1.5 HIGH-RESOLUTION LAND DATA ASSIMILATION IN THE NCAR/ATEC REAL-TIME FDDA AND FORECASTING SYSTEM

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1. INTRODUCTION

In the past four years, the National Center for Atmospheric Research (NCAR) and the Army Test and Evaluation Command (ATEC) have been developing a multiscale (with grid sizes of 0.5–45 km), rapidly cycling (at time intervals of 1–12 hours), real-time four-dimensional data assimilation and forecasting (RTFDDA) system. The RTFDDA system is based on the PSU-NCAR MM5 model (Dudhia 1993; Grell et al. 1994) and uses continuous data assimilation that employs the forecast model with Newtonian relaxation terms. The details of the system design, model and observational data used can be found in Cram et al. (2001) and Liu et al. (2002). For more information on the ATEC RTFDDA project please refer to the RAP/ATEC web page at http://www.4dwx.org/atec. The atmospheric model is coupled to the Noah land surface model (Chen et al. 1996). One of the latest additions to the RTFDDA system is the development and implementation of a high resolution land-surface data assimilation (HRLDAS) system that provides a continuous analysis of the land-surface state for each of the model domains. This paper describes the implementation of such a system and the validation of the mesososcale model analysis and forecasts with and without the use of assimilated land surface conditions.

2. THE REAL-TIME LAND SURFACE DATA ASSIMILATION SYSTEM

Traditionally, land surface model initial conditions (i.e., soil temperature, volumetric soil moisture, snow cover) in the RTFDDA system have been initialized from the much coarser resolution Eta (NCEP regional mesoscale model) model initial analysis. Because the local and regional forcing induced by small-scale heterogeneity in surface conditions is critical for the Army test range operations, more accurate surface conditions than those provided by a coarse resolution model are required to initialize the coupled RTFDDA/Noah land surface model system. An example of the model grid configurations and land surface categories for one of these ranges, the Dugway Proving Grounds (DPG) in western Utah, is shown in Fig. 1.

Land surface models depend heavily upon accurate forcing data in order to produce realistic simulations of land surface processes (Cosgrove et al. 2003). With this in mind, the HRLDAS system utilizes atmospheric forcing derived from the RTFDDA system for most variables, but observed incident shortwave radiation and precipitation fields when available.

Hourly surface incident shortwave radiation fields are derived from GOES satellite measurements and produced, with a 24-hour delay from real time, by the University of Maryland. For more detail see Pinker et al. (2003). This field, originally at 0.5° grid increment, is interpolated to each model grid.

Observed precipitation fields are derived from the 4-km NCEP Stage IV analysis which is a mosaicked national product from the regional hourly multi-sensor (radar + gauges) precipitation analyses. Because of missing data, particularly over the western US, the Stage IV product is corrected using the daily NCEP Climate Prediction Center (CPC) gauge-based precipitation analysis as it becomes available in real time. The corrected precipitation is obtained by downscaling the CPC rainfall in time using the Stage IV estimates. For the period when the CPC analysis is unavailable, raw Stage IV fields are used. And, since the HRLDAS fields must be available in real time to initialize the RTFDDA system, when either observed radiation and/or precipitation fields are unavailable, model-derived fields are used.

The HRLDAS system is integrated in off-line mode four times daily (at 2000, 0200, 0800 and 1400 UTC), with hopefully increasingly more accurate atmospheric forcing, because more observational data is available at a later time. Each run uses the same set of 0000 UTC initial conditions derived from the previous day integration. Each of these overwrites the previous estimate of soil moisture and ground temperature fields, and the initial conditions for the next day HRLDAS integration, thus producing a continuous depiction of the land surface state. The estimates of soil moisture and temperature in all soil layers are then used as initial conditions

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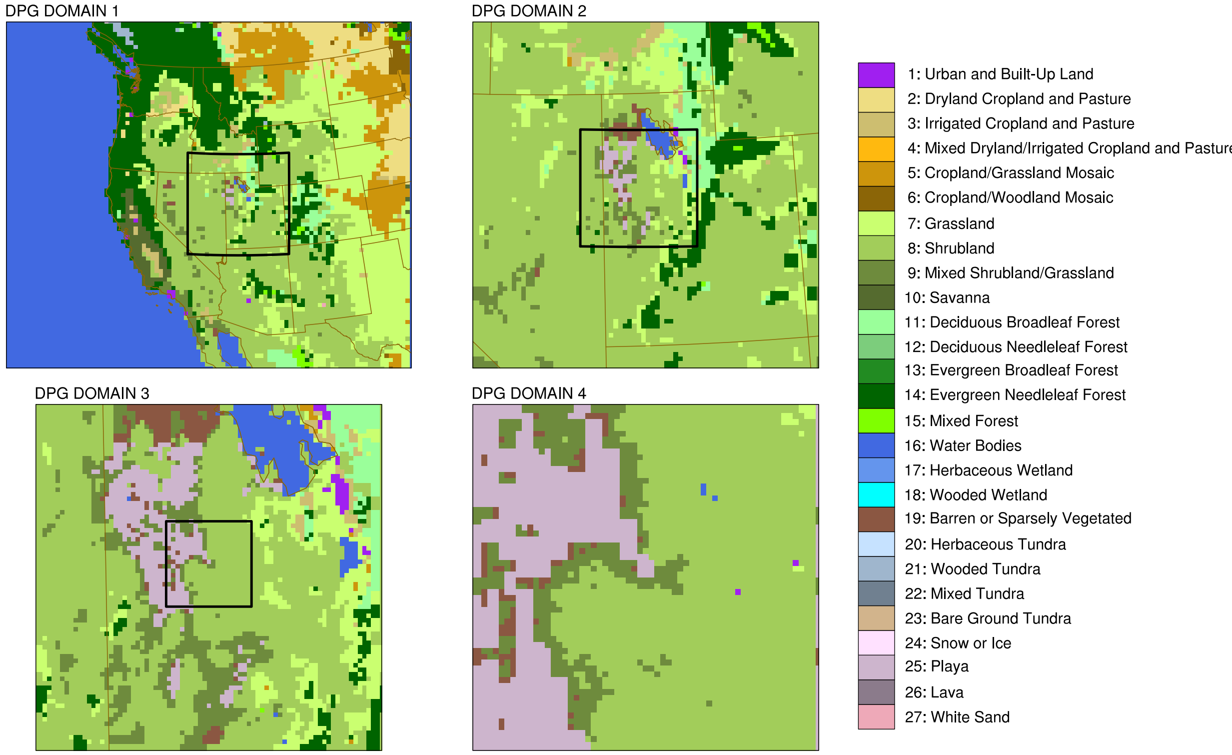

Figure 1: The four domain configuration and their respective land-use categories for the Dugway Proving Grounds (DPG) ATEC RTFDDA system. Domains 1, 2, 3, and 4 have a 30, 10, 3.3, and 1.1 km horizontal grid spacing, respectively.

for the RTFDDA/Noah model integration. Snow fractions and/or water equivalent snow depth fields are yet to be used in the model initialization. The original development of the HRLDAS system, and an example of it application to the Weather Research and Forecast (WRF) model for high-resolution weather forecasts is summarized in Chen et al. (2004)

The principal impact of the HRLDAS system on the initial surface conditions is, as expected, much larger spatial variability in surface soil properties and a reduced spatial scale of these properties. There is also an overall decrease in soil moisture content in the uppermost layers of the soil column relative to the Eta analysis. Figure 2 illustrates the time-evolution of the domain-averaged volumetric soil moisture content for the three uppermost soil layers (of depth of 10, 40, and 100 cm). For reference the figure also includes the domain-averaged 12-hour precipitation that was used as input to the HRLDAS system. These averages are computed with all land grid points of DPG Domain 1 (Fig. 1). The figure illustrates the rapid decrease in water content (by either drainage or surface evaporation), interrupted by occasional precipitation events, of the uppermost soil layer. The same type of behavior is seen in all domains and for all “western” ranges (whose domains are centered over western Utah, southwest Arizona, and southern New Mexico). Therefore, over the western US, the top layer HRLDAS-derived soil moisture field is normally drier than that available from the Eta data assimilation system and interpolated to the DPG domains.

3. MODEL VERIFICATION STATISTICS

During the late summer and early fall of 2004, we have conducted pairs of parallel model integrations of the real time RTFDDA system for some of the ATEC ranges. The only difference between these is that in one of the integrations the volumetric soil moisture content and soil temperature fields produced by the real time HRLDAS system are used to initialize the model integration. All other initial conditions and assimilated observations are identical. Because the RTFDDA system relays on a continuous data assimilation method, “cold-starts” are forced twice-weekly so that updated HRLDAS soil conditions can be introduced. The usual verification statistics against observed station data (biases, mean errors, etc.) are computed for both model integrations to access the impact of the initial HRLDAS-derived fields on the model analysis and forecasts.

Figure 3 shows a comparison of the bias, root-mean square error (RMSE), and mean absolute error (MAE) of 2-meter temperature (°C) between the model simu-

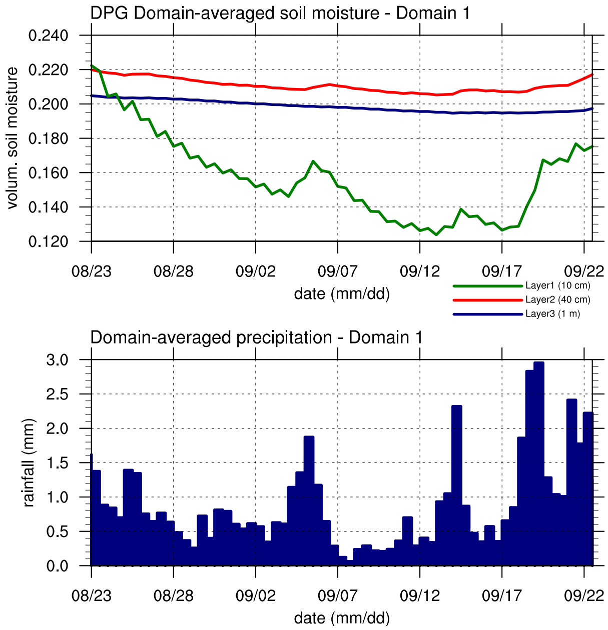

Figure 2: Domain-averaged soil moisture content in the 3 uppermost soil layers (top), and the domain-averaged 12-hour precipitation totals (bottom) that were used to forced the HRLDAS system as a function of time for the period August 23–September 22 2004. Domain averages correspond to all land grid points within DPG Domain 1 (see Fig. 1). In this figure, the HRLDAS system was initialized at 0000 UTC 23 August 2004.

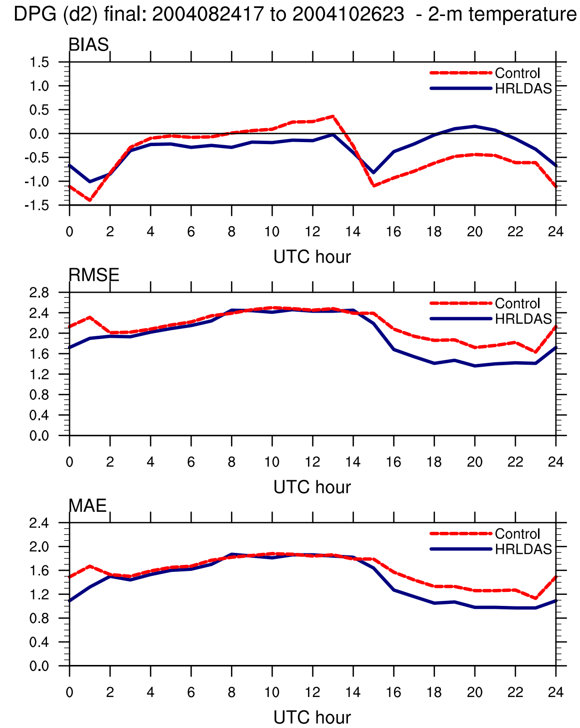

Figure 3: Comparison of the bias (top), root-mean square error (center), and mean absolute error (bottom) of 2-meter temperature (°C) between the model simulation (during its "final" data assimilation period) and surface observations over domain 2 of the DPG RTFDDA system as a function of the time of the day. The statistics are computed for every available observation in the period 24 August to 27 October 2004 and then averaged over the entire domain for each hour of the day (in UTC hour). The red line is for the standard RTFDDA system; the blue line is for that initialized with HRLDAS-derived soil fields.

lation (during its "final" analysis period) and surface observations over domain 2 of the DPG RTFDDA system as a function of the time of the day. To produce these, model versus observation pairs are archived for every available observation point during the period 24 August to 27 October 2004 and then compiled as average statistics over time and over the respective domain for each hour of the day. The results show that for DPG Domain 2 the standard model analysis tends to have a cold bias in surface air temperature during the daytime and early evening (1400–0200 UTC; 1000 to 2000 LST), but a very good depiction of surface temperature during the nighttime hours. The bias is most negative at sunrise and sunset. These large biases are apparently related to problems in the model boundary-layer parameterization. RMSE and MAE are smaller during the daytime; larger at night. The RTFDDA integration that uses initial HRLDAS-derived soil conditions has a smaller (less negative) temperature bias during the day but tends to make the surface slightly colder at night. RMSE and MAE are smaller during the day but unchanged at night. Biases at sunset and sunrise are less negative in this integration as well. The bias in surface specific humidity (not shown) tends to be more negative (by a few tenths of a g/km) in the HRLDAS integration over all times of the day. Overall, the results shown here for the final analysis over domain 2 of DPG are characteristic of other domains and carry into the forecast phase of the model integration.

To illustrate the improvements in the simulation of 2-meter temperature induced by the HRLDAS-derived soil conditions, Fig. 4 shows the spatial distribution of model biases for 1900 UTC (1300 LST) at the observation locations for 2-meter temperature for the standard RTFDDA system and that with the more realistic initial soil conditions. Results are for the final data assimilation period. The standard RTFDDA results displays negative biases (up to -1.94°C over western Utah) over most of the domain. When HRLDAS-derived soil conditions are incorporated into the model initial conditions, most stations show that biases are considerably reduced. Some stations have a slight positive bias in 2-meter temperature with the new soil initialization. Similar results are seen at the other daytime hours with lesser amplitude. Most of the changes in the biases between the two simulations are seen within the intermountain west and southwest

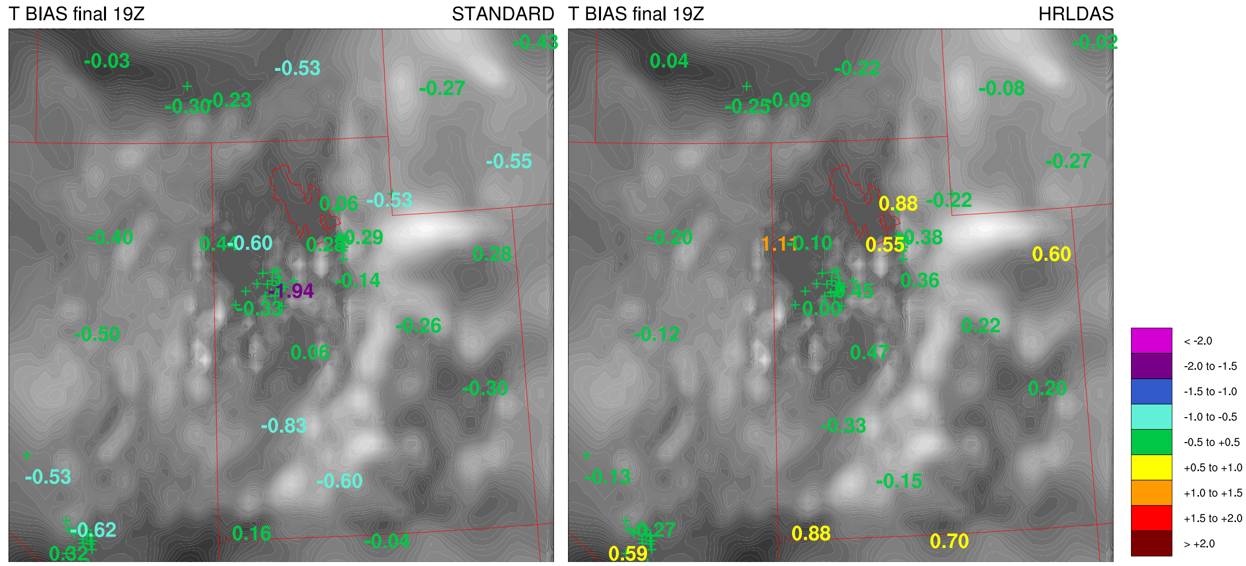

Figure 4: Station-averaged bias of 2-meter temperature for the period August 24 to October 26 2004 over DPG Domain 2 during its final data assimilation period. Top: standard RTFDDA system; bottom: system initialized with HRLDAS soil fields. Some stations have been removed to make the figure more legible. Color codes are on the right. The background shading represents the local topography, with black (white) as the lowest (highest) terrain elevation.

desert areas, without affecting the already good simulations of surface temperatures over the western plains and California.

The most likely mechanism responsible for the daytime warming and slight nighttime cooling of the surface in the model simulations with HRLDAS is related to the overall drying of the uppermost layers of the soil. Under drier conditions, the daytime net available energy at the surface is partitioned toward increased sensible heat flux, due to a decrease in soil evaporation, and thus increased near surface temperatures. At night, because of the drying of the lower troposphere due to the reduced surface source of water, there is less longwave radiation absorbed by the surface and thus an overall cooling. The mechanisms generating the sharp model biases at sunrise and sunset are not fully understood at the moment, and will be investigated further.

4. SUMMARY AND FUTURE IMPROVEMENTS

This paper describes initial results of the implementation of a high resolution land data assimilation system for use within a mesoscale analysis and modeling system. HRLDAS-derived soil moisture fields are generally drier and display larger spatial variability that those obtained from the Eta model initial analysis over most of the western US. When these fields are incorporated in the RTFDDA modeling system, initial results show a reduction of a negative daytime bias in 2-meter temperatures as compared to the standard model integration. Most of the differences in near surface air temperature can be attributed to the overall drying of the soil in the HRLDAS system and the impacts of reduced evaporation on the lowest layers of the atmosphere.

Many issues in the HRLDAS system are yet unresolved. The values of hourly precipitation provided by the Stage IV analysis seem to underestimate precipitation over the complex terrain of the western US. Therefore, the HRLDAS soil moisture fields are probably too dry in these regions. To remediate this issue, we are currently considering using observed precipitation in data-rich regions and the model estimate over more data-sparse ones. Exactly how these areas will be determined is still unresolved. Another related issue under consideration, and perhaps much more complicated, is the use of derived snow fields. While a good source of snow cover fraction is available at excellent spatial resolution, the Noah LSM requires fields of water equivalent snow depth. Furthermore, this field is highly influenced by surface elevation and other topographic features of the terrain, which makes its use at high resolution a problematic issue. We are currently considering potential algorithms to downscale a combination of the available snow fields to the HRLDAS high resolution grid.

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