OGP Abstract – Progress Report – April 2003

Title of Abstract

Improving the Initial Land-Surface State over Mountainous Areas through Assimilation of Observed Precipitation in a Coupled Model

Project Duration

3 years – FY01-FY03

Name of PI

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Introduction

The accuracy of cycled soil moisture and snow cover and liquid equivalent fields from coupled global and regional models has been limited by the accuracy of precipitation forecasts from those models, especially for the effects of warm-season precipitation on soil moisture. Out of this deficiency has grown development of off-line land-surface models forced by surface analyses of temperature, wind, and humidity, and most importantly, by analyzed precipitation fields derived from radar and gauge observations. This type of off-line model has been named Land Data Assimilation System, or LDAS. A NOAA/NASA collaborative effort, in particular, has made remarkable progress toward regional and global LDASs with different land-surface schemes. However, even the LDAS concept is limited by its total reliance on the observation-based quantitative precipitation estimates (QPE). These QPEs have known errors, especially for orographic precipitation in mountainous areas where radar estimates are problematic and gauge observations have limited spatial representativeness and are often located in valleys. Moreover, estimation of the phase of precipitation, liquid or snow, must be performed using relatively simple techniques with surface elevation and surface temperature fields. Errors in QPEs for LDASs from these sources are especially problematic for estimation of cold-season precipitation and snow cover.

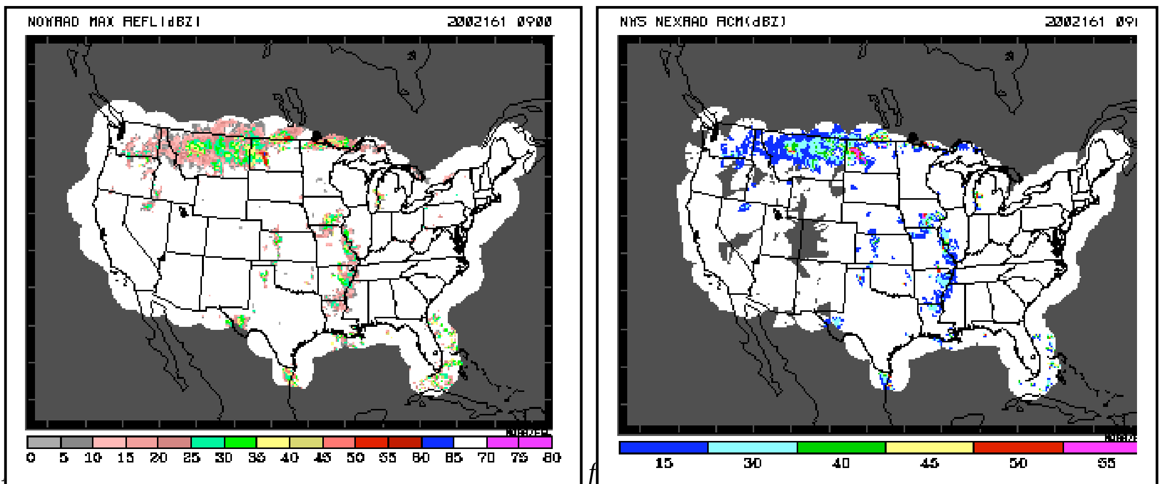
To address these problems, this project is directed toward development of a ‘coupled land-surface / atmospheric data assimilation system’, or CDAS based on the Rapid Update Cycle (RUC).
The design of a RUC CDAS to produce LDAS-type results constrained by optimized precipitation estimates using both observations *and* atmospheric model constraints is a key aspect of our proposal. The approach taken will use a solution in which errors in both the observations and model forecast are accounted for. It is anticipated that this approach will be particularly beneficial in optimally estimating ongoing land-surface conditions in mountainous areas such as the western United States.

Project Goals

- Develop a 4-dimensional assimilation system using a forward full-physics model in which the precipitation and clouds are an optimized combination of observed and forecast fields. Observed precipitation and cloud fields will be updated hourly. This system using the LSM and hourly observed fields coupled with a full 3-d atmospheric model to improved precipitation estimates is the CDAS. The assimilation techniques will be extensions of hydrometeor analysis techniques developed by Kim and Benjamin (2000) and related to the precipitation assimilation techniques of Lin et al. (1999). The developed techniques will be combined with the hourly forward assimilation cycle in RUC using a 3-d variational analysis with assimilation of raob, sfc, profiler, aircraft, satellite, radar, and GPS precipitable water observations. The resolution of both the RUC cycles without radar reflectivity assimilation and CDAS (with radar reflectivity) will be 20 km, with high-resolution fixed surface fields from USGS (land-use) and Penn State (STATSGO – soil type).
- Collaborate with NCEP and NASA toward possible implementation of a RUC-based LDAS as part of the NOAA/NASA LDAS project with multiple LSMs using surface temperature/humidity /wind forcing from RUC analyses that have the advantages of hourly availability and a closer fit to METAR observations than other regional model analyses, together with hourly precipitation and radiation forcing from the NOAA/NASA LDAS project.
- Run both the RUC-based CDAS over warm-season and cold-season trial periods of 1-2 months and compare results from it, the RUC cycle without radar reflectivity assimilation, the NOAA/NASA LDAS systems if available, and with in situ and satellite land surface observations. Use these results to refine the RUC CDAS to ensure reasonable overall performance.
- Run the RUC CDAS for a 7-month winter period (October – April). Verify results using SNOTEL observations, in situ soil moisture and temperature observations, and other available independent data sources. Special attention will be given to the western United States, where differences in LDAS and CDAS behavior are expected to be largest.
- Run regional climate simulations for a 2-mo. period (May-June) using two sets of initial land-surface fields, one from the RUC CDAS and one from the Eta model. Intercompare results from these two regional climate runs using verification against accumulated precipitation, surface, and upper-air observations over the 2-month period.
- Provide RUC gridded data and consultation to NOHRSC for their operational snow analyses using RUC data for near-surface atmospheric and snow forecast boundary conditions. Provide RUC CDAS output of surface variables including SWE and runoff to Bureau of Reclamation, as needed for their projects.
- Provide gridded data (in GAPP-approved format) from a 1-h assimilation cycle and 20km version of the RUC/MAPS with advanced physics during the Coordinated Enhanced Observing Period (CEOP) of GAPP. This area of the RUC/MAPS domain will include all of the GAPP LSAs (large-scale study areas) as well as the Saskatchewan model transferability area.

Method

During the first two years of the project, we have been developing assimilation of national domain radar reflectivity data from WSR-88D radars. Two different products have been considered, one from Weather Services International (WSI) and one from the National Weather Service (NWS). The WSI product, called NOWRAD®, is manually edited (better quality control), is available every 15 minutes, and has a dynamic range of 5 dBZ. However, the NOWRAD product does not differentiate no-echo area from no-coverage of NEXRAD coverage. The second product, a radar-coded message (RCM) product from the NWS, provides reflectivity data along with an indication of no-coverage, which is very important information for the reflectivity assimilation method (even though the NWS dynamic range is coarser than that of NOWRAD). Figure 1 shows an example of the two reflectivity products mapped on 20-km RUC domain. The RUC CDAS radar reflectivity assimilation technique developed up to this point uses both products.



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10 June 2002. Relative advantages of combining two are apparent in higher dynamic range in WSI product, and beam blockage (no-coverage) in NWS product.

The adjustment of hydrometeors with respect to NOWRAD reflectivity is done at each grid point as long as the NWS reflectivity identifies the grid as within radar coverage. The contribution towards each species of hydrometeor (rain water or snow) in a vertical profile is computed using the observed maximum reflectivity as a function of temperature from the 1-h background forecast at that grid point. In addition to that, the assimilation technique builds rain/snow hydrometeors down to the surface if the echo is larger than 20 dBZ (Kim et al. 2002, Benjamin et al. 2002). The adjusted hydrometeors are cycled in a 1-hour assimilation system. This radar reflectivity assimilation technique was incorporated into a parallel RUC data assimilation system starting in April 2002. Its results are being compared to a control RUC20 cycle at FSL without radar reflectivity assimilation. The technique has been refined several times since the initial implementation to project the radar reflectivity observations onto the explicit precipitation and sub-grid-scale cumulus physical parameterizations used in the RUC model. The latter is accomplished by removing the constraint of negative buoyant energy (CIN – convective inhibition) if reflectivity > 20 dBZ is present. Lightning data were also added as a proxy for radar reflectivity in regions where no reflectivity data are available (i.e., over mountains and oceanic areas).

Results and Accomplishments for April 2002 – March 2003

During the second year of the project, the impact of the assimilation technique modifying 3-d hydrometeor fields from the national mosaic 2-km resolution maximum reflectivity data has been monitored and evaluated on the regular basis. In April 2002, a parallel cycle of the RUC20 was started with hourly radar reflectivity assimilation. As described above, this technique has been considerably revised during the last year. The operational RUC20 without radar reflectivity assimilation is used as the control experiment.

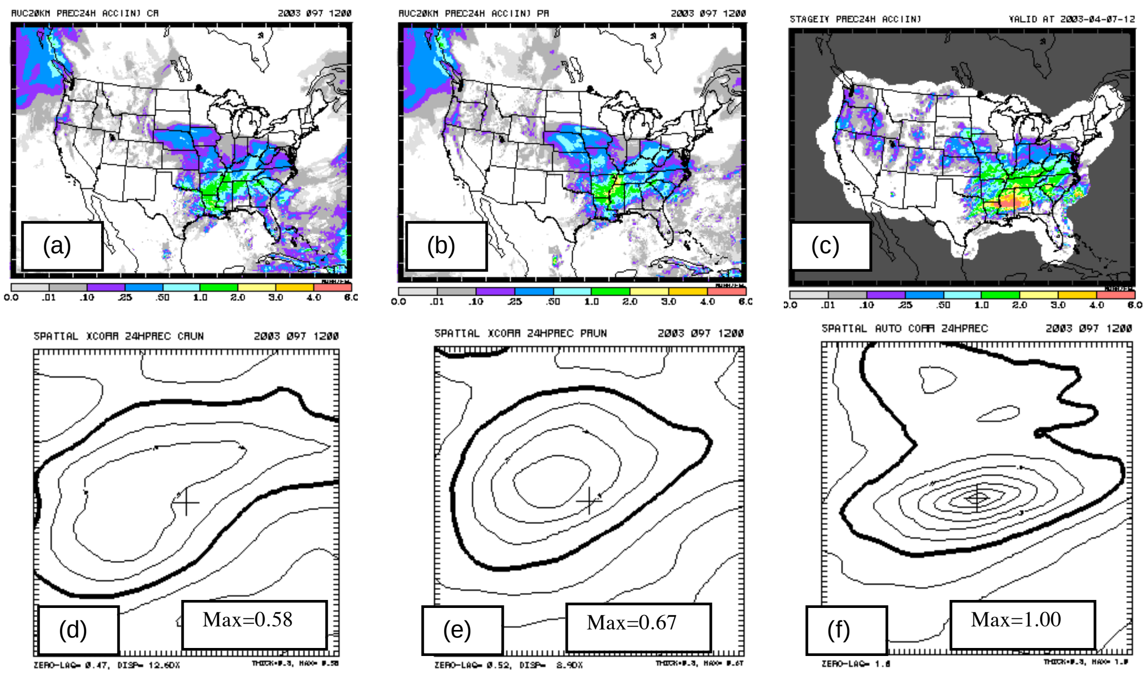


Fig 2 (left) An 24-h accumulation of precipitation for the period ending 1200 UTC 7 April 2003 from (a) control run, without radar reflectivity assimilation, (b) parallel run with radar reflectivity, and (c) Stage IV precipitation amounts (sum of four 6-h totals). Forecast amounts are for 8 consecutive 3-h forecasts from RUC cycles. d), e), and f) are spatial correlation functions corresponding to a), b), and c), and the maximum correlation is also shown. See text for more explanation.

The NCEP Stage II hourly quantitative precipitation estimation (QPE) (Baldwin and Mitchell 1997) is used to verify the 3-hour accumulated precipitation, and quality controlled Stage IV is used for the verification of 24-hour accumulations.   The Stage IV precipitation data are at 4-km resolution and are derived from both NEXRAD reflectivity and gauge observations and include quality control. The original 4-km resolution Stage IV precipitation data are remapped to the RUC20 grid by taking the maximum value in the grid box to represent the grid point. The verification of accumulated forecast precipitation from a sequence of 1-h forecasts in RUC20 assimilation cycles over a 24-h period is performed on the daily basis, and Figure 2 depicts an example of this verification.

A spatial correlation field was computed as a measure of precipitation verification (Webster and Oliver 2001). The spatial cross-correlation is a function of x-y displacement between two fields, QPF and QPE within a predetermined evaluation window (60 x 60 grid points on a 20-km grid). The distance of maximum correlation to the center (zero displacement) is a measure of QPF phase error, and the maximum value of correlation coefficient provides an approximate measure of forecast accuracy modulated by spatial variability of rainfall amount. The shape of the contours gives information on the directional dependency of precipitation forecast accuracy.

The two contour fields were compared with the spatial autocorrelation field, which is computed from QPE against itself. The preferred orientation of reflectivity during this period is evident, with strong anisotropy oriented from WSW to NNE. The spatial patterns also depend on the duration of accumulation. As an overall assessment, better QPF should result in a QPF-QPE correlation pattern similar to that of the spatial auto correlation. In the example shown in Fig. 2, the maximum value of cross correlation coefficient of parallel run (with radar reflectivity assimilation) is 0.73, better than 0.54 for the control run (without radar reflectivity assimilation) indicating that the QPF error in the parallel run is reduced from that of the control run. Also, the contour lines of the parallel run result are better defined, suggesting that its spatial scales and directional orientations are more accurate than those of the control run in this case.

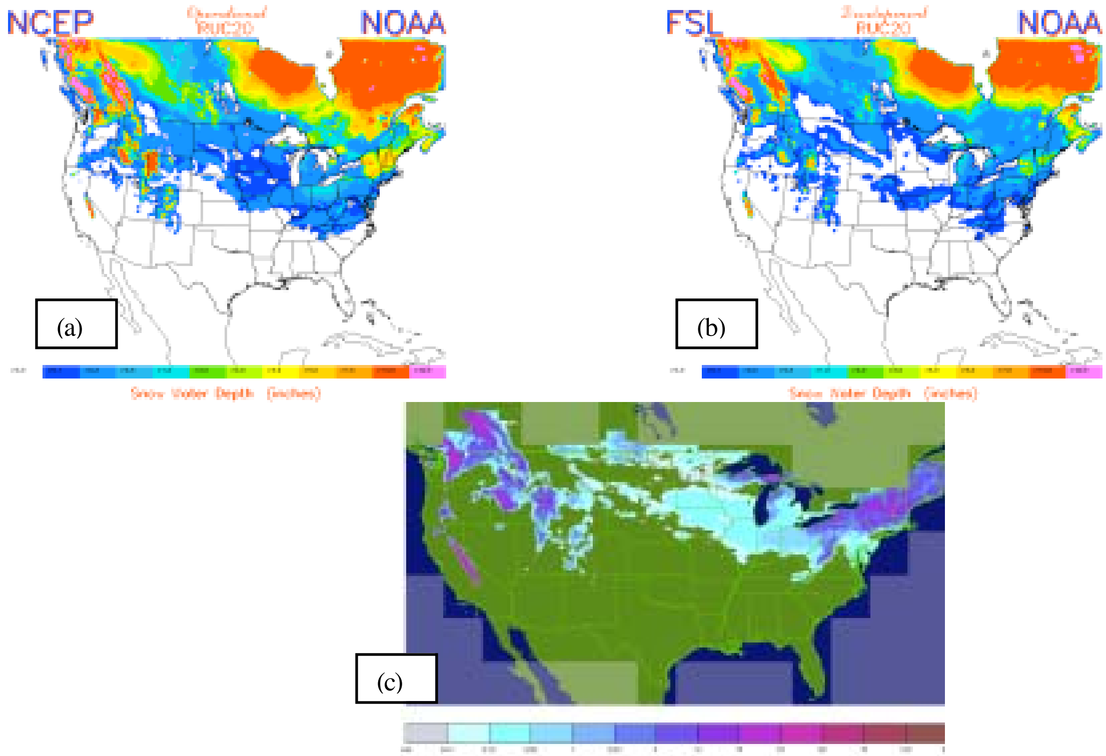


Figure 3. Snow depth from the (a) control RUC and (b) RUC CDAS verified against NOHRSC snow analysis (c) valid 30 January 2003.

The impact of the radar reflectivity assimilation is the most pronounced during the first 3 hours of the forecast, and especially for the 1-h precipitation forecast important for the evolution of the snow depth and the soil moisture fields in the RUC cycle. The winter of 2002/2003 was the first cold season when RUC Control and RUC CDAS were run in parallel, and the advantages of the RUC CDAS could be monitored in the evolution of the snow depth field driven by the 1-h precipitation forecast. Although the atmospheric forcing from RUC 1-h cycle often corrects the misplaced snow precipitation by providing the energy for snow melting, still the snow field is a very good indicator of the improvements in the precipitation forecasts in the RUC CDAS. The example on Figure 3 (a-c) demonstrates the comparison of snow depths from the RUC Control and RUC CDAS cycles against the NOHRSC (National Operational Hydrologic Remote Sensing Center – Chanhassen, MN) daily snow depth analyses. The NOHRSC product combines the snow model assimilation with all available snow observations and provides one of the most reliable datasets of this variable.

The snow depths from both RUC cycles are in good agreement with the NOHRSC product, but the snow coverage is generally more accurate in the RUC CDAS. As a result, the RUC CDAS also has more realistic soil temperature and moisture fields than the operational RUC (not shown). The feedback from these changes in the soil fields can be evaluated by the verification of RUC CDAS surface fields against METARs. This verification has continued since April 2002. The statistics for the cold season showed more pronounced improvements of land-surface fields from the radar reflectivity assimilation in the mountainous areas. The biases of surface temperature and dew point averaged over three winter months (Fig. 4 a,b) are significantly better during the day-time hours when the thermodynamics of the surface layer is determined by the land state. At night the biases are practically the same for temperature, but still improved for the dew point in RUC CDAS. Both models were slightly too dry during the winter causing cold biases at night and small warm biases during the day.

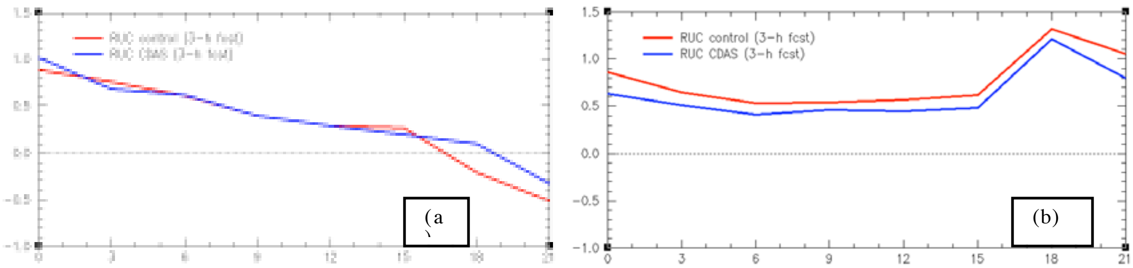


Figure 4. The diurnal cycles of forecast biases of (a) 2-m air temperature and (b) dew point for the Western United States from the control RUC and the experimental RUC CDAS averaged for the period from 1 December 2002 to 1 March 2003.

Under our evaluation of RUC LSM and CDAS behavior, the diurnal variation of skin temperature from RUC 1-h forecasts were verified against the GOES product at the ARM/CART SGP Site. To provide valid verification of skin temperature versus the satellite product, only RUC forecasts under clear conditions were taken into account. At the present time, the verification has been finished for the RUC Control, and the results for October, November and December 2002 are presented in Figure 5.

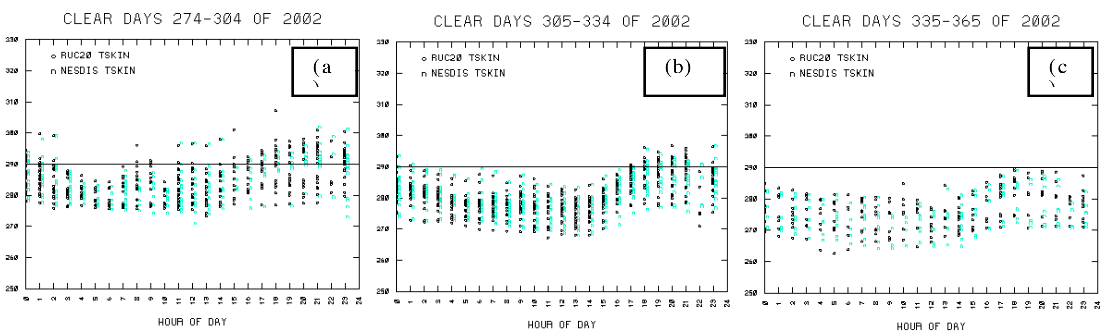
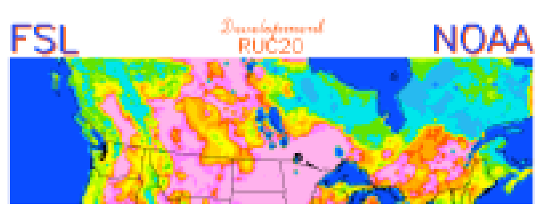


Figure 5. The verification of the diurnal cycle of skin temperature from the operational NCEP RUC (black) against NESDIS product (green) for (a) October, (b) November, and (c) December 2002.

There is a good agreement between RUC and NESDIS skin temperatures, especially in the nighttime hours, and during the day the RUC Control has a slight warm bias, which was also evident in the statistics for 2-m air temperature forecasts in Fig. 4a.

Improvements in the surface (METAR) verification from RUC CDAS forecasts (Fig. 4a) suggest that the cycled soil moisture field affecting the processes in the surface layer is fairly realistic in this cycle and better than in the operational RUC. The comparison between the top layer soil moisture from RUC operational and RUC CDAS is demonstrated on Fig.6. There are many similarities between the two fields, although there are also some significant differences. For example, the top layer of soil in RUC CDAS contains more moisture in eastern Kansas, Missouri, Illinois, and along the Mississippi River, but it is drier in the northern part of Georgia and in Alabama, perhaps due to differences in forecast precipitation over the few hours preceding this time.



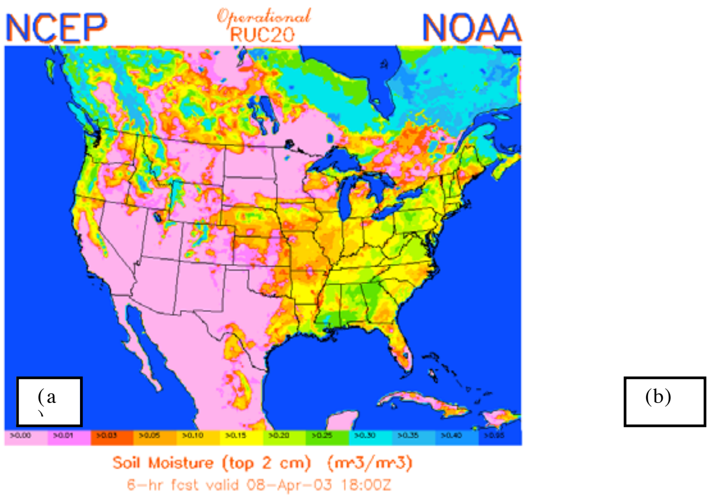


Figure 6. Top layer soil moisture from (a) operational RUC, and (b) RUC CDAS, valid 1800 UTC 8 April 2003.

The top layer of soil moisture has a short-term memory of the most recent precipitation and snow melting events. Therefore, the total soil moisture in the soil column could be a more useful parameter to evaluate the long-term effects from radar reflectivity assimilation in the RUC CDAS. The snapshot of such a field from the RUC CDAS is presented in Fig. 7a and compared to a similar product provided by the Eta model (Fig.7b) (using assimilation of precipitation analyses, Lin et al. 2001), and to a Palmer Drought Index product provided by the NOAA Climate Prediction Center (CPC). The comparisons of RUC and Eta fields are only qualitative, because the depths of the soil domains are different: 3 m in RUC, 2 m in Eta. The RUC total soil moisture shows some common features with the RUC top layer soil moisture (Fig. 6): very dry southwest US and south central areas. At the same time the north central US areas still contain moisture in the deeper layers, and the areas along the Atlantic coast are still very dry with only the top layer moistened by the recent precipitation events. The RUC total soil moisture agrees with the Eta soil moisture in many areas, although there are also several differences. For example, Texas has much more total soil moisture in the RUC than the Eta, and the Palmer Drought Index supports the RUC result for this area. In the North Central states the RUC shows much more total moisture than the Eta and the Palmer Index field also supports drier conditions as in the Eta. It is not certain if this difference could be from recent snowfall and melt reflected in the RUC CDAS field or its extra meter depth. Much more extensive intercomparisons between the RUC CDAS and Eta soil moisture fields using a different assimilation procedure will be conducted over the next year of the project.

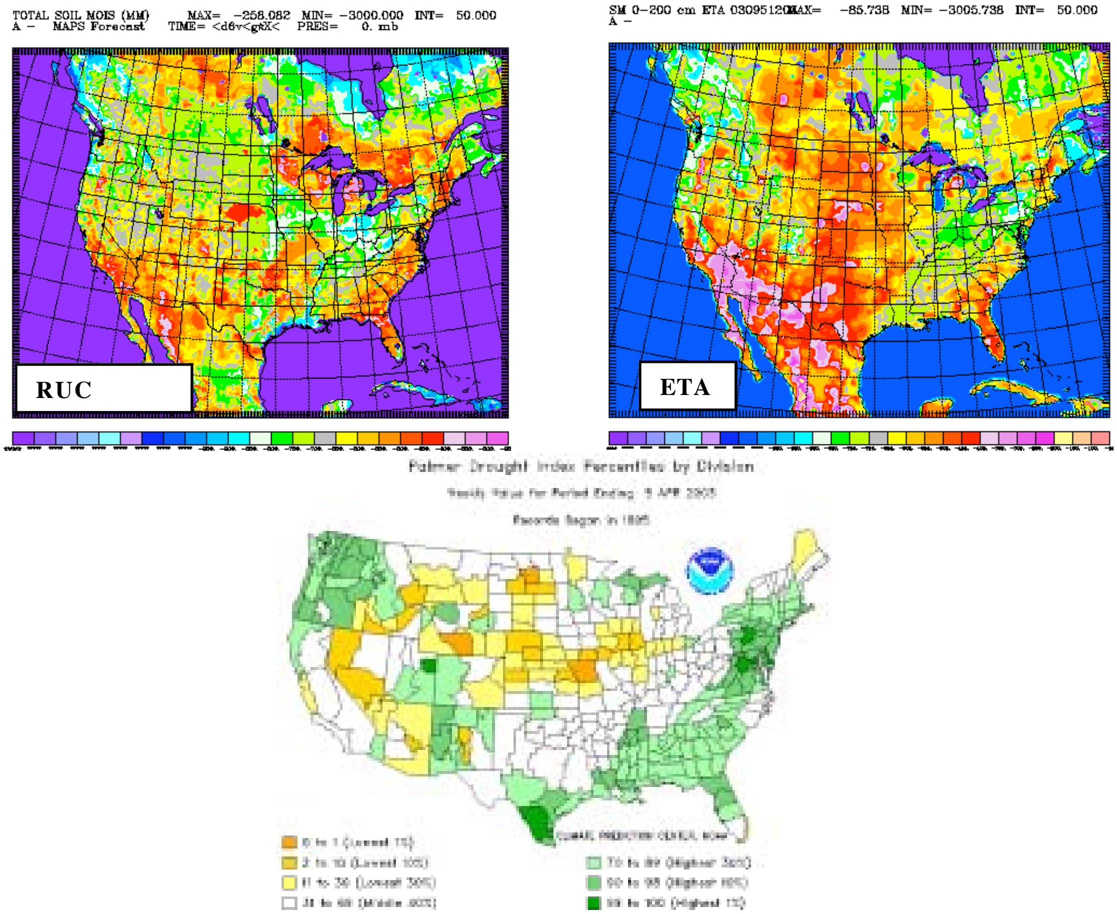


Figure 7. Deep-layer soil moisture from (a) RUC CDAS (3 m depth), (b) operational Eta model (2 m depth) valid 1500 UTC 5 April 2003, and (c) Palmer Drought Index from NOAA/CPC for week ending 5 April 2003.

Future Work

In the coming year, we plan the following specific tasks:

- Further revisions in radar/cloud/lightning assimilation technique, including use of lowest beam height masks (Figs. 8b,c below) for radar clearing, assimilation of surface cloud and weather observations, and projection of radar information onto stratiform vs. convective precipitation processes in the RUC model.
- Comparison of land-surface fields between RUC CDAS and operational RUC. We expect to see improvements over areas where radar data are generally available.
- Comparison of snow fields (cover, snow water equivalent) between RUC, which cycles snow variables in a CDAS-like mode, to those from the Eta model.
- Perform regional climate runs for spring 2003 period using land-surface initial conditions from RUC and Eta to investigate effects of CDAS procedure in RUC vs. analysis of precipitation analyses used in Eta. The different land-surface models used in the RUC and Eta also have some effect on the different evolution of land-surface fields.
- Comparison of skin temperature forecasts from RUC Control and RUC CDAS vs. GOES observations for ARM/CART site over 24-h diurnal cycle. Combining this with soil moisture observations may allow us to identify sources of skin temperature bias. design verification of QPF results for different regions of the RUC domain from both parallel and control runs to better diagnose the impact of radar assimilation. As a first step we have developed the mask field for four regions over the US (Fig. 8a) divided this way according to regional climatology. Spatial correlation statistics for these regions will be compared with commonly used equitable threat

scores. The results of the verification will be used to refine the radar assimilation technique. Verification statistics will include all surface variables from the METAR observations, GOES skin temperature, and various in situ soil temperature and moisture observations.

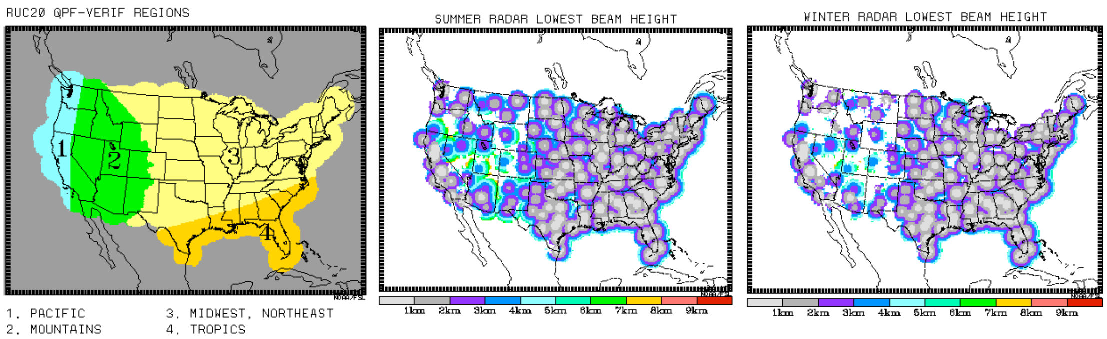


Figure 8. (a) Regional mask field for QPF verification, and lowest beam height coverage maps of WSR-88D radar echoes for (b) warm and(c) cold seasons.

Publications from this project

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