7.4 USING CEOP EOP-1 and EOP-3 OBSERVATIONS TO ASSESS LAND SURFACE PROCESSES SIMULATED IN THE NCEP GLOBAL MODEL

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1. INTRODUCTION

The Coordinated Enhanced Observing Period (CEOP) is a coordinated international activity aimed to establish an integrated global observation system. It contains satellite data, model and assimilation output, and in situ observations, with a focus on hydrometeorological processes in the atmosphere and land surface.

In the study here, in situ observations from two Enhanced Observing Periods (EOP-1 and EOP-3) of CEOP are used to evaluate land surface processes simulated in the NCEP Global Forecast System (GFS), and for comparison, in NCEP's North American Land Data Assimilation System (NLDAS). This study not only evaluates the impact of the Noah Land Surface Model (LSM) upgrade on GFS forecasts, but also assesses the impact of land state spin-up on GFS forecasts. In addition, the land surface processes simulated by Noah LSM in coupled and uncoupled mode are compared. This study is a broad follow-up to an earlier study (Lu and Mitchell, 2004) in which GFS forecasts are assessed at three CEOP reference sites during EOP-1.

The CEOP reference site observations are described in Section 2. The GFS model and experiment set up are discussed in Section 3. The comparison results are presented in Section 4, followed by the conclusions.

2. CEOP REFERENCE SITES

CEOP is an element of the World Climate Research Program (WCRP), initiated by the Global Energy and Water Cycle Experiment (GEWEX) Hydrometeorology Panel (GHP). Under WCRP coordination, CEOP is creating an integrated and centralized global observation database, focused on measuring, modeling, and understanding of the water and energy cycles within the climate system. It contains satellite data, model and assimilation output, and in situ observations at reference sites.

In situ observations of CEOP are organized around 40+ CEOP "reference sites" distributed around the globe. Data sets sampled at these references sites includes:

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(1) hourly near-surface meteorology, (2) hourly surface energy fluxes including radiation, and (3) subsurface soil moisture and soil temperature. Under the GEWEX American Prediction Project (GAPP) sponsorship, the site managers and CEOP have collaborated with the National Center for Atmospheric Research (NCAR) to establish a centralized database for reference-site data in a common format. This greatly facilitates use of the CEOP data by the scientific community.

In this study, observations at CEOP reference sites during CEOP EOP-1 (covers the time period from 1 July, 2001 to 30 Sept, 2001) and EOP-3 (spans from 1 Oct, 2002 to 30 Sept, 2003) are used to evaluate summer-time land surface processes simulated in the NCEP GFS. For references sites located in continental US, the comparisons are extended to include the results from NLDAS.

3. MODEL AND EXPERIMENT DESIGN

The model used for this study is the global spectral model of the NCEP GFS, configured with T62 horizontal resolution (~ 200km) and 28 levels in the vertical. It is slightly modified from the operational medium-range weather forecasting model at NCEP. Key model physical parameterizations include the simplified Arakawa Schubert convection, longwave and short-wave radiation, explicit cloud microphysics, non-local vertical diffusion, and gravity wave drag.

The operational version of GFS utilizes the Oregon State University (OSU) LSM (Pan and Mahrt, 1987). As part of NCEP efforts to unify the land-model component in all NCEP global and regional models and their associated data assimilation systems, the NCEP Noah LSM (Ek et al., 2003) has been implemented into the test bed of the NCEP GFS and NCEP Global Data Assimilation System (GDAS). The Noah LSM, an advanced descendant of the OSU LSM, was developed at NCEP and executed in NCEP's recently completed 25-year Regional Reanalysis (Mitchell et al., 2004a). In addition, the Noah LSM is one of the four LSMs executing in parallel in uncoupled mode over the continental U.S. domain (NLDAS, Mitchell et al., 2004b). Key advances in the Noah vs. OSU LSM include soil layers changed from 2 (10 and 190 cm thick) to 4 (10, 30, 60, 100 cm thick), addition of frozen soil physics and patchy snowpack treatments, and improvements in bare soil evaporation, snow albedo and ground heat flux under snowpack and non-sparse vegetation.

Two sets of retrospective GDAS (low resolution, T62L28, with respect to the operational GDAS) starting from 1 Aug 2002 are in progress; one is based on the operational version of GFS employing the OSU LSM (CNTR/OSU), and the other an experimental version of GFS coupled with the newer Noah LSM (TEST/Noah). The efforts for conducting retrospective GDAS aim to evaluate the impact of LSM upgrade on GFS forecasts as well as to provide continuously cycled Noah LSM land states in GDAS.

The experiment set up is as follow:

(a) *Comparative study for EOP-1.* Daily 5-day forecasts with hourly output are executed and day-1 forecast results are presented. Initial conditions are taken from the 00Z analysis of the NCEP operational GDAS. Note the NCEP operational GDAS is executed using the OSU LSM, which yields non-optimal initial land states for the Noah LSM in the TEST/Noah runs (implications discussed below).

(b) *Comparative study for EOP-3.* Daily 5-day forecasts with 3-hour output interval are executed. Again, results from day-1 forecasts are presented. Initial conditions for CNTR/OSU runs are taken from OSU cycled T62L28 GDAS, while initial conditions for TEST/Noah runs are taken from Noah cycled T62L28 GDAS (reflecting 11 month Noah cycling). An additional TEST/Noah runs initialized from OSU cycled T62L28 GDAS are also conducted.

The periods of study are boreal summer (Jul to Aug) for 2001 and 2003, corresponding to EOP-1 and EOP-3, respectively. Comparison between GFS simulations and in situ observations are conducted over the reference sites where both surface and sub-surface fields were measured. For reference sites located in the continental U.S. (CONUS), the comparisons are extended to include the results from NLDAS.

In summary, this study evaluates the impact of LSM upgrade on GFS forecasts (by comparing TEST/Noah and CNTR/OSU results) as well as assesses the impact of land state spin-up on GFS forecasts (by comparing TEST/Noah runs initialized from Noah cycled GDAS versus those initialized from OSU cycled GDAS). In addition, the land surface processes simulated by Noah LSM in coupled and uncoupled mode are compared (e.g., TEST/Noah versus NLDAS).

4. RESULTS

Figure 1 shows the monthly mean diurnal cycle of surface solar insolation, latent heat flux, sensible heat flux, and ground heat flux at the GAPP Southern Great Plains (SGP) reference site during 1-31 July 2001 from observations, NLDAS, CNTR/OSU runs, and TEST/Noah runs. The TEST/Noah runs yield notably higher daytime latent heat flux than the CNTR/OSU runs, with both having higher latent heat flux than the observations. Yet the daytime sensible heat fluxes of both GFS runs are close to each other and to the observations. Thus net radiation and ground heat flux differences must contribute notably to the latent heat flux differences.

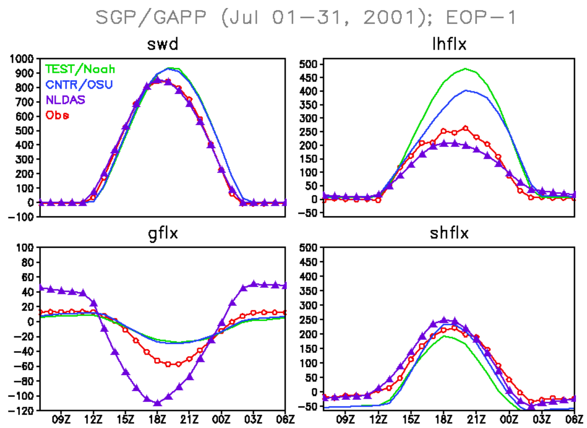

Figure 1. For in situ observations (red with circles), NLDAS (purple with triangles), and GFS runs of CNTRL/OSU (blue line) and TEST/Noah (green line), the mean diurnal cycle for 1-31 July 2001 at the GAPP SGP reference site for surface solar insolation in W/m^2 (top-left), latent heat flux in W/m^2 (top right), ground heat flux in W/m^2 (bottom-left), and sensible heat flux in W/m^2 (bottom-right).

A high bias in the GFS surface solar insolation compared to the in situ observations is evident (top-left in Figure 1). Such biases in solar insolation are also found at other reference sites (not shown here). The Noah LSM assessment in the global model is affected by surface forcing errors in the parent atmospheric model. Additionally, the Noah LSM assessment for EOP-1 is hindered by the aforementioned lack of Noah-based, continuously-cycled land states in the operational GDAS. NLDAS surface forcing fields include observation-based precipitation (from gauges and radar) and satellite-based surface solar insolation (Pinker et al., 2003), both of which manifest substantially less bias in NLDAS than in the GFS. Using the same Noah LSM as in the coupled GFS TEST/Noah runs, the NLDAS at the SGP site yields simulations of both latent heat flux and sensible heat flux (right panels in Figure 1) that agree well with the CEOP in situ observations during July of EOP-1. The improvement in the latent heat flux of the Noah LSM in the NLDAS vs. the GFS TEST/Noah runs is especially dramatic. Hence the NLDAS offers an appealing and complementary uncoupled assessment of the Noah LSM via surface forcing with substantially reduced bias and properly spun-up land states.

Figure 2 shows the monthly mean diurnal cycle of near surface temperature at The Baltic Sea Experiment (BALTEX) Lindenberg and the GAPP SGP reference sites during 1-31 July 2001 from observations, CNTR/OSU runs, and TEST/Noah runs. At both sites, the GFS employing the Noah LSM leads to a modestly lower daytime air temperature than that using the OSU LSM. The cold biases shown in GFS runs are generally consistent with the bias in energy partition (excess latent heat flux) shown in Figure 1. The corresponding modeled sensible heat fluxes, however, are somehow higher than anticipated, considering the biases mentioned above. This hints the possibility that surface exchange coefficients used in GFS are too large. Sensitivity study with exchange coefficients reduced by half is conducted and the results over the Lindenberg and SGP sites are shown in Figure 3. As surface exchange coefficients are reduced, near surface temperature increases by 1-2 deg, leading to a better agreement with observations. Further studies are needed to evaluate the formulation of surface exchange coefficients used in the GFS and in situ observations such as the CEOP reference site observations could greatly assist the evaluation efforts.

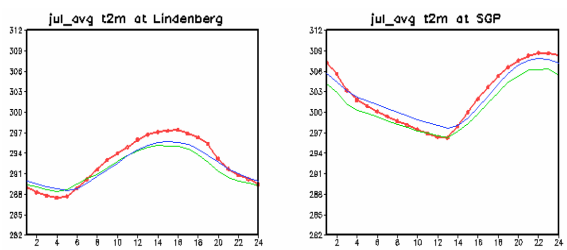

Figure 2. The mean diurnal cycle of near surface temperature (in K) for 1-31 July 2001 from in situ observations (red with circles) and GFS runs of CNTR/OSU (blue line) and TEST/Noah (green line) at the BALTEX Lindenberg (left panel) and the GAPP SGP (right panel) reference sites.

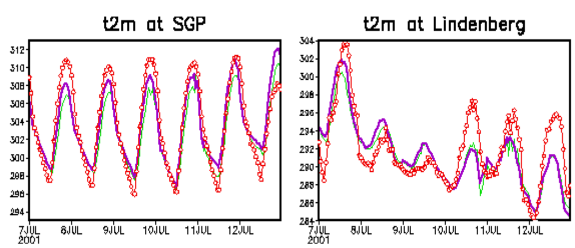

Figure 3. Time series of near surface temperature (in K) for 7-12 July 2001 from in situ observations (red with circles), TEST/Noah runs (green line), and TEST/Noah runs with reducing exchange coefficients (purple line) at the GAPP SGP (left panel) and the BALTEX Lindenberg (right panel) reference sites.

Prior to presenting the comparison results for EOP-3, features of the two retrospective T62L28 GDAS (one using CNTR/OSU, the other using TEST/Noah) are examined. Figure 4 shows time series of column soil moisture (in fraction) and precipitation (in mm/day) averaged over four CONUS sub-regions (Northwest, Northeast, Southwest, and Southeast) for the period of 2002 August to 2004 January. The evolution of soil moisture in Noah cycled GDAS differs greatly from that in OSU cycled GDAS, except for the Southwest CONUS. The distinctive differences in land states seem impose fairly weak impact on the overall rainfall pattern (which is comparable between the two GDAS runs). The weak response of precipitation to soil moisture states is likely due to the inherent characteristics of the land surface scheme and how the moisture convection is formulated in the GFS.

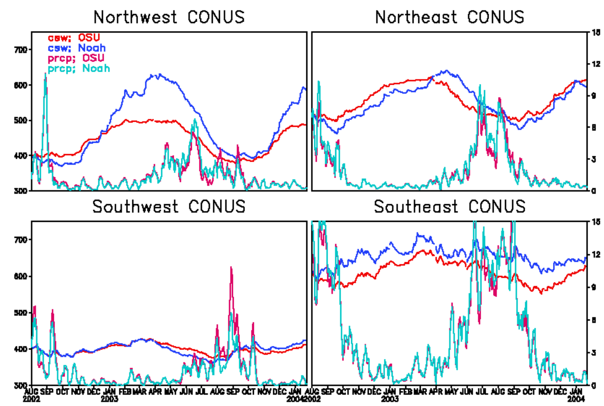

Figure 4. Time series of column soil moisture (in fraction) and precipitation (in mm/day) for four CONUS sub-regions (top left for Northwest, top right for Northeast, bottom left for Southwest, bottom right for Southeast) for the period of 2002 August to 2004 January. Results from OSU-cycled GDAS are displayed in red (soil moisture) and magenta (precipitation) and those for Noah are displayed in blue (soil moisture) and cyan (precipitation).

Figure 5 shows the monthly mean diurnal cycle of surface solar insolation, latent heat flux, sensible heat flux, and ground heat flux at the air SURFace eXchange sites (SUFRX) Fort Peck reference site during 1-31 August 2003 from observations, NLDAS, and three GFS runs (CNTR/OSU runs initialized from OSU cycled GDAS, TEST/Noah runs initialized from OSU cycled GDAS, and TEST/Noah runs initialized from Noah cycled GDAS). Figure 6 shows the corresponding monthly mean diurnal cycle of near surface temperature.

Mitchell et al. (2004b) shows that the spin-up of soil moisture takes 1-2 years, dependent on LSM, in the NLDAS study. The initial conditions taken from Noah cycled GDAS reflect 11 month cycling of Noah LSM, and thus the initial land states used here are not yet optimal for testing Noah LSM. Nevertheless, the impact of land state spin-up on the near-surface fields is evident. High bias in latent heat fluxes and cold bias in near surface temperature are found when GFS is initialized from incompatible land states (such as TEST/Noah runs for EOP-1 and TEST/Noah runs initialized from OSU cycled GDAS for EOP-3). The results indicate that initial land states compatible with the experimental LSM are essential for a fair evaluation of LSM.

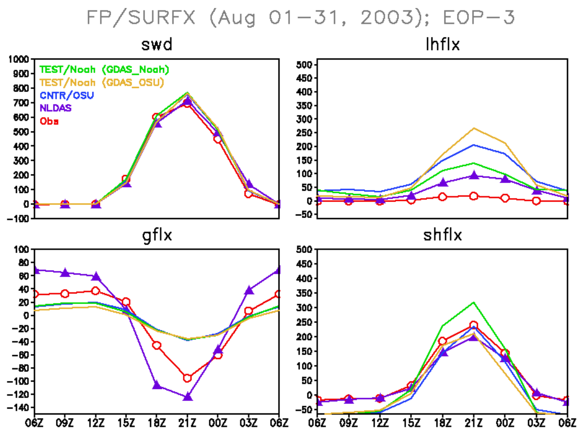

Figure 5. For in situ observations (red with circles), NLDAS (purple with triangles), GFS CNTR/OSU runs (blue line), GFS TEST/Noah initialized from OSU cycled GDAS (brown line), and GFS TEST/Noah initialized from Noah cycled GDAS (green line), the mean diurnal cycle for 1-31 August 2003 at the SURFX Fort Peck reference site for surface solar insolation in W/m^2 (top-left), latent heat flux in W/m^2 (top-light), ground heat flux in W/m^2 (bottom-left), and sensible heat flux in W/m^2 (bottom-right).

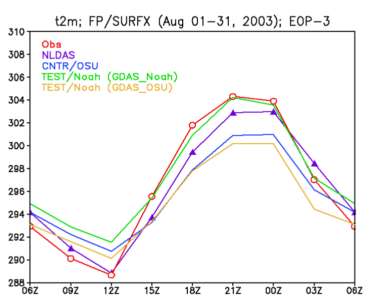

Figure 6. The mean diurnal cycle of near surface temperature (in K) for 1-31 August 2003 from in situ observations (red with circles), NLDAS (purple with triangle), GFS CNTR/OSU runs (blue line), GFS TEST/Noah initialized from OSU cycled GDAS (brown line), and GFS TEST/Noah initialized from Noah cycled GDAS (green line) at the SURFX Fort Peck reference site.

5. CONCLUSIONS

This study illustrates the utility of the CEOP reference site observations for assessing land-surface processing in the NCEP global model. Caveats in this study to the Noah LSM assessment in the coupled model were highlighted: (a) surface forcing biases in the parent atmospheric model and (b) lack of Noah-LSM compatible initial land states. The simultaneous assessment of the Noah LSM in the uncoupled NLDAS is a useful companion analysis that largely avoids caveats (a) and (b) above.

Conclusive LSM assessment for the coupled model awaits follow-on study including the following:

§ Cycle the coupled GDAS using the Noah LSM for at least 1-2 year to provide initial land states compatible with the Noah LSM,

§ Extend the number of reference sites examined and add the periods of EOP-3 through EOP-4.

§ Quantify other surface forcing errors in the parent model (e.g., precipitation).

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