J5.4 RECENT RESULTS FROM THE 12KM NORTH AMERICAN LAND DATA ASSIMILATION SYSTEM (NLDASE) PROJECT

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1. INTRODUCTION

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, 1997; Hall 1988). Unfortunately, errors in land surface forcing, model physics and parameterizations can accumulate in the integrated land surface states of fully coupled numerical weather prediction (NWP) land surface models (LSMs). Because of this, accurate initialization of land surface conditions in such fully-coupled models is vital for short term to seasonal meteorological and hydrological prediction.

Land Data Assimilation Systems (LDAS), consisting of uncoupled LSMs forced by observations and unaffected by the biases mentioned above can be valuable sources of accurate initial land surface conditions for NWP models. Accuracy can be further improved with the assimilation of quantities such as snow cover, soil moisture, surface temperature, and snow depth, which acts to constrain unrealistic storages arising from errors in LSM physics or parameterizations. NWP model forecast accuracy should benefit from the use of such initial conditions, and this concept forms the central hypothesis of the 12km North American Land Data Assimilation System (NLDASE) project.

Building on the concepts discussed above, and on the success of the collaborative 1/8th degree North American Land Data Assimilation System (NLDAS, Mitchell et al., 2004), the NLDASE project centers on the initialization of the land surface fields of a workstation version of NCEP's mesoscale 12km coupled Eta model (Rogers et al., 1996). Using the same version of the Noah LSM as is coupled to the Eta model, forced by observations, and assimilating MODIS snow cover, this system supplies the workstation Eta model with uncoupled initial land surface conditions on its native Arakawa E grid (Figures 1 and 2).

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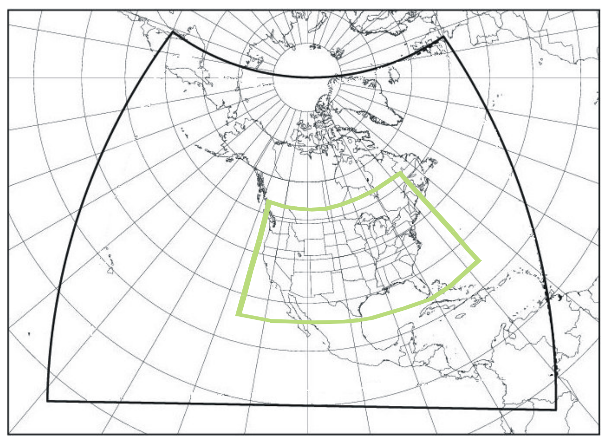

Figure 1. NLDASE / Eta (black) and NLDAS (green) domains.

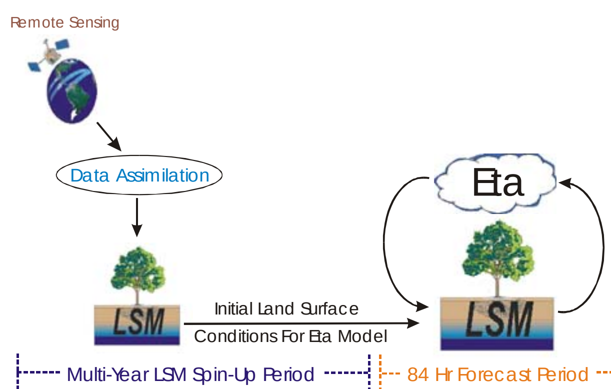

Figure 2. Overview of NLDASE system.

2. BENCHMARK SIMULATIONS

The NLDASE project recently undertook an effort to benchmark the impact on Eta model forecasts of using NLDASE land surface states as Eta model initial land surface conditions. These land surface states reflected not only the uncoupled modeling approach of the NLDASE system, but also the assimilation of MODIS snow cover data. In order to accomplish this, three main things were needed: 1) A series of uncoupled NLDASE simulations to provide initial land surface conditions, 2) A series of benchmark experiments utilizing a workstation version of the coupled Eta model, and 3) A robust verification system.

To provide the necessary base of initial land surface conditions for the Eta model, NCEP's Noah LSM was executed within NASA's Land Information System (LIS) modeling framework from October 2000 through August 2003. Three separate simulations were conducted, each initialized on October 1, 2000 with Eta Data Assimilation System (EDAS) land surface states. In the first of these simulations (LIS1), the Noah LSM was executed without MODIS snow cover assimilation. Forcing data consisted of a backbone of EDAS data, on which observations of downward solar radiation and precipitation were overlaid. In particular, UMD GOES radiation (Pinker et al., 2003) was preferentially used over EDAS data, except in snow covered areas in which the Global LDAS (GLDAS) AGRMET-based radiation product (Rodell et al., 2004) was instead used. Similarly, the NLDAS merged gauge-radar precipitation product (Cosgrove et al., 2003) was used over the continental United States (CONUS), while the GLDAS CMAP-based observed precipitation product was used over all other areas (Rodell et al., 2004). In cases where CMAP was unavailable, the CMORPH product was used (Joyce et al. 2004). This overlay approach closely follows the general procedures adopted in the NLDAS project (Cosgrove et al., 2003).

The second and third retrospective simulations (LIS2 and LIS3, respectively) are identical to LIS1 with the exception that each run includes the assimilation of daily MODIS snow cover. Snow cover was continually updated throughout both of these simulations according to the rule based approach of Rodell and Houser (2004). At each grid point at 10:30 A.M. local time, the MODIS snow cover was compared to the modeled snow water equivalent (SWE) output from the Noah LSM. If the Noah LSM had zero snow depth, but MODIS snow cover was greater than 40%, then a small layer of snow was added in the LSM. In the retrospective simulations, 5mm (LIS2) and 10mm (LIS3) of SWE were chosen as the amount of snow to add. If the Noah LSM had non-zero snow depth but the MODIS snow cover for that particular grid point was less than 10%, then the Noah LSM snow water equivalent was set to zero. If the Noah and MODIS values were in agreement or the MODIS snow cover was between 10% and 40%, the Noah snow water equivalent value was left unchanged. The differences in snow cover between MODIS and non-MODIS Noah LSM simulations are illustrated in Figure 3.

The NCEP operational set of land surface parameters and version 2.3.1 of the Noah LSM were used for all three LIS simulations. This is the same version of the LSM that was used operationally by NCEP during the 2003 benchmarking period (described below) and thus facilitates direct transfer of land surface states from the uncoupled Noah LSM simulations to the Eta model (which also makes use of the Noah LSM).

Given computing limitations, it was impractical to execute the workstation Eta model over the entire three year length of each LIS simulation. As such a 10 day benchmark experiment period was chosen to analyze the impact of NLDASE initial conditions on Eta model forecasts. Extending from May 1^{st} to May 10^{th} 2003, this collection of benchmark experiments consisted of a total of 80 separate 84-hour Eta model simulations. Specifically, 84-hour Eta model simulations were executed each day at 00Z and 12Z over the 10 day time period.

Four sets of Eta model runs were conducted in this fashion, each using different types of restart files that included: 1) NCEP operational restart files to establish a baseline control run, 2) NLDASE LIS1 restart files to test

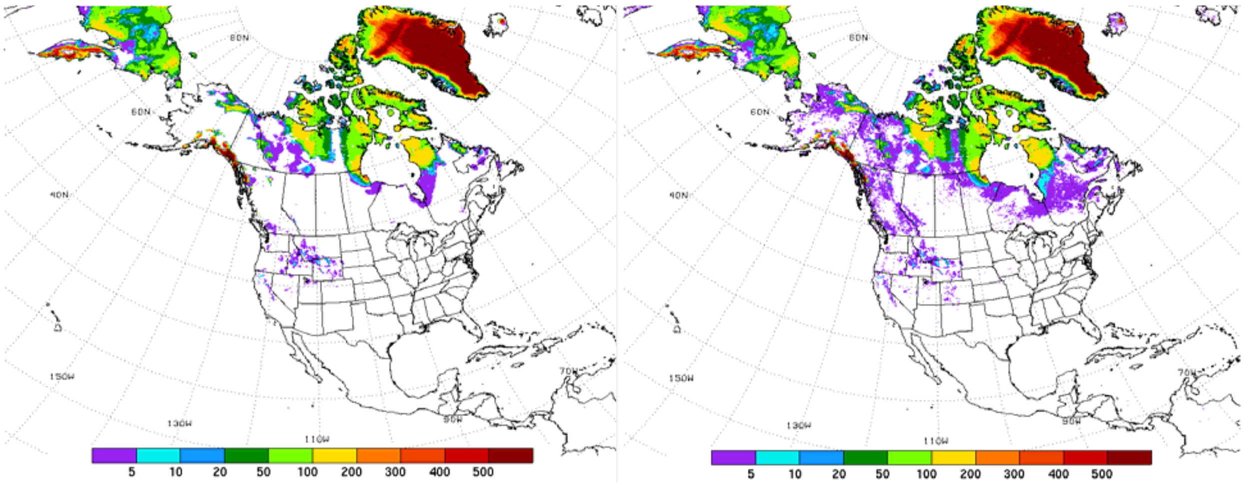

Figure 3. Noah LSM snow water equivalent output (mm) from the NLDASE retrospective simulations on 00 Z May 1, 2003: Left – Simulation without MODIS snow cover assimilation, Right – Simulation with MODIS snow cover assimilation (5mm update amount).

the basic effects of uncoupled NLDASE initial conditions, 3) NLDASE LIS2 restart files to test the effect of MODIS snow assimilation using a 5mm SWE value, and 4) NLDASE LIS3 restart files to test the effect of MODIS snow assimilation using a 10mm SWE value. The timing of the test case was chosen to balance the need for snow-covered areas to test the impact of MODIS snow assimilation, with the need for a time period with the type of strong land-atmosphere interactions that characterize the warm season. Care was taken to choose a challenging forecasting time period, featuring a large-scale severe weather outbreak. In this type of weather regime, even modest increases in forecast skill may have far reaching impacts in areas of public safety and resource management.

All 80 Eta model forecasts executed during the benchmark period were then compared with observations and with each other to gauge forecast improvement/degradation from the use of NLDASE uncoupled land surface states. NCEP's Forecast Verification System (FVS) was chosen as the centerpiece of the regional and national benchmarking effort, while a separate suite of site-specific benchmarking metrics was utilized to provide complementary local analyses.

Following NCEP operational practices, bias and root mean squared error (RMSE) statistics were computed for Eta model surface meteorological output (2m relative humidity, 10m wind speed, 2m temperature) and upper air output (850mb temperature, 300mb temperature, 700mb relative humidity, 500mb height, and 250mb wind speed). Similarly, a subset of FVS statistics consisting of the false alarm ratio (FAR), the equitable threat score (ETS), the probability of detection (POD), and the bias was selected for application to precipitation forecasts. Surface and precipitation statistics were computed for each of the 19 FVS validation regions depicted in Figure 4, while upper air statistics were computed as CONUS-wide averages.

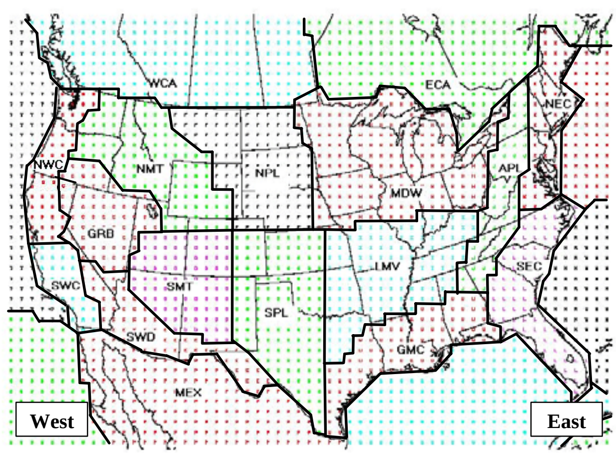

Figure 4. NCEP Forecast Verification System regions used in this experiment. CONUS regions to the east of the NPL and SPL boundaries are combined into an overall "East region" while CONUS regions west of MDW, LMV, and GMC are combined into an overall "West region".

3. RESULTS

Alterations in the Eta model's initial land surface states affected not only Eta model forecasts of surface conditions, but also upper air conditions and precipitation. These effects are illustrated in the sections which follow, which are divided into three main parts for clarity: 1) surface verification (2m temperature, 2m relative humidity, 10m wind speed), 2) upper air verification (850mb temperature, 300mb temperature, 700mb relative humidity, 500mb height, and 250mb wind speed), and 3) precipitation verification.

Although raw numerical verification scores were computed for each of these fields, the following discussion focuses on the percent improvement (versus the control run) of each of these scores as opposed to the raw scores themselves—a more intuitive measure of the effect of the initialization strategy being examined.

3.1. *Surface Verification*

The percent improvement values of Table 1 summarize the performance of the Eta model over all of the 84 hour forecast periods covering May 1st through May 14th, 2003. More specifically, raw FVS verification values from each three hour forecast period from 0 hours out to 84 hours were averaged together to form an overall verification score. This averaging process was necessitated by the large amount of verification information output by the FVS.

Although impact varied by region, Table 1 shows that Eta model forecasts over the East and West regions of the CONUS overwhelmingly benefited from NLDASE initial conditions, with very large improvements in bias, and sizeable improvements in RMSE. An example of RMSE improvement in the relative humidity field is given in Figure 5. Several notable conclusions can be drawn from this table and the additional extensive analysis conducted as part of the benchmark process:

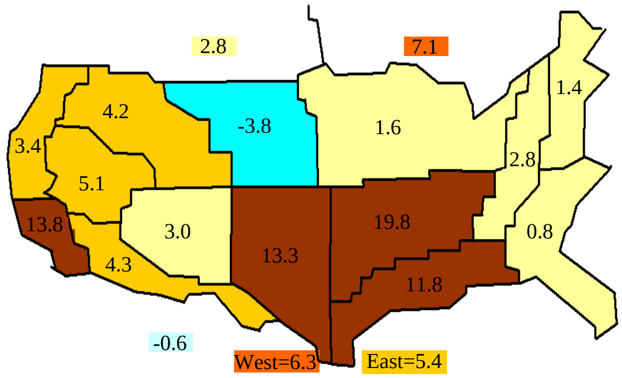

Figure 5. Percent improvement in 2m relative humidity RMSE versus control run. Results are from LIS3 12Z cycle. Warm colors indicate improvements, while cool colors indicate degradations.

- The use of NLDASE conditions to initialize the Eta model led to greatly improved forecasts of humidity and temperature overall.
- The largest improvements were seen in relative humidity forecasts, while the smallest improvements (and some declines in accuracy) were seen in the forecasts of wind speed.

Percent Improvement Over Eta Model Control Simulation

	T2ML1	T2ML2	T2ML3	RH2ML1	RH2ML2	RH2ML3	V10ML1	V10ML2	V10ML3
00Z East Bias	13.72	17.54	21.05	56.59	68.30	78.21	4.66	4.48	4.31
00Z West Bias	10.94	13.42	16.12	12.91	13.64	14.90	-7.22	-7.22	-7.69
12Z East Bias	-0.31	2.72	7.22	42.64	51.95	60.34	4.16	3.85	3.38
12Z West Bias	6.63	8.63	12.11	14.42	15.25	17.03	-6.85	-6.56	-6.13
00Z East RMSE	2.31	2.31	2.44	4.49	4.45	4.51	1.03	0.95	0.98
00Z West RMSE	1.66	2.04	2.36	4.72	5.01	5.45	0.66	0.63	0.73
12Z East RMSE	2.42	2.67	3.09	5.28	5.36	5.38	0.86	0.84	0.57
12Z West RMSE	1.60	2.04	2.26	5.61	5.92	6.34	0.65	0.67	0.02

Table 1. Percent improvement in bias and RMSE of LIS1 (L1), LIS2 (L2), and LIS3(L3) runs versus control simulation for 2m temperature (T2M), 2m relative humidity (RH2M), and 10m wind speed (V10M). Warm colors indicate improvements, while cool colors indicate degradations.

- Use of initial conditions based on assimilated MODIS snow cover data generally improved forecasts.
- In general, the use of the 10mm SWE layer in the MODIS assimilation scheme led to better Eta forecasts than did the use of the 5mm SWE layer.
- The addition of MODIS data into the initial conditions had a generally continental-scale effect on bias scores, influencing even snow-free regions. However, RMSE scores, in general, were only impacted on smaller regional scales.
- The impact on Eta model forecasts of initialization with NLDASE conditions varied with the diurnal cycle, but not in a clear-cut, constant fashion. Improvements in 00Z simulations were not consistently more or less than those seen in the 12Z forecasts.

3.2. *Upper Air Verification*

As with the surface verification analysis above, the percent improvement values presented in this section summarize the performance of the Eta model over all of the 84 hour forecast periods covering May 1st through May 14th, 2003. Due to the scarcity of upper air observations, verification was performed by averaging all CONUS data together, and statistics were not broken down by region. This procedure follows NCEP's operational verification procedure.

Percent Improvement Over Eta Model Control Simulation

	00Z Bias	12Z Bias	00Z RMSE	12Z RMSE
T850L1	-216.47	-146.50	1.63	1.42
T850L2	-150.47	-118.17	2.23	1.97
T850L3	-90.34	-84.01	2.46	1.66
T300L1	2.62	-0.11	0.71	0.55
T300L2	2.59	0.12	0.61	0.50
T300L3	2.35	-0.69	0.44	-0.91
RH700L1	-37.82	-35.22	-0.34	0.90
RH700L2	-35.34	-32.88	-0.38	0.59
RH700L3	-36.46	-41.56	-0.28	0.41
W250L1	-1.86	-5.30	-0.09	-0.52
W250L2	-1.12	-4.90	-0.06	-0.43
W250L3	-0.51	-3.23	-0.10	-1.95
Z500L1	-1.38	15.05	0.61	0.22
Z500L2	-6.65	9.42	1.12	0.09
Z500L3	-12.40	-8.08	-0.64	-2.75

Table 2. Percent improvement in bias and RMSE of LIS1 (L1), LIS2 (L2), and LIS3(L3) runs over control simulation for 850mb and 300mb temperature (T850, T300), 700mb relative humidity (RH700), 250mb wind speed (W250), and 500mb height (Z500). Warm colors indicate improvements, while cool colors indicate degradations.

As illustrated in Table 2, initialization of Eta land surface states with NLDASE conditions had mixed impacts on Eta model upper air forecasts of 500mb height, 850mb temperature, 300mb temperature, 700mb relative humidity, and 250mb wind speed. Impacts varied by variable and by forecast lead time (not shown), with short lead times generally benefiting from uncoupled initialization, and long lead times generally degrading from this type of initialization. Several significant conclusions arose from an analysis of the benchmark experiment results:

- The impacts on upper air forecasts of using NLDASE states to initialize the Eta model were more mixed than was the case with surface forecasts.
- 300mb temperature, shown in Figure 6 and Table 2, was the only upper air element examined which consistently benefited from uncoupled initialization
- RMSE improved more often in relation to the control run than does bias, although the changes in RMSE were very small.
- The worst impacts on bias were focused on the 850mb temperature and 700mb relative humidity fields, while the worst impacts on RMSE were manifested in the 250mb wind speed fields.
- Simulations utilizing MODIS snow information (LIS2, LIS3) performed better than the simulation lacking MODIS snow information (LIS1); however this benefit was often overshadowed by the large detrimental impact of the uncoupled initialization approach, and LIS1, LIS2, and LIS3 often underperformed the control simulation.
- Overall, the 5mm MODIS SWE depth option held little or no advantage over the 10mm SWE depth option—LIS2 performed best in 7 out of 20 cases, while LIS3 performed best in 6 out of 20 cases.
- Forecast results varied with the diurnal cycle; however no discernable pattern emerged from the analysis, with 00Z simulations outperforming 12Z simulations in some cases, but not others.

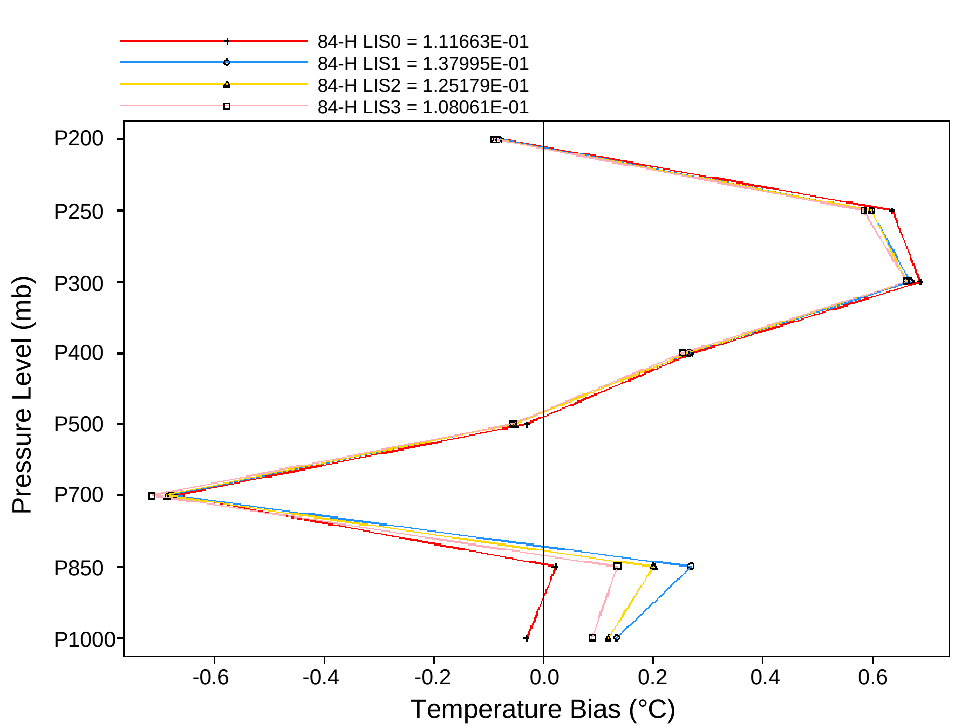

Figure 6. Temperature bias (°C) of 84 hour forecasts over CONUS for control (LIS0) and experimental (LIS1, LIS2, LIS3) Eta simulations. Average values for all pressure levels are listed to right of color key. Results are from 00Z cycle forecasts.

3.3. *Precipitation Verification*

Following NCEP's operational procedures, verification of Eta model precipitation forecasts was performed against the 1/8th degree CPC gauge precipitation product, valid each day over a 24 hour period extending from 12Z to 12Z. Due to the timing of this 24 hour period, only certain temporal subsets of Eta forecasts could be validated. In particular, raw verification values were computed for the 0-24 hour and 24-48 hour forecasts of each 12Z Eta forecast. These values were averaged together to form overall short lead 0-24 hour forecast scores, and medium lead 24-48 hour forecast scores. A similar procedure was followed to compute overall scores for the entire 0-84 hour forecast period. Unlike the short and medium lead forecast scores, this last score included precipitation forecasts from the 00Z runs as well as the 12Z runs.

The bias, POD, ETS, and FAR verification analyses performed highlighted the mixed impacts that NLDASE initial conditions had on Eta model precipitation forecasts. As summarized by Table 3, these impacts were generally minor in nature with the exception of

Percent Change Over Eta Model Control Simulation

	0-24HPL1	0-24HPL2	0-24HPL3	24-48HPL1	24-48HPL2	24-48HPL3	0-84HPL1	0-84HPL2	0-84HPL3
East Bias	-7.79	-8.23	-6.93	0.01	0.01	0.02	4.02	4.02	5.80
West Bias	27.36	24.53	24.53	-0.02	-0.01	0.01	-217.65	-123.53	-52.94
East ETS	0.40	0.40	0.54	-0.25	-0.12	0.00	0.12	0.12	0.00
West ETS	0.25	0.25	0.13	0.72	0.60	0.60	0.24	-1.77	-1.88
East POD	-0.18	0.00	0.00	-0.16	-0.16	0.32	0.16	0.16	0.16
West POD	1.05	1.05	0.90	2.38	1.96	1.96	0.68	0.68	0.82
East FAR	2.53	2.53	2.34	-0.81	-0.49	-0.33	0.17	0.17	0.00
West FAR	-11.91	-0.76	-0.95	0.16	-0.16	-0.31	-0.46	-6.49	-6.65

Table 3. Percent improvement in bias, equitable threat score (ETS), probability of detection (POD), and false alarm ratio (FAR) scores of LIS1 (L1), LIS2 (L2), and LIS3(L3) runs over control simulation for 0-24 hour, 24-48 hour, and 0-84 hour forecast periods. Warm colors indicate improvements, while cool colors indicate degradations.

changes to the bias score. Several significant conclusions can be drawn from this data:

- The impacts on precipitation forecasts of using NLDASE states to initialize the Eta model were more mixed and generally smaller than was the case with surface forecasts.
- Impacts in regions were often much larger than CONUS-wide impacts.
- ETS (considered a good overall measure of precipitation forecast skill) and POD values benefited most often from NLDASE initial conditions, although improvements were very small. These changes indicate slight improvements both in precipitation placement, and in the fraction of time the Eta model issued a non-zero precipitation forecast given the occurrence of an observed precipitation event.
- NLDASE initial conditions led to improvements in bias over the western CONUS in short term forecasts, but to a worsening in bias in long term forecasts. The reverse was true for the eastern CONUS.
- Although usually very minor, the influence of MODIS snow cover data was continental in nature, affecting even snow-free regions.
- Utilization of MODIS snow cover data in LIS2 and LIS3 led to small improvements in bias over the non-MODIS LIS1 simulations, but had only mixed impacts on POD, FAR, and ETS statistics (ETS shown in Figure 7).

3.4. *Site Specific Verification*

The FVS benchmark metrics discussed above are frequently used by NCEP to evaluate Eta model performance, and provide solid information as to where weaknesses are present in numerical forecast guidance. However, these benchmarks are regional in nature and cannot depict the true impact that the forecast improvement/degradation may have on a single location. In addition, such analyses did not include verification of surface pressure and short wave radiation. As such, site-specific analyses were conducted to complement the regional verification efforts. Although results from these site-specific

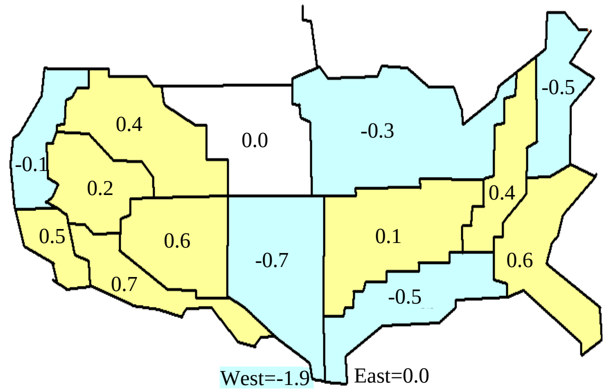

Figure 7. Percent improvement in daily precipitation equitable threat score for entire 84 hour forecast period of LIS3 simulations versus control run. Warm colors indicate improvements, while cool colors indicate degradations.

comparisons are detailed in Poster JP1.16 (Alonge and Cosgrove), a brief summary is given below:

- Site-specific analysis revealed larger impacts than did regional FVS analysis.
- In general, the largest differences in forecasts occurred between the NLDASE simulations as a whole and the control forecast.
- Mean sea level pressure was only slightly impacted by NLDASE initialization.
- Inopportune location of SURFRAD observation sites failed to capture the large differences in control run and LIS1, LIS2, and LIS3 radiation forecasts present across domain.
- In general, downwelling shortwave radiation was poorly forecast in all simulations during cloudy conditions, while upwelling and downwelling longwave radiation fluxes were well forecast in all simulations.
- In some cases, the timing of dry-lines and fronts was impacted (both positively and negatively) by the use of NLDASE land surface states.
- Short term precipitation forecasts were impacted less than long lead (> 48hr) forecasts.
- In general, precipitation distribution was impacted less than precipitation timing and intensity.
- NLDASE-based forecasts featured improved precipitation magnitude or timing at some locations, and degraded precipitation timing or magnitude at other locations.

4. SUMMARY AND CONCLUSIONS

At the center of this benchmarking exercise was the initialization of NCEP's Eta model with uncoupled NLDASE land surface states. To investigate whether or not the use of such initial conditions can improve Eta model forecasts, two 84-hour workstation Eta model simulations were executed each day over the May 1st through May 10th 2003 time period. Four sets of Eta model runs were conducted in this fashion, each using different types of restart files that included: 1) NCEP operational restart files to establish a baseline control run, 2) LIS1 restart files to test the basic effects of uncoupled NLDASE initial conditions, 3) LIS2 restart files to test the effect of MODIS snow assimilation using a 5mm SWE value, and 4) LIS3 restart files to test the effect of MODIS snow assimilation using a 10mm SWE value. Following NOAA operational practices, NCEP's FVS was used to verify the resulting forecasts against observations. Bias and RMSE values were computed for 2m temperature, 2m relative humidity, 10m wind speed, 850mb temperature, 300mb temperature, 700mb relative humidity, 500mb height, and 250mb wind speed. Bias, ETS, FAR, and POD statistics were computed for the purposes of precipitation verification.

Overall, initialization of Eta land surface states with NLDASE output had a mixed impact on forecasts. Surface fields including 2m temperature and 2m humidity greatly benefited from the uncoupled initialization process, while the upper air and precipitation fields featured a mix of desirable and undesirable impacts.

With these results in mind, the uncoupled initialization approach is promising, but needs further development before any transfer of methodology into the operational community is considered. Future NLDASE research will address four main issues: 1) The need to benchmark Eta simulations in a non-Spring month, 2) Initialization using NLDASE conditions derived from additional permutations of forcing and data assimilation procedures, 3) The need to benchmark Eta simulations over a longer study period of one month, and 4) The need to determine how best to apply this initialization system to the WRF model—the Eta model's successor.

5. ACKNOWLEDGEMENTS

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