downward solar and longwave radiation fluxes (W m^{-2}) as monthly averaged diurnal cycle.

Fig.4 shows an example of radiation forcing verification. Bias in GOES derived downward solar radiation is usually small except during early morning and late afternoon during low solar angle periods, and the GOES derived solar radiation are always overestimated for those time periods. Comparing with errors in satellite-derived downward solar radiation forcing, the errors in EDAS downward long wave radiation are in general quite small and negligible for land surface modeling purpose. Positive (negative) bias in EDAS longwave radiation for daytime (nighttime) may be reflective of temperature bias in EDAS.

Through these verification and sensitivity tests, we have found:

- HRLDAS compares well with Mesonet and IHOP soil moisture in terms of seasonal tendency, and the correct specification of soil texture in HRLDAS is critical for comparing HRLDAS results with observations (see Fig. 5)
- Forcing conditions used in HRLDAS generally verified well against Mesonet and IHOP data
- Using HRLDAS soil state to initialize MM5 simulations for our dryline case produced reasonable pre-storm conditions for convection initiation and significantly improved the quantitative precipitation forecast for this case

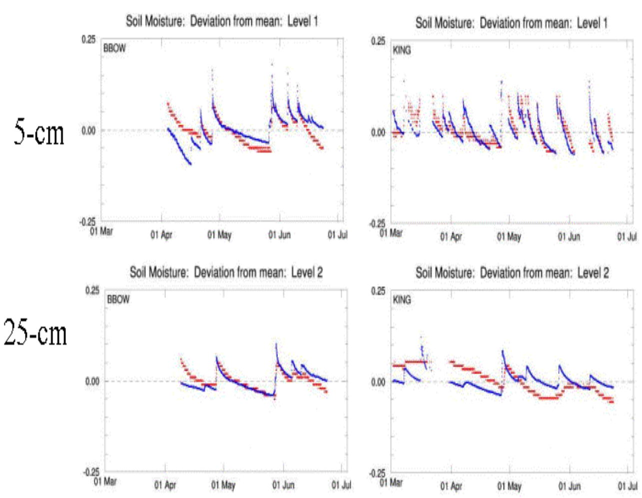

Figure 5: Comparison of soil moisture at 5-cm and 25-cm between HRLDAS and those observed at two Mesonet stations (BBOW and KING). Blue line is the deviation of HRLDAS output for the two stations from their 5-month mean values; and red line is the deviation of observed soil moisture at two stations from their 5-month mean values.

3.2 IMPACT OF HRLDAS SOIL DATA ON DRYLINE CONVECTION INITIATION

The HRLDAS generated soil moisture and temperature fields were used, as initial soil state conditions, in our high-resolution MM5 simulations of 1998 dryline deep convection case. Our simulations were conducted over a regional scale domain with 30-km horizontal grid spacing that had additional domains with 10- and 3.3-km grid spacing nested within. Initial atmospheric fields were obtained from Rapid Update Cycle (RUC-II) analyses. Deep convection formed along or slightly ahead of the NE-SW oriented surface moisture gradient (dryline) from west Texas into central Oklahoma by mid to late afternoon on 19 June.

Initialization of fine-scale gradients of soil moisture is clearly important in the simulated evolution of the dryline and convective initiation for the current case. In one sensitivity test, MM5 was initialized with the relatively coarse and somewhat too wet soil moisture from the NCEP EDAS (Fig. 5b) as compared to the HRLDAS field (Fig. 5a). As a result, the intensity of precipitation over Texas was much reduced (Fig. 6b). Also, deep convection was initiated over 100 km east of the dryline, compared to that at the vicinity of dryline in both the control simulation (Fig 6a) and observations

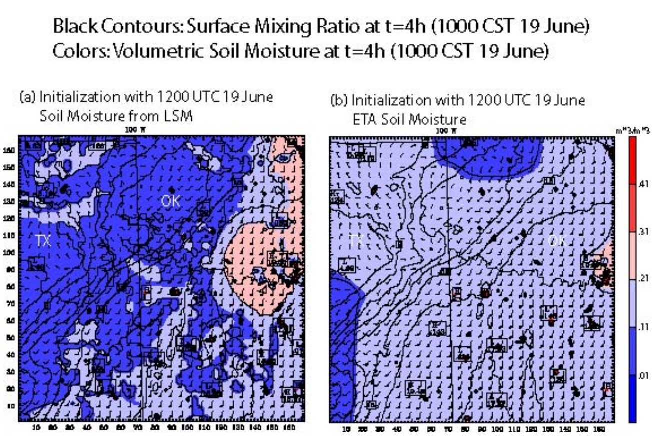

Figure 5: Domain 3 surface winds (barbed symbols), water vapor mixing ratio (g/kg, contoured every 2 g/kg), and volumetric surface soil moisture

(color scale at right) at t=4h (1000 CST 19 June 1998) for simulations initialized with (a) 1200 UTC (0600 CST) 19 June 1998 soil moisture from HRLDAS; control simulation, (b) the coarser resolution soil moisture field from EDAS.

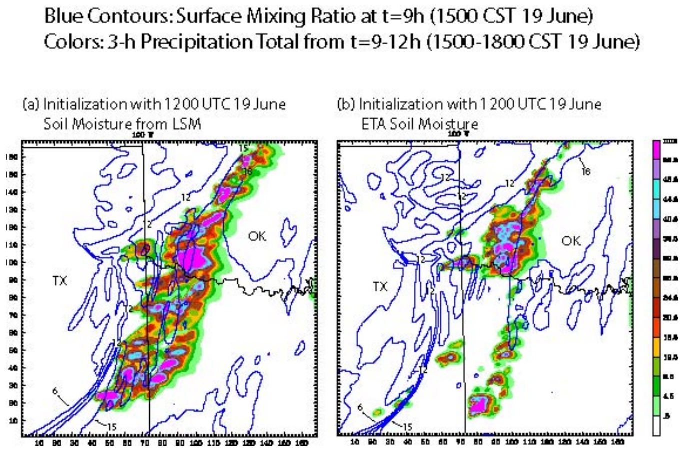

Figure 6: As in Fig. 5, but for water vapor mixing ratio valid at t=9h (1500 CST 19 June 1998) and 3-h accumulated precipitation (color scale at right) valid for the period of t=9-12 h (1500-1800 CST 19 June 1998)