5A.4 IMPROVED MODELING OF LAND-ATMOSPHERE INTERACTIONS USING A COUPLED VERSION OF WRF WITH THE LAND INFORMATION SYSTEM

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1. INTRODUCTION

The exchange of energy and moisture between the Earth's surface and the atmospheric boundary layer plays a critical role in many hydrometeorological processes. This energy exchange is parameterized in atmospheric numerical weather prediction (NWP) models using Land Surface Models (LSMs) such as Noah (Ek et al. 2003) or the Common Land Model (CLM, Dai et al. 2003). Accurate and high-resolution representations of surface properties such as vegetation, soil temperature and moisture content, sea-surface temperature (SST), and ground fluxes are necessary to better understand the Earth-atmosphere interactions and to improve numerical predictions of weather and climate phenomena facilitated by LSMs.

The NASA Short-term Prediction Research and Transition (SPoRT) Center is investigating the potential benefits of assimilating high-resolution NASA datasets derived from the Earth Observing System Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard the Aqua and Terra satellites into an atmospheric model. Using the Weather Research and Forecasting (WRF) model in conjunction with the NASA Goddard Space Flight Center Land Information System (LIS) software, the objective of this project is to evaluate the impacts of high-resolution lower boundary data derived from NASA systems and tools on regional short-term NWP guidance (0–24 hours). The ultimate goal of this and other SPoRT projects is to accelerate the infusion of NASA Earth Science observations, data assimilation and modeling research into National Weather Service forecast operations and decision-making at the regional and local level.

This paper provides an overview of the experiment design for evaluating the potential impacts of running a version of WRF coupled with LIS. The paper also presents some preliminary results of spin-up runs using the Noah LSM as run within the LIS software framework. The remainder of the paper is organized as follows. Section 2 provides background information on the LIS. Section 3 describes the coupled LIS/WRF framework. The experiment design is presented in Section 4 with some results of offline LIS spin-up runs given in Section 5. Sections 6–8 consist of the summary, acknowledgements, and references, respectively.

2. THE LAND INFORMATION SYSTEM (LIS)

The LIS is a software framework that integrates satellite-derived datasets, ground-based observations, and model reanalysis data to force a variety of LSMs. By using scalable, high-performance computing and data management technologies, LIS can run LSMs offline globally with a grid spacing as fine as 1 km to characterize land surface states and fluxes. The software infrastructure enables LIS to ingest high-resolution datasets such as leaf area index and vegetation fraction derived from the MODIS instruments (Kumar et al. 2006). The LIS has also been used to demonstrate land surface modeling capability at 1-km grid spacing over urban areas (Peters-Lidard et al. 2004).

To predict water and energy processes, LSMs require (1) initial conditions, (2) boundary conditions from the atmosphere (i.e. forcings such as temperature, precipitation, radiation, wind, etc) and lower soil states, and (3) parameters describing the soil, vegetation, topography, and other surface properties. Using these inputs, LSMs solve the governing equations of the soil-vegetation-snowpack medium, and predict surface fluxes and soil states in order to provide a realistic representation of the transfer of mass, energy, and momentum between the land surface and the atmosphere (Kumar et al. 2006; Sellers et al. 1986).

By itself, LIS runs in an uncoupled, offline mode using various atmospheric forcings to drive one of several community LSMs: the Noah LSM, the CLM, the Variable Infiltration Capacity model (VIC, Liang et al. 1994; Liang et al. 1996), the Mosaic model (Koster and Suarez 1996), and the SiB model with Hydrology (Sellers et al. 1986; Sud and Mocko 1999). For this paper, the Noah LSM is used with atmospheric forcings from the North American Land Data Assimilation System (NLDAS, Mitchell et al. 2004), which provides atmospheric analysis data at 1/8° resolution every hour.

3. COUPLED LIS/WRF

In addition to running in an offline mode, the LIS can be run in a coupled mode with WRF to integrate surface and soil quantities using the LSMs available in LIS. The LIS has been coupled to the Advanced Research WRF (ARW, Skamarock et al. 2005) by following the Earth System Modeling Framework (Hill et al. 2004), giving users the ability to run an ensemble

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system of LSMs within the ARW dynamical core (Kumar et al. 2005).

The benefits of running LIS coupled to WRF for regional modeling are numerous. First, LIS provides the user with the capability to optimize the initialization of surface and soil variables by tuning the spin-up time period and specifying atmospheric forcings, which cannot be done in the standard WRF. Second, users can run WRF with any of the LSMs available in LIS, whereas only the Noah or Rapid Update Cycle's LSM can be run within the standard WRF. Third, offline LIS output can be generated at the same resolution as the regional WRF grid, and then be used directly as input to the coupled LIS/WRF. Finally, the LIS provides a framework from which to introduce new high-resolution land datasets such as MODIS-derived vegetation fields.

4. EXPERIMENT DESIGN

Experiments are being conducted to measure the potential benefits of using the coupled LIS/WRF model versus the standard WRF over the Florida peninsula during May 2004. This month experienced relatively benign weather conditions, which allow the experiments to focus on the local and mesoscale impacts of the high-resolution datasets and optimized soil and surface initial conditions on predictions of surface temperature, dewpoint, wind, and fluxes.

The model domain covers the entire Florida peninsula stretching from the northern edge of the Florida Keys to southern Georgia, including the adjacent waters of the Gulf of Mexico and Atlantic Ocean. The domain has 3-km grid spacing with 250 mass points in both the zonal and meridional directions, and 42 sigma-pressure vertical levels (WRF only).

For the standard and coupled WRF simulations, the physics options consist of the rapid radiative transfer model (Mlawer et al. 1997) and Dudhia scheme (Dudhia 1989) for longwave and shortwave radiation, respectively. The Thompson graupel microphysics scheme (Thompson et al. 2004) is used without any cumulus parameterization of sub-grid scale convection. Vertical diffusion and planetary boundary layer processes are parameterized by the Yonsei University scheme (Hong et al. 2006) while horizontal diffusion is handled by the two-dimensional Smagorinsky first-order closure scheme (Smagorinsky et al. 1965). As stated previously, all comparison runs use the Noah LSM.

4.1 Offline LIS Spin-up Simulations

The first component of our methodology is to determine the spin-up time required for the Noah LSM to reach "equilibrium" by 1 May 2004 over the Florida domain. Given hourly atmospheric forcing from the NLDAS at 1/8° resolution (~14 km), experiments were conducted to run the offline LIS for 1, 2, 4, 6, 9, and 12 months, all with an ending time of 0000 UTC 1 May 2004. A first-guess soil temperature of 290 K and volumetric soil moisture of 30% was applied to all four levels of the Noah LSM in LIS at the initial time for each offline simulation.

The hourly NLDAS atmospheric data forced the Noah LSM from the upper boundary using a Noah timestep of 30 min, while a constant value of 290 K served as the bottom boundary for the deep soil temperature. The goal of these spin-up simulations is to converge to an equilibrium state in the Noah LSM that has no memory of the first-guess soil temperature and moisture values. The convergent time length is determined by examining the final soil temperature and particularly the deep soil moisture fields at 0000 UTC 1 May 2004 for each offline LIS simulation listed above. Given that the *(n+1)th* simulation has a longer integration length than the *nth* simulation, equilibrium is considered achieved for the *nth* simulation if the *(n+1)th* simulation has a negligible difference in the deep soil temperature and moisture fields compared to the *nth* simulation.

A restart of the *nth* LIS/Noah offline output was then used to continue the offline LIS simulations during the entire study month, again using the hourly NLDAS atmospheric forcing data. Beginning with the simulation data valid at 0000 UTC 1 May 2004, LIS/Noah integration was continued through 0000 UTC 1 June 2004, with output written every 3 hours to serve as soil initialization data for prospective LIS/WRF coupled model runs. In addition, the 3-hourly output of LIS/Noah serves to characterize the daily soil model conditions and adjustments that occur in response to the NLDAS atmospheric forcing.

4.2 Standard WRF vs. Coupled LIS/WRF

To evaluate the potential impacts of the coupled system versus the standard WRF, the experiment design involves running standard and coupled WRF simulations (using the equilibrium LIS initial conditions) daily for the entire month of May 2004. The standard WRF simulations (i.e. control runs) will use the ARW dynamical core from the same WRF version as the coupled LIS/WRF software. Soil initial conditions in the control runs will be obtained through a typical interpolation of the soil temperature and moisture values from the external NWP model data used for initial and boundary conditions (in our case, the Eta model on a 40-km grid). Model verification statistics such as RMS error and bias will be generated for the control simulations and coupled LIS/WRF predictions to include surface temperature, dewpoint, and winds at surface observation sites. In addition, forecast fields will be examined to identify and compare possible changes in predicted mesoscale phenomena such as sea and lake breezes, as well as differences in predicted sensible and latent heat fluxes.

5. RESULTS OF OFFLINE LIS SPINUP RUNS

The "dry season" over central and southern Florida typically occurs fom November to May each year. Conditions over the Florida peninsula were quite dry in the months preceding May 2004, particularly in March and April where many stations received less than 2 inches of precipitation per month and in some instances, less than an inch. The dry conditions combined with the quick-response characteristics of the prevailing sandy soil type across much of Florida led to significant drying in all layers of the Noah LSM from the first-guess 30% volumetric soil moisture.

The near-surface layer of the soil model (0–10 cm) typically responds directly to daily atmospheric forcing, so the deep layers are most important to determine whether the soil model has reached an equilibrium state. This section focuses on the deepest Noah layer (100–200 cm, layer 4) since this layer is slowest to respond to atmospheric forcing. The layer-4 simulated volumetric soil moisture at 0000 UTC 1 May 2004 for each of the spin-up runs is given in Figure 1. The 2-month LIS simulation (Figure 1b) is drier than the 1-month simulation (Figure 1a) by 2–4% or more across much of the land domain. Noticeable decreases in volumetric soil moisture continue to occur in the 4-month (Figure 1c) and 6-month simulations (Figure 1d). A plot of the difference fields between successive spin-up simulations shows a domain-wide adjustment of -0.5 to -3.0% (i.e. drying) from the 2-month to 4-month simulations (Figure 2a), and again from the 4-month to 6-month simulations (Figure 2b).

Significant drying of Noah soil layer 4 continues across much of the domain from the 6-month to 9-month simulations (Figure 1e and Figure 2c). However, by the 12-month simulation (Figure 1f), additional drying of the layer is mainly confined to the region around the Florida-Georgia border, with differences up to 2% in some areas (Figure 2d). Much of the domain experiences less than a 0.5% change in volumetric soil moisture compared to the 9-month spin-up run. These simulations indicate a convergence of the layer-4 volumetric soil moisture to ~16–26% over south Florida, ~14–18% over most of the central peninsula, and the driest values of 10% or less across portions of north Florida and southern Georgia.

The deep soil temperatures tend to converge more quickly than the soil moisture, as indicated in Figure 3 and Figure 4, possibly because the first-guess temperature is already close to the converged values. Temperatures warm from ~18–20°C to ~20–24°C over south Florida from the 1-month to 4-month simulations (Figure 3a-c). Only very minor changes occur in the 6-month to 12-month simulations, mainly over the Bahamas island on the eastern edge of the domain (Figure 3d-f). The difference plots indicate subtle warming of soil layer 4 over portions of south Florida and more widespread, but still subtle cooling over Georgia from the 2-month to 4-month simulations (Figure 4a). However, all temperature differences are less than 0.5°C in magnitude between the 4-month and 6-month simulations (Figure 4b) and remain of negligible magnitude for the rest of the successive spin-up runs (not shown). Therefore, based on these spin-up simulation results (and others not shown), 9 months is deemed a good compromise for an offline LIS/Noah spin-up integration length. The 9-month simulation data at 0000 UTC 1 May were then used to continue the offline LIS/Noah simulation throughout the rest of May 2004, which will provide soil initial conditions to the coupled LIS/WRF simulations, as described in Section 4.1.

6. SUMMARY

This paper described an experiment design for comparing daily regional simulations of standard WRF versus coupled LIS/WRF model runs on a 3-km grid over the Florida peninsula for a month-long time frame. The coupled LIS/WRF model runs will feature high-resolution soil initialization data generated by running the Noah LSM within the LIS software over a period of 9 months prior to 0000 UTC 1 May 2004. Preliminary results from the WRF comparison runs will be presented at the conference.

This paper also presented a methodology for determining the minimum integration length required to adequately spin-up a LSM within the LIS software. Based on the presented results and corresponding discussion, an offline spin-up time of 9 months was deemed adequate for our domain and application. The required spin-up time in this case is somewhat shorter than most applications because the predominant soil over the Florida peninsula consists of mostly porous, sandy types. Different geographical regions with soils that have slower responses to atmospheric forcing (particularly precipitation infiltration) may require an offline spin-up time of up to several years.

Follow-on experiments could examine the utility of the coupled LIS/WRF configuration to more complex weather scenarios such as convective initiation. In addition, high-resolution observational data sets (such as those derived from MODIS instruments) could be incorporated to improve the atmospheric forcing for the offline LIS runs and/or improve the accuracy of the land-use fields. Furthermore, experiments could be conducted in near real time to assess the utility of such a coupled system to operational weather forecasting.

7. ACKNOWLEDGEMENTS/DISCLAIMER

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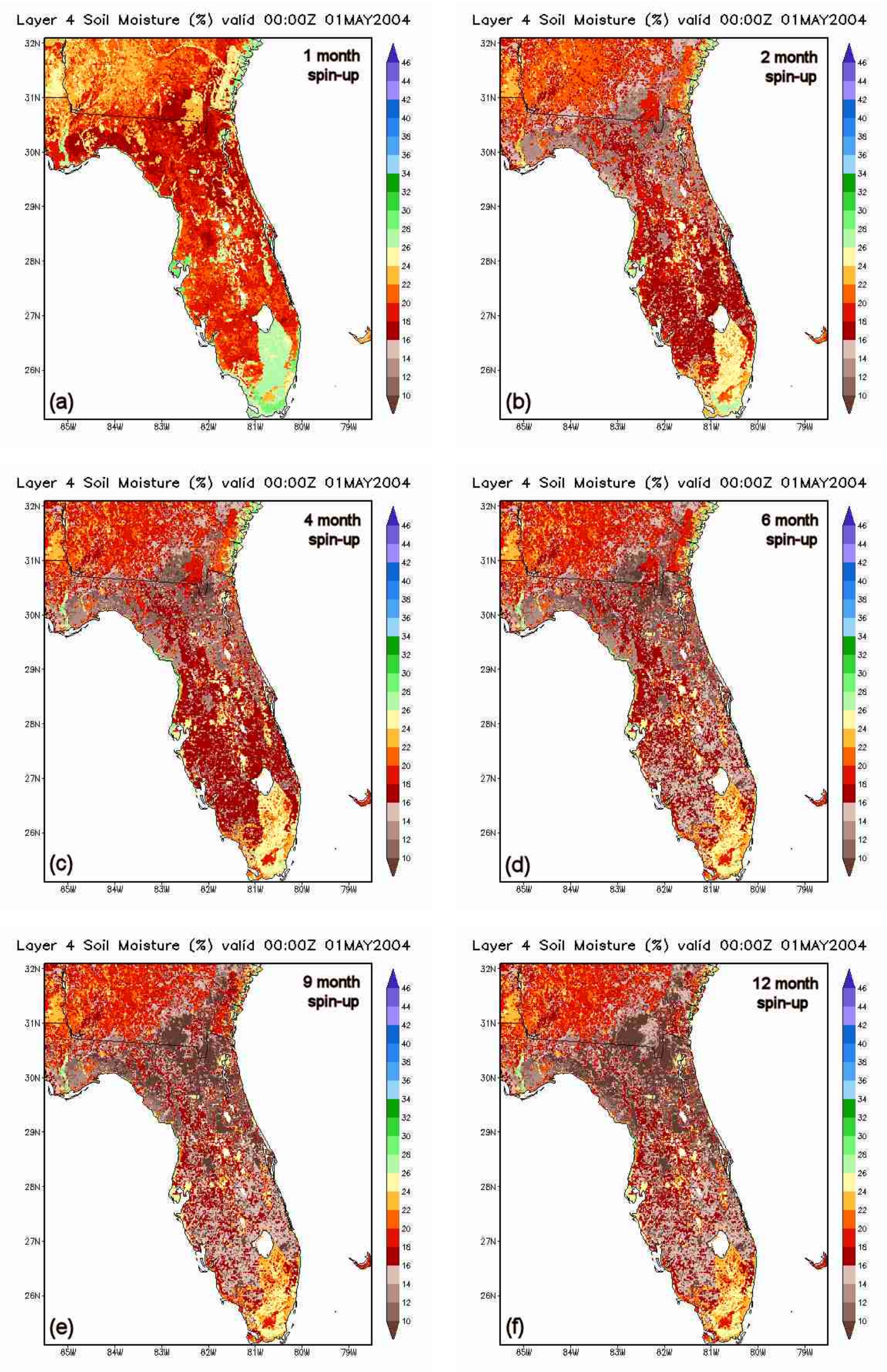

Figure 1. Offline LIS simulations of 100–200 cm (layer 4) volumetric soil moisture in the Noah LSM, valid at 0000 UTC 1 May 2004 for (a) 1-month simulation initialized on 1 Apr 2004, (b) 2 month simulation initialized on 1 Mar 2004, (c) 4month simulation initialized on 1 Jan2004, (d) 6-month simulation initialized on 1 Nov 2003, (e) 9month simulation initialized on 1 Aug 2003, and (f) 12-month simulation initialized on 1 May 2003.

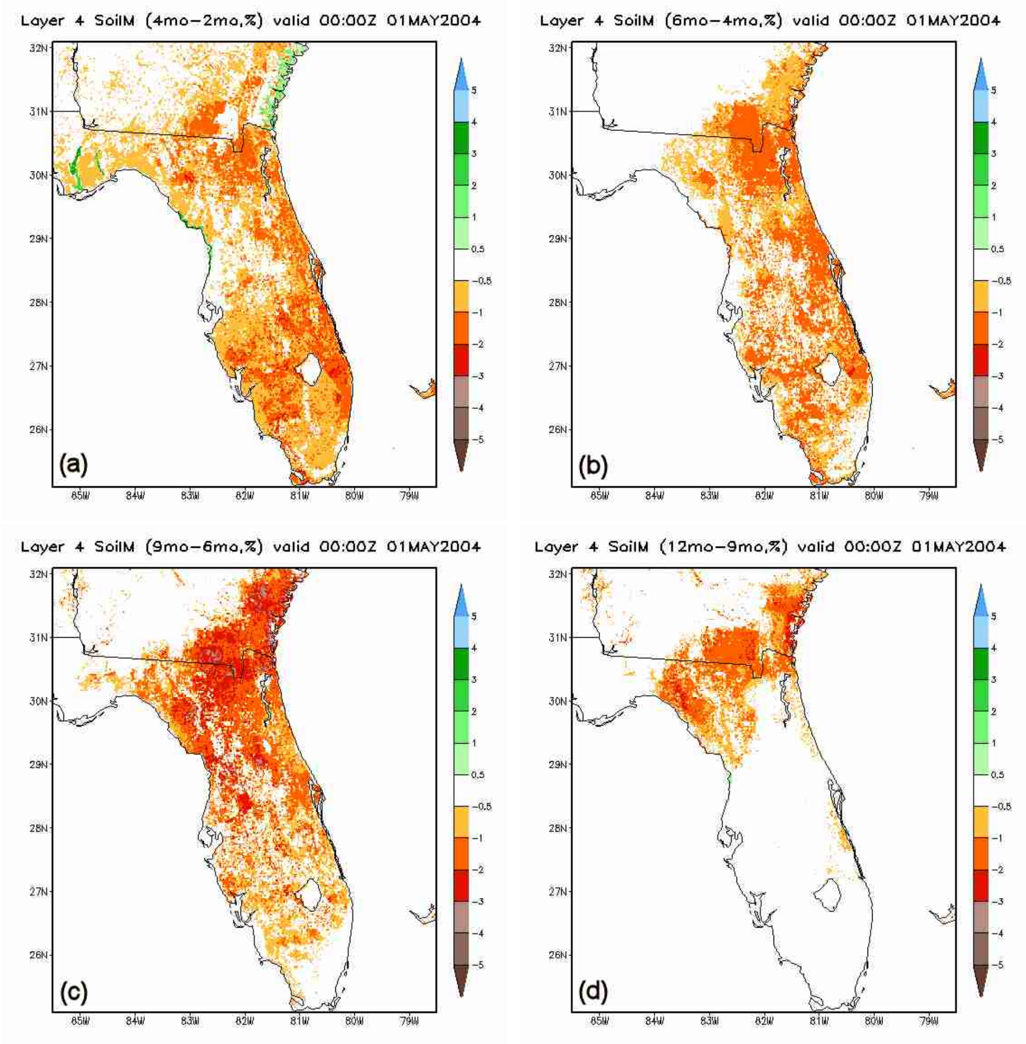

Figure 2. Difference fields between successive offline LIS spin-up simulations of 100–200 cm (layer 4) volumetric soil moisture in the Noah LSM, valid at 0000 UTC 1 May 2004 for (a) 4-month minus 2-month simulations, (b) 6-month minus 4-month simulations, (c) 9-month minus 6-month simulations, and (d) 12-month minus 9-month simulation.

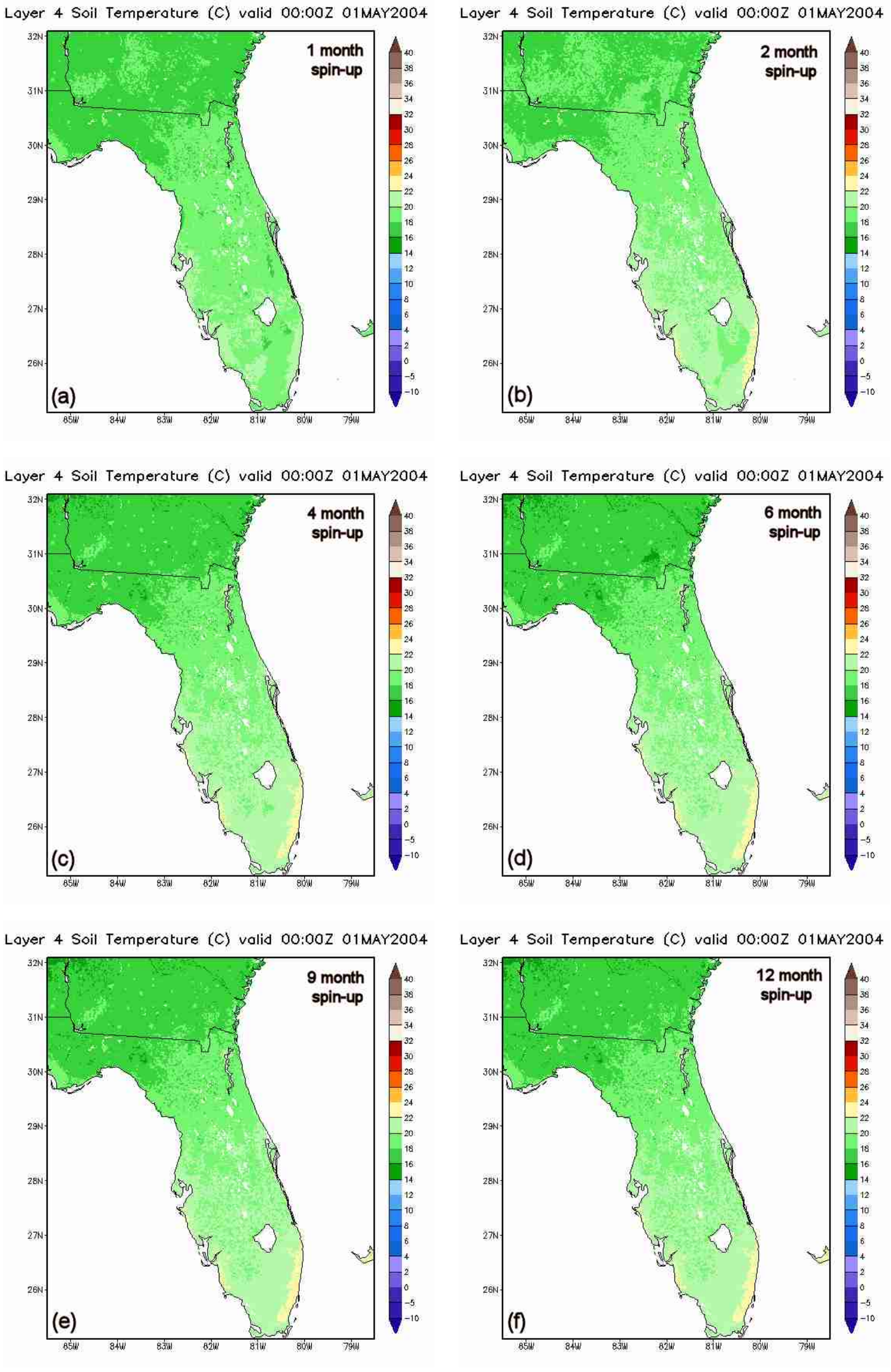

Figure 3. Offline LIS simulations of 100-200 cm (layer 4) soil temperature (°C) in the Noah LSM, valid at 0000 UTC 1 May 2004 for (a) 1-month simulation initialized on 1 Apr 2004, (b) 2 month simulation initialized on 1 Mar 2004, (c) 4-month simulation initialized on 1 Jan 2004, (d) 6-month simulation initialized on 1 Nov 2003, (e) 9-month simulation initialized on 1 Aug 2003, and (f) 12-month simulation initialized on 1 May 2003.

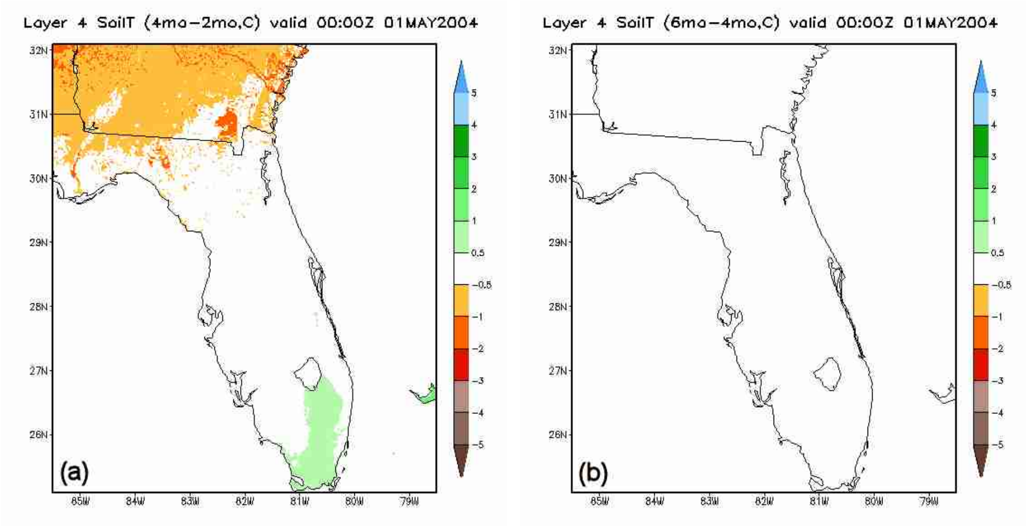

Figure 4. Difference fields between successive offline LIS spin-up simulations of 100–200 cm (layer 4) soil temperature (°C) in the Noah LSM, valid at 0000 UTC 1 May 2004 for (a) 4-month minus 2-month simulations, and (b) 6-month minus 4-month simulations.

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