ARL-TN-1041 ● OCT 2020

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The Weather Running Estimate–Nowcast Realtime Software Tool as a Rapid Update Mesoscale Nowcasting Solution for Forward-Deployed Army Application

by Robert E Dumais Jr, Brian P Reen, and Leelinda P Dawson

NOTICES

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REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
October 2020	Technical Note	November 2019–September 2020

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
The Weather Running Estimate–Nowcast Realtime Software Tool as a Rapid Update Mesoscale Nowcasting Solution for Forward-Deployed Army Application	**5b. GRANT NUMBER**
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Robert E Dumais Jr, Brian P Reen, and Leelinda P Dawson	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
CCDC Army Research Laboratory ATTN: FCDD-RLC-EM White Sands Missile Range, NM 88002-5501	ARL-TN-1041
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

The Weather Running Estimate–Nowcast Realtime (WREN_RT) software tool was developed to run tailored configurations of the Advanced Research version of the Weather Research and Forecasting model by providing a scripted system to retrieve input data, run preprocessors, perform observation quality control, and execute the model. It also includes the ability to apply observation nudging four-dimensional data assimilation through ingesting local and regional weather observations. The WREN_RT is currently being tested in a limited area nesting configuration that can be executed in real time using a substantially constrained dedicated computing solution. Such a computational environment could be the case within the Army's Distributed Common Ground System, which is interested in using the WREN_RT as a tool to provide high-resolution rapid update nowcasting support for forward echelons like battalions to support critical environmental decision support tools.

15. SUBJECT TERMS

meteorology, nowcast, model, numerical, Army

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Robert E Dumais Jr
Unclassified	Unclassified	Unclassified	UU	17	**19b. TELEPHONE NUMBER (Include area code)** 575-694-5022

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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1. Introduction

The Weather Running Estimate–Nowcast Realtime (WREN_RT) software tool, developed at the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL), runs tailored configurations of the Advanced Research version of the Weather Research and Forecasting model (WRF-ARW; Skamarock et al. 2019) by providing a scripted system to retrieve input data, run preprocessors, perform observation quality control, and execute WRF-ARW (Reen and Dawson 2018). It also includes the ability to apply observation nudging four-dimensional data assimilation (FDDA) through ingesting local and regional weather observations as collected in databases such as the National Oceanic and Atmospheric Administration's (NOAA's) Meteorological Assimilation Data Ingest System (MADIS) (https://madis.ncep.noaa.gov/).

The complete process of obtaining the input data needed to run the WRF-ARW model, preprocessing these data, and properly configuring namelist settings for the model (which include user specifications of resolution, domain size, and physics options) can be a complicated, error-prone, and time-consuming process, particularly when multiple sources of input data are being used in combination with FDDA. Thus, a properly designed scripted system to carry out these tasks simplifies the production of WRF weather forecasts, reduces the chances of errors occurring in the process, and allows weather forecasts to be more rapidly generated.

This is especially the case if the forecast system is aimed toward Army operational usage at a forward-deployed echelon (such as at a battalion), where on-site numerical weather prediction modeling expertise will be unavailable and dedicated computer hardware resources may be limited. In addition, tactical communication channels could be either constrained by bandwidth, susceptible to intermittent drop-outs, or allocated to higher-priority mission applications. To work in real time for mesoscale nowcasting within such an environment, the more typical WREN_RT configurations and options used in research will need to be downscaled to achieve such a goal. We will from henceforth refer to such a downscaled version of WREN_RT as Battalion WREN_RT (BWREN_RT) for simplicity.

2. The Weather Research and Forecast Model

The WRF-ARW model V4.1.2 (Skamarock et al. 2019) is used for the initial configuration of the BWREN_RT currently under testing at the CCDC Army Research Laboratory, with 51 vertical layers and using a horizontal double-nest strategy of 9- and 1.8-km grid spacing. The outermost domain has dimensions of 151 × 151 in the horizontal, while the inner nest has dimensions of 71 × 71 in the horizontal. Both nests use the same center latitude and longitude location (telescopic nesting), and for most regions of the globe a Lambert Conformal map projection is used (options for Mercator and Polar Stereographic also exist).

This nesting configuration appears to be, based on our own early benchmark testing, one that could potentially be executed for real-time purposes on a limited compute platform such as a quad or dual-core desktop or laptop. During the tests using two cores of a Dell workstation running Linux (dual 8-core Intel Xeon CPU E5-2667 v4 3.20GHz), it was found that a 6-h forecast with 1-h FDDA could execute in 1.7 h, and a 3-h forecast with 1-h FDDA could execute in 1.7 h. Taking other potential latency issues into account (potential battlefield meteorological observation collection and transmission, post processing of output), it would seem that a 6-h forecast/nowcast updated every 3 h might be the best initial option, and this is currently being pursued. Additionally, running the same configuration on a more reduced hardware platform that might be offered on a deployed system (we are currently working with the Army's Distributed Common Ground System, or DCGS-A; https://peoiews.army.mil/programs/intel-systems-and-analytics/) might alter our approach even further (e.g., a single dual-core Intel Core i5-6300U Processor with 3-MB Cache running at 2.40 GHz). Table 1 identifies the important WRF-ARW namelist and physics option settings being used in the current configuration of BWREN_RT.

Table 1 WRF-ARW model namelist and settings in BWREN_RT

Parameter	Option	Extra notes
Planetary Boundary Layer physics	YSU	Nonlocal scheme includes top–down mixing for stratus
Surface layer physics	…	…
Shortwave radiation	RRTMG	Shadow and slope options = on
Longwave radiation	RRTMG	…
Land surface scheme	Noah	…
Microphysics	Thompson aerosol-aware	…
Deep cumulus convection	Grell–Frietas (Nest 1)	…
Shallow cumulus convection	Grell–Frietas (Nest 1)	…
Upper damping	…	w-Rayleigh damping to prevent wave reflection off model top
Turbulent diffusion	Horizontal Smagorinsky 2D on Cartesian-z levels	Horizontal diffusion diagnosed from horizontal deformation (vertical diffusion from planetary boundary layer scheme)
Sixth-order diffusion	Yes (adjusts coefficient per slope)	Additional explicit filter for 2–4 delta wavelengths in weak winds in daytime boundary layer
EPSSM	0.5	Sound-wave damper/time step offset that can stabilize steep slope treatment by dynamics
Advection	Fifth order (horizontal) and third order (vertical)	Upwind-biased diffusion property

To supply even greater value to the Army over global and mesoscale modeling solutions already provided by the Air Force's 557th Weather Wing based upon the Global Air–Land Weather Exploitation Model (GALWEM) (Stoffler 2017), it would be advantageous to run even more frequent hourly update cycles while resolving scales up to at least 1-km grid spacing. However, these update frequencies and resolutions will initially be driven by 1) a computational platform provided at the tactical echelon such as via DCGS-A and 2) the spatial and temporal frequency of additional forward weather observations available for ingest into the FDDA.

The cycling frequencies will also rely upon the availability of larger-scale model forecasts used as first-guess background and lateral boundary conditions via the 557th Weather Wing (such as GALWEM; Stoffler 2017), as well as other potential input data that could improve lower boundary conditions (snow cover, sea surface temperature, lake temperature, etc.). These data are especially susceptible to communication drops (or lowering of priority to use limited available bandwidth) in the field during periods of engagement (where loss of bandwidth would negatively impact timely transmission of new data), and thus strategies are being developed to safeguard up to 72 h of stand-alone capability due to an extended loss of bandwidth and communication. Given the generally high forecast skill of modern operational center global models out to 3–5 days, locally archiving downloaded model forecasts out to at least a 3-day forecast extent for each cycle when bandwidth allows is one way to approach this challenge.

For planetary boundary layer turbulence, the nonlocal parameterization method developed by Yonsei State University is used (YSU; Hong et al. 2006), including an option to treat top-down mixing processes in conditions of stratus cloud/fog (Wilson and Fovell 2018). Horizontal turbulent diffusion uses the approach of Smagorinsky (1993) and is performed along Cartesian-z surfaces, while diffusion in the vertical is handled by the YSU planetary boundary layer scheme. The surface layer is treated using the scheme of Jimenez et al. (2012). Also used are the Thompson aerosol-aware microphysics parameterization (Thompson and Eidhammer 2014), the computationally efficient version of the Rapid Radiative Transfer Model for Global climate modeling (RRTMG) for both shortwave and longwave schemes (Iacono et al. 2008) with slope and shadow effects included for shortwave; the Grell–Freitas deep and shallow cumulus scheme (for Nest 1 only; [Grell and Freitas 2014]); and the Noah land surface model (Tewari et al. 2004). To eliminate the reflection of waves off the model top, the w-Rayleigh damping approach (Klemp et al. 2008) is applied.

To eliminate the potential for instabilities at acoustic frequencies generated along steeper slopes, the damping approach of Dudhia (1995) is applied with a moderately strong coefficient value of 0.5. To eliminate spurious noise of wavelength two to four times the grid spacing length, which can be generated in light winds within daytime boundary layers, a horizontal sixth-order diffusion is further applied (Knievel et al. 2007) and gradually reduced in strength with increasing model terrain slope. This extra diffusion becomes necessary because the model uses a fifth-order horizontal advection scheme, which has an implicit centered upwind-biased diffusion property that is wind speed dependent. So, at low wind speeds in convective conditions (where small perturbed conditions can become increasingly noisy and amplified, compared with under stable stratification), the advective diffusion property becomes less effective. A third-order vertical advection scheme is applied, and time integration uses the third-order Runge–Kutta method (Wicker and Skamarock 2002). Finally, a hybrid terrain-following mass coordinate in the vertical is used by the WRF-ARW model configuration in BWREN_RT (Park et al. 2019).

3. Four-Dimensional Data Assimilation

To improve short-range nowcasts, it is important that the WRF-ARW modeling component of BWREN_RT assimilates available local and regional weather observations into new forecast cycles as soon as they are collected and preprocessed. Operational forecast centers and research institutions apply a number of different atmospheric data assimilation schemes to do this, ranging in complexity from 4D hybrid ensemble Kalman filter (4D-EnVar; Desroziers et al. 2014) to strictly 3D or 4D variational (3DVar/4DVar) approaches (Zhao et al. 2008; Huang et al. 2009; Brewster et al. 2015; Jiang et al. 2015). The 4DVar and 3D/4D-EnVar hybrid systems are typically only run at large operational centers due to their considerable computational requirements, although they are now considered the state of the art in atmospheric data assimilation. The WRF-ARW model offers another approach called Four-Dimensional Data Assimilation, which involves nudging toward observations (observation nudging) or analyses (analysis nudging), also known as Newtonian relaxation (Stauffer and Seaman 1995; Liu et al. 2005; Deng et al. 2009; Reen 2016).

The observation nudging approach is being targeted for eventual use in the BWREN_RT discussed in this report. In terms of computational efficiency, it offers significant advantages over the 4DVar and ensemble Kalman filter approaches, and it is also a simpler system to implement and operate. It is also based upon the same general principles of the Kalman gain theory, as are the variational and ensemble methods (Liu et al. 2005). On the other hand, it does contain certain shortcomings: the method cannot easily handle indirect weather observations (such as radar reflectivity and satellite radiance), and does not guarantee optimal statistical or flow-dependent assignments of horizontal and vertical observation correlation distances. However, approaches do exist to address these shortcomings, and the BWREN_RT FDDA employs many of these (Liu et al. 2005; Reen 2016;). Although not a part of the BWREN_RT configuration discussed here, hybrid approaches based upon FDDA and 3DVar are being researched at ARL for future consideration (Reen et al. 2017).

4. Summary and Future Efforts

An extensive archive of simulations (using the battalion BWREN_RT double-nest configuration) has been completed that will next be used in a verification study aimed at comparing different perturbations of the system configuration. The perturbations involve choice of model planetary boundary layer physics, radiation parameterizations, NOAA MADIS meteorological observations to use in the FDDA, and use of three-day-old versus current NOAA 0.25° Global Forecast System (GFS; https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs.php) output for initial condition and lateral boundary tendency fields (for outer 9-km nest). A two-week period of March 2020 has been used to generate the simulations, with 6-h forecasts generated every 6 h (also using an additional 3-h preforecast FDDA period).

An example of model output from one of the March 2020 simulations is shown in Fig 1. The figure illustrates the size of the inner nest domain (1.8 km), which is centered over the Jornada Experimental Range just northwest of the White Sands Missile Range Main Post, and shows the surface wind vector (meters per second) and shaded temperature contour (°C) forecasts (along with terrain elevation line contours) for 21 UTC of March 27, 2020. This is the primary nest domain that will be evaluated more closely over the next year using different National Center for Atmospheric Research Model Evaluation Tools (Bullock et al. 2016) and Design of Experiments (Cleveland et al. 2020) tools for generating output verification, along with the potential for including observations from the local ARL Meteorological Sensor Array in addition to those routinely available via NOAA MADIS (https://madis.ncep.noaa.gov/) for ground truth.

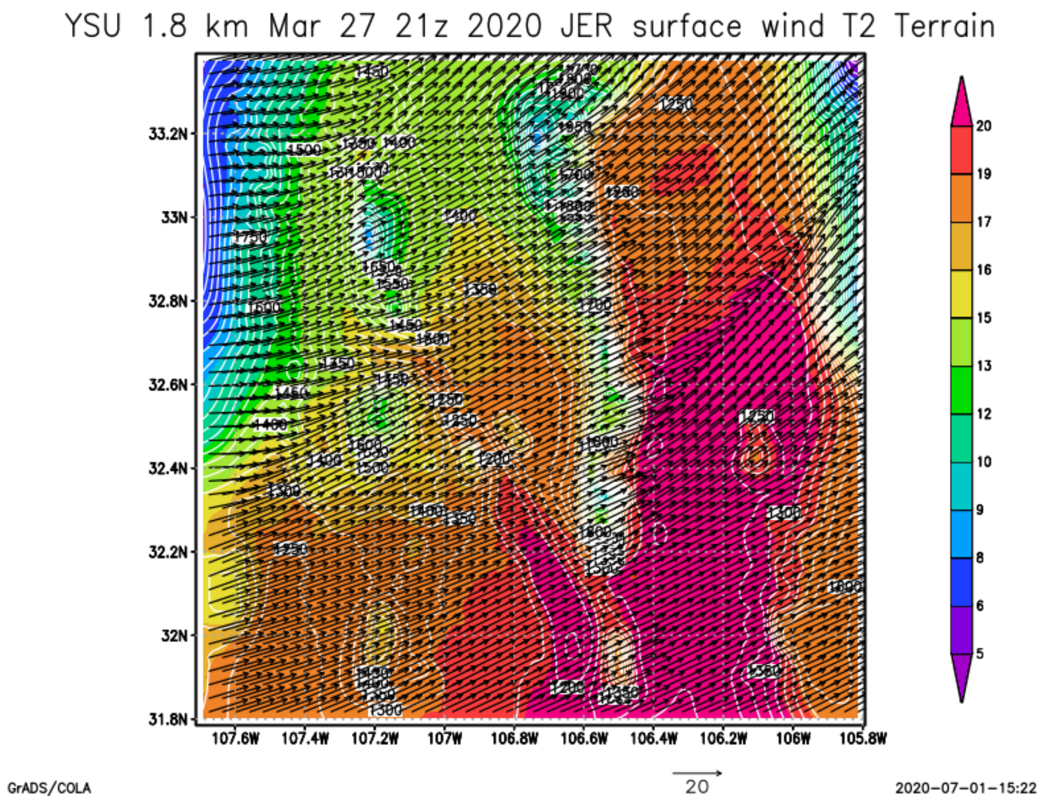

Fig. 1 Surface wind vector (meters per second) and shaded temperature contour (°C) forecasts (along with terrain elevation line contours) for 21 UTC March 27, 2020

Further work with BWREN_RT will include continued testing of the ingest of GALWEM forecast grids to replace GFS, along with completion of an automated backend postprocessing of output using the NOAA Unified Post Processor software (https://dtcenter.org/sites/default/files/community-code/upp-users-guide-v4.1.pdf). This is necessary to convert the BWREN_RT output produced by WRF-ARW into a format more easily ingested by decision support tools to be hosted on DCGS-A such as MyWIDA (Brandt et al. 2013). Later during FY21, an initial transition of BWREN_RT is expected to be made to DCGS-A for initial testing.

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List of Symbols, Abbreviations, and Acronyms

2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
ARL	Army Research Laboratory
BWREN_RT	Battalion Weather Running Estimate–Nowcast Realtime
CCDC	US Army Combat Capabilities Development Command
DCGS-A	Distributed Common Ground System–Army
FDDA	four-dimensional data assimilation
FY	fiscal year
GALWEM	Global Air–Land Weather Exploitation Model
GFS	Global Forecast System
MADIS	Meteorological Assimilation Data Ingest System
MyWIDA	My Weather Impacts Decision Aid
NOAA	National Oceanic and Atmospheric Administration
RRTMG	Rapid Radiative Transfer Model for Global climate modeling
UTC	universal time coordinate
WREN_RT	Weather Running Estimate–Nowcast Realtime
WRF-ARW	Advanced Research version of the Weather Research and Forecast
YSU	Yonsei State University

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