JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D22, 8845, doi:10.1029/2002JD003316, 2003

Land surface model spin-up behavior in the North American Land Data Assimilation System (NLDAS)

Brian A. Cosgrove,[1] Dag Lohmann,[2] Kenneth E. Mitchell,[2] Paul R. Houser,[3] Eric F. Wood,[4] John C. Schaake,[5] Alan Robock,[6] Justin Sheffield,[4] Qingyun Duan,[5] Lifeng Luo,[6] R. Wayne Higgins,[7] Rachel T. Pinker,[8] and J. Dan Tarpley[9]

Received 13 December 2002; revised 29 August 2003; accepted 9 September 2003; published 21 November 2003.

[1] The process of a model adjusting to its forcing (model spin-up) can severely bias land surface simulations, and result in questionable land surface model (LSM) output during the spin-up process. To gain a better understanding of how spin-up processes affect complex spatial and temporal land surface modeling situations in general, and the Retrospective North American Land Data Assimilation System (NLDAS) simulations in particular, a two-phase study was conducted. The first phase examined results from Control, Wet, and Dry 11 year-long Mosaic simulations, while the second phase attempted to explain spin-up behavior in NLDAS Retrospective simulations from the Mosaic, Noah, VIC and Sacramento LSMs based in part on the results from phase 1. Total column and root zone soil moisture spin up slowly, while evaporation and deep soil temperature spin up more quickly. Mosaic soil moisture initialization with NCEP/DOE Global Reanalysis 2 (NCEP/DOE R-2) data (Control run) leads to a faster spin-up time than saturated (Wet run) or dry (Dry run) initialization, with the Control run reaching equilibrium 1 to 2 years sooner than the Wet run and 3 to 4 years more quickly than the Dry run. Overall, practical drift of land surface stores and output ceased in the Control run within approximately 1 year, and fine-scale equilibrium was reached within 5.5 years. Spin-up times exhibited large spatial variability, and although no single causal factor could be determined, they were correlated most strongly with precipitation and temperature forcing. In general, NLDAS models reach a state of rough equilibrium within the first 1 to 2 years of the 3-year Retrospective simulation. The Sacramento LSM has the shortest spin-up phase, followed by the Mosaic, VIC, and Noah LSMs. Initial NCEP/DOE R-2 conditions were too dry in general for the VIC and Noah LSMs, and too moist for the Mosaic and Sacramento LSMs. These results indicate that in most cases, the 1-year spin-up time used in the Retrospective NLDAS simulations eliminated spin-up problems from the subsequent period that was used for analysis. *INDEX TERMS:* 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation; 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 1866 Hydrology: Soil moisture; 1829 Hydrology: Groundwater hydrology; *KEYWORDS:* LDAS, LSM, spin-up

Citation: Cosgrove, B. A., et al., Land surface model spin-up behavior in the North American Land Data Assimilation System (NLDAS), *J. Geophys. Res.*, *108*(D22), 8845, doi:10.1029/2002JD003316, 2003.

1. Introduction

[2] Land surface processes play an important role in the Earth system, governing exchanges of heat, moisture and momentum between the surface and atmosphere. Soil moisture, albedo, surface temperature, snow pack and runoff anomalies at various spatial and temporal scales greatly impact agriculture, large-scale water resource water management, and global weather patterns [*Shukla and Mintz*, 1982; *Dirmeyer and Shukla*, 1993; *Hall*, 1988]. Land surface models (LSMs) are valuable tools in the exploration of these impacts, and form the basis of the North American Land Data Assimilation System (NLDAS) project (K. E.

[1]Science Applications International Corporation, Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

[2]Environmental Modeling Center, National Centers for Environmental Prediction, Camp Springs, Maryland, USA.

[3]Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

[4]Department of Civil and Environmental Engineering, Princeton University, Princeton, New Jersey, USA.

0148-0227/03/2002JD003316$09.00

[5]Office of Hydrologic Development, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA.

[6]Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey, USA.

[7]Climate Prediction Center, National Centers for Environmental Prediction, Camp Springs, Maryland, USA.

[8]Department of Meteorology, University of Maryland, College Park, Maryland, USA.

[9]Office of Research and Applications, National Environmental Satellite Data and Information Service, National Oceanic and Atmospheric Administration, Camp Springs, Maryland, USA.

Mitchell et al., The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system, submitted to *Journal of Geophysical Research,* 2003, hereinafter referred to as Mitchell et al., submitted manuscript, 2003). NLDAS project goals include the accurate offline initialization of NWP models with NLDAS land surface fields, and the intercomparison and improvement of the Mosaic [*Koster and Suarez*, 1992, 1996], Noah [*Mitchell et al.*, 2000], VIC [*Liang et al.*, 1996] and Sacramento [*Burnash et al.*, 1973] LSMs. Since realistic land surface states are vital to reach these goals, model spin-up processes must be understood and properly accounted for.

6. Concluding Remarks

[41] The land surface is an active part of the Earth system, influencing the weather through fluxes of moisture and energy, and affecting society through changes in vegetation, soil moisture and water resources. Land surface models like those in the NLDAS project are important tools in the effort to understand such interactions, and to predict how this system may change in the future. Unfortunately, results from LSMs can be easily tainted by spin-up-induced biases, and until the model states come into equilibrium with the supplied meteorological forcing, model output will not be realistic. In order to gain further insight into the spin-up characteristics of land surface models, and to determine how model spin-up processes might impact the three year NLDAS Retrospective simulation, two separate analyses were conducted. Serving as a broadening of previous, single-vegetation, single-soil type experiments, the first analysis concentrated on a series of three LSM experiments conducted with the Mosaic model. These experiments were conducted over six large spatial windows encompassing a variety of soil, vegetation and climate types. In order to establish typical spin-up times as well as maximum spin-up values, these runs were initialized with a) Zero soil moisture (Dry run), b) Saturated soil moisture (Wet run), and c) NCEP/DOE R-2 soil moisture conditions (Control run) which were also used to initialize the NLDAS Retrospective simulations. The second analyses focused on the NLDAS Retrospective simulation, drawing on information gleaned from time series and anomaly plots as well as data from the 11 year runs to explore the spin-up behavior of the Noah, VIC, Sacramento and Mosaic models over the Retrospective time period.

[42] Results from the two analyses described above indicate that initialization of Mosaic with NCEP/DOE R-2 soil moisture is far more desirable than either a saturated or dry initialization. Overly moist though it was, the Control run reached practical equilibrium 1 to 2 years more quickly than the Wet run, and 3 to 4 years more quickly than the Dry run in which spin-up was slowed by the dependence on precipitation events. Over the region of study as a whole, practical drift generally ended within 1 year, and fine scale equilibrium was achieved after 5.5 years. E-folding times generally ranged from 0.25 years to 0.75 years, often exceeding the observation-based values of *Entin et al.* [2000], and were longest in arid regions and regions in which negative soil moisture anomalies were present. Spin-up was not temporally or spatially uniform, varying greatly by region and often clustered by season. In fact, differences within regions were often higher than those seen between simulations. PC times were generally lowest for deep soil temperature and for the SE region. They were generally highest for total column soil moisture and for the SW region which often did not reach fine scale equilibrium in the 11 year simulation. Significantly, evaporation often reached practical equilibrium more slowly than root zone and total soil moisture, but reached fine scale equilibrium more quickly.

[43] PC equilibrium times are well-correlated most commonly with precipitation and temperature values, but soil and vegetation parameters also appear to impact the spin-up process. In general, correlation values associated with 0.01% PC times are larger those associated with 1% PC times. However, even when examining these stronger correlations, it was found that the spatial heterogeneity of single climate and land surface parameters does not often serve as the dominant influence on spin-up times, and that these times are most often affected by the complex interaction of the spatial distribution of the entire range of LSM parameters, making it extremely difficult to isolate a single dominant influence.

[44] Building on this information, analysis of the NLDAS Retrospective simulation provided insight into the spin-up behavior of the four participating models. Assuming a level of similarity with the Mosaic model, none of the LSMs in the Retrospective run reach an overall state of fine scale equilibrium within the 1996–1999 time period. However, inspection of Retrospective time series and anomaly plots, along with information from the Control run described above point toward the following result—that with a few notable exceptions, the Sacramento, VIC, Noah and Mosaic models each reach rough equilibrium within 1 to 2 years. Given NCEP/DOE R-2 conditions as a starting point, Sacramento appears to spin up most quickly, and is followed by the Mosaic, VIC and Noah LSMs. In general, root zone soil moisture spins up more quickly than does total column soil moisture, an occurrence especially apparent in the Noah model. Trends in deep soil temperature and evaporation were smaller and any spin-up behavior that was identified disappeared within the first 6 months. With this in mind, it appears that the NLDAS project's decision to set aside the first year as a spin-up year was a valid one, and that in a few cases, additional years may need to be considered spin-up as well.

[45] Overall, the results described above underline the fact that LSM spin-up can take a significant amount of time, and can vary greatly between models even when such models use identical soil moisture initialization data. This spin-up time varies for each land surface state, and is affected differently by soil, vegetation, and climate variables depending on the geographic region of study. Using some measures of spin-up, it may take greater than 10 years for a model to reach fine scale equilibrium. However, many experiments have been conducted utilizing results from LSMs which were allowed to spin-up for 1 month or less. This study has shown that this is generally not an adequate amount of time, and care must be taken to allow sufficient spin-up time so that model output is not severely biased or unrealistic.