Evaluation of the Surface Layer Scheme in WRFDA

Fuhong Liu[1], Jing Zhang[1], Jeremy Krieger[2], Martha Shulski[3], and Xiangdong Zhang[4]

[1]*NOAA ISET Center, North Carolina A&T State University, Greensboro, NC 27411*
[2]*Arctic Region Supercomputing Center, University of Alaska Fairbanks (UAF), Fairbanks, AK 99775*
[3]*High Plains Regional Climate Center, University of Nebraska-Lincoln, Lincoln, NE 68583*
[4]*International Arctic Research Center, UAF, Fairbanks, AK 99775*
Email: fliu@ncat.edu

1. INTRODUCTION

The Weather Research and Forecasting (WRF) model has been applied to the Beaufort Sea region to investigate the mesoscale features of the surface wind field. In order to improve the model performance, various observational data types have been assimilated via the WRF variational data assimilation system (WRFDA). The results have been carefully analyzed and a feature of WRFDA has been identified that can cause unpredictable results if not corrected. WRFDA uses both model background fields and observations to estimate an optimal analysis, which can then be used as an initial condition for the model. However, WRFDA does not include an option to select different physical schemes, as is done in WRF. The schemes in WRFDA can thus be inconsistent with the schemes used to produce the model background field.

In both WRF and WRFDA, near-surface variables, including wind, temperature, and moisture, are diagnosed in the surface layer scheme. When assimilating surface observations, WRFDA uses its own surface variables diagnosed from the model background, in concert with the observations, to calculate innovation vectors. These vectors, along with the estimated errors in the background and observations, are then used to minimize the prescribed cost function and produce a new analysis. Thus, a surface layer scheme used in WRFDA inconsistent with that in WRF might result in inaccurate diagnosed surface variables, thereby limiting the performance of WRFDA when assimilating surface observations. To correct this discrepancy, the surface layer scheme in WRF is imported into WRFDA and the results are thoroughly investigated. The modified surface layer scheme includes the complete MM5 similarity scheme from WRF, followed by a section from the land surface model that updates near-surface temperature and moisture based on the surface skin temperature, moisture, and corresponding fluxes. In order to evaluate the modified WRFDA, a series of simulations have been conducted, in which both original and modified codes are tested and verified against observational data.

2. MODEL AND CONFIGURATION

The model used in this study is the Advanced Research WRF (ARW) v3.2, a widely used community mesoscale model developed by the National Center for Atmospheric Research (NCAR). The assimilation system used is the WRF Data Assimilation system (WRFDA) v3.2, a flexible, state-of-art atmospheric data assimilation package. WRFDA has been carefully tested to evaluate how the assimilation of observational data affects the performance of WRF in our research area. WRFDA uses a slightly different surface layer scheme, used to diagnose surface variables, than does WRF. This version of WRF includes the choice of five different surface layer schemes, while WRFDA includes only one simplified scheme that differs from all of those in the model. How this inconsistency in the surface layer schemes affects the performance of WRFDA has not previously been evaluated. Investigating this is the focus of this study.

The modeling domain was established to encompass the entire North Slope of Alaska and adjacent Brooks Range, as well as the Chukchi and Beaufort Seas and portions of the Canadian Yukon and the eastern tip of Russia, as shown in Figure 1. The domain has a grid spacing of 10 km and 235 X 136 horizontal points, as well as 49 vertical levels. The physical schemes used include Morrison double-moment microphysics, RRTMG longwave and shortwave radiation, MM5 similarity surface layer, Yonsei University PBL, Noah land surface model, and Kain-Fritsch cumulus parameterization.

The simulation period was chosen to be the entire year of 2009, based on consideration of Arctic conditions across the region. The oceanic portion of the domain experiences high variability throughout the year in its sea ice coverage, and the land portion similarly varies in its snow coverage. This extreme variability greatly influences land surface, surface layer, and planetary boundary layer processes, as well as the development of low-level circulations near the coast where the thermal contrast between land and ocean plays an important role. Due to the limitations inherent in model physical schemes, the performance of WRF varies significantly from month to month. To conduct a thorough evaluation, it is thus necessary to examine the model performance throughout the entire year. The experiments consisted of a series of short-term runs, each covering 2 days and 6 hours; the first 6 hours are used as spin up time and not used in the validation. The observational data were assimilated every 6 hours, at 00, 06, 12, and 18 UTC. Observations assimilated include in situ observations from 119 stations distributed throughout the model domain, NASA's Quick Scatterometer (QuikSCAT) SeaWinds data, radiosonde profiles, and MODIS retrieved profiles. A customized CV5 background error covariance (BE) was used in WRFDA, which was calculated with the NMC method from a separate one-year simulation.

3. RESULTS

In this section, some preliminary results are shown, including a comparison of the time series of surface variables produced by the original and modified versions of WRFDA. At this time, the modified version has only been tested over the first two weeks of 2009. The time series of several surface variables, including 2-meter temperature (T2) and 10-meter wind speed and direction, are made at different stations. One apparent feature of the original WRFDA is that time series of T2 display sharp spikes at the times when observations are assimilated, as shown in Figure 2a. Similar spikes are also evident in the time series of wind speed, as shown in Figure 2b, though they are not as pronounced as in T2. While spikes generally occur when the observed values differ significantly from the model background, we have also observed their existence when the background closely matches the observation. The spikes more frequently occur in the cold season, although they do exist to a lesser extent during the warm season as well. Another feature of the spikes is that their direction is not always directed towards the observations; sometimes they point the opposite way. Several tests were conducted to determine the cause of these discontinuous results at the times when WRFDA is applied. We observed that the spikes occur even if no observations are assimilated, eliminating the assimilation itself as a possible cause. After further investigation, we discovered that WRFDA uses its own algorithm to diagnose surface variables that differs from all those available in WRF, the output of which are then included in the final analysis. The output of WRFDA thus varies from that of WRF even when assimilation is not performed. This inconsistency influences the calculation of the innovation vector, potentially negatively impacting the assimilation. In order to keep the surface layer scheme in WRFDA consistent with WRF, the MM5 similarity scheme from WRF was imported to WRFDA, and a short-term test conducted. This initial test covers the first two weeks of 2009, when significant spikes are observed at several stations. The time series plots comparing results from the original and modified WRFDA are shown in Figure 3. The spikes are significantly reduced. Small spikes still exist due to the assimilation of new information. A comprehensive evaluation has not yet been completed, however, and further analysis and evaluation will be conducted in the future.

4. SUMMARY AND CONCLUSIONS

In this preliminary study, the surface layer scheme in WRFDA is identified as causing discontinuous results in the diagnosed surface variables, which we believe can negatively impact the quality of the assimilation. After carefully locating the cause of the problem, the surface layer scheme in WRFDA was identified as diagnosing surface variables differently from WRF. We imported the MM5 similarity surface layer scheme from WRF in an attempt to solve the problem. While the full consequences of this discrepancy are still not clear, an initial test demonstrates that the inconsistent surface variables have been improved significantly. A more comprehensive evaluation is still ongoing.

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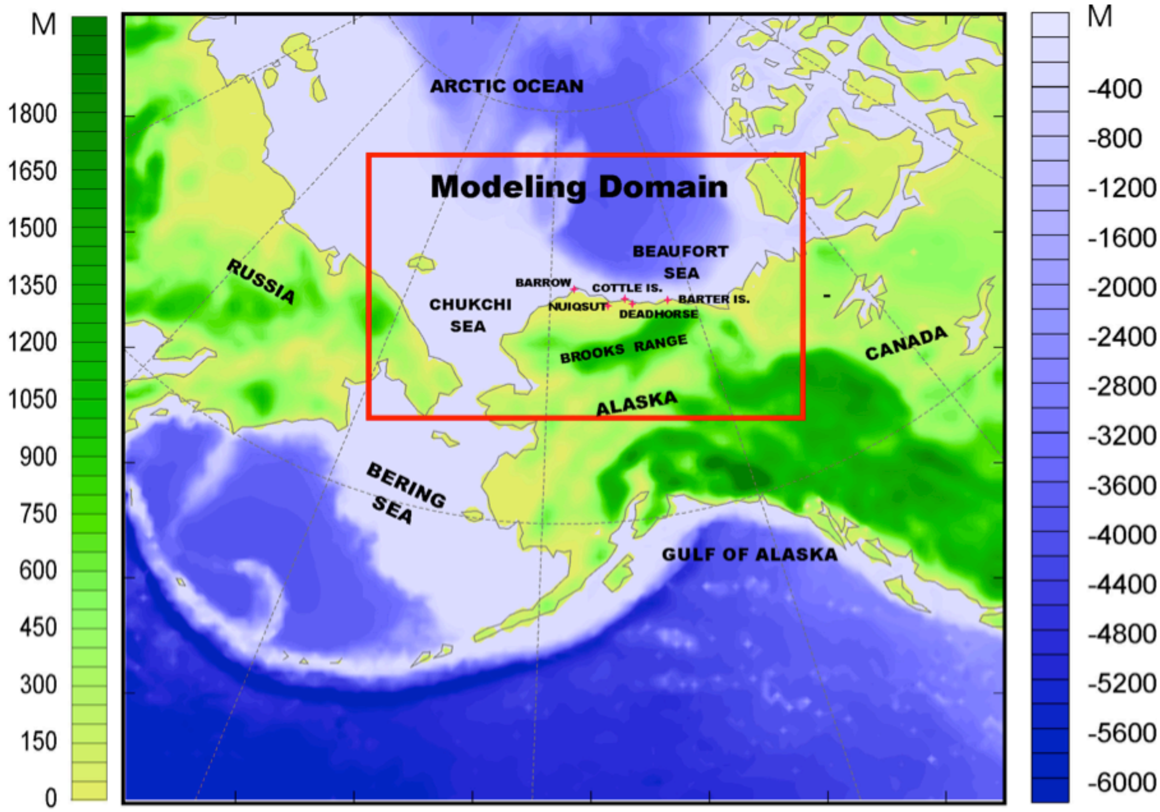
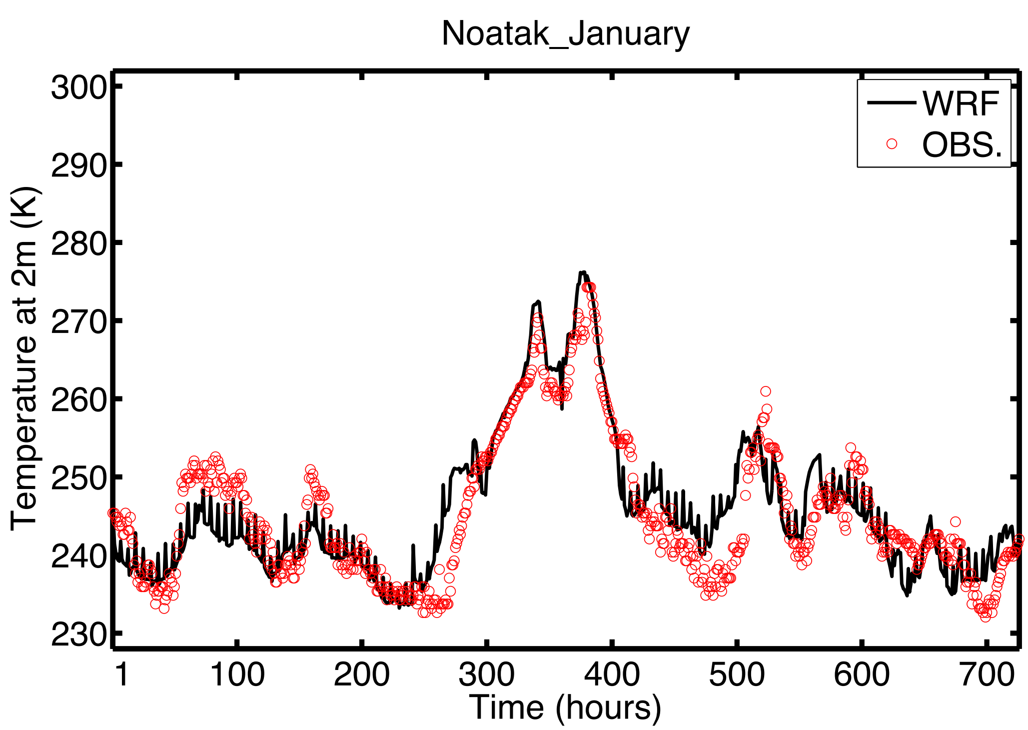


Figure 1. WRF modeling domain (red box) encompassing the Beaufort and Chukchi Seas, the North Slope of Alaska, and the Brooks Range. Some stations used for verification are indicated with red dots.



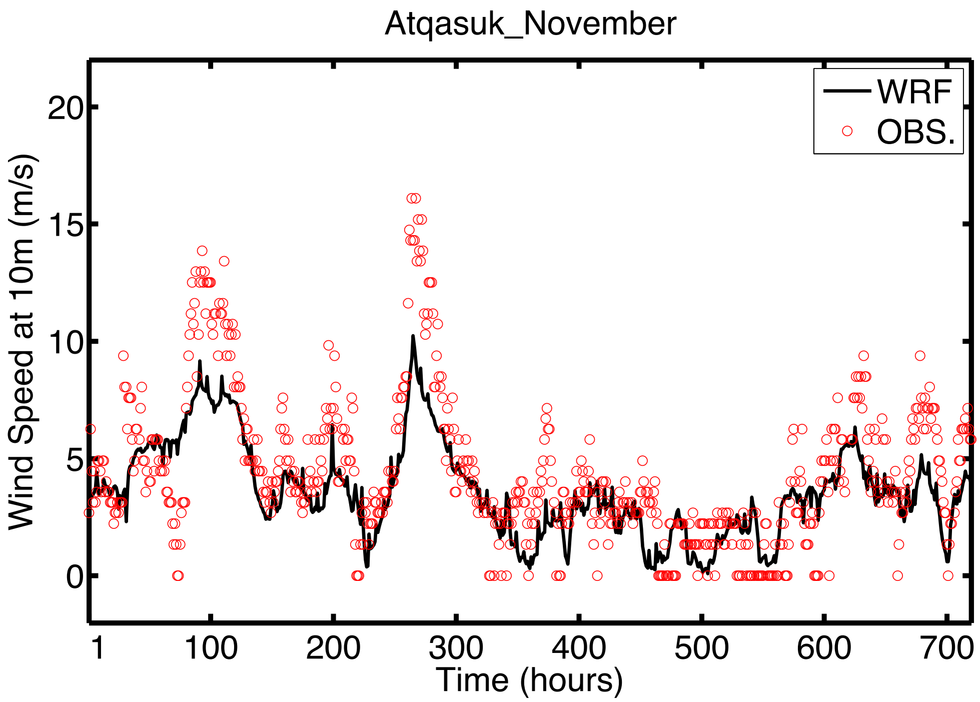


Figure 2. Time series plots for Jan 09 surface temperature at Noatak (upper) and Nov 09 wind speed (lower) at Atqasuk when applying unmodified WRFDA. Both exhibit spikes (black solid line) when data are assimilated. Observations are indicated by red circles.

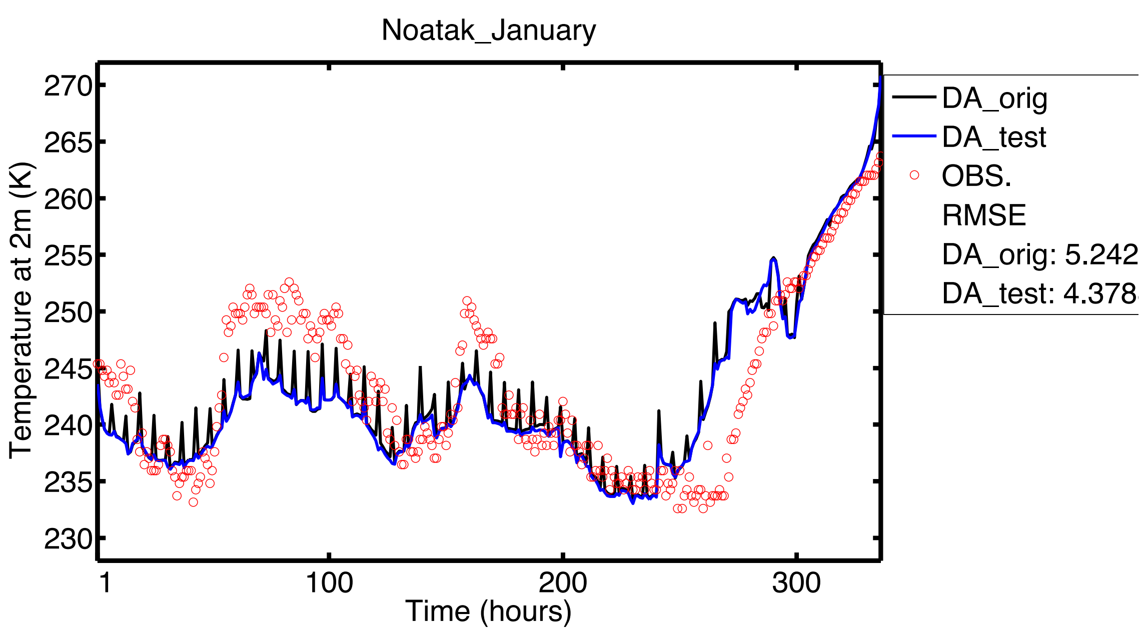


Figure 3. Time series plots for Jan 09 surface temperature at Noatak when applying modified WRFDA (blue), compared to original WRFDA (black). Red circles indicate observations. Our modification greatly reduces the discontinuities as well as the overall RMSE.