# Implementation and testing of WRF Digital Filter Initialization (DFI) at NOAA/Earth System Research Laboratory

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## 1. INTRODUCTION

Initialization refers to the process in which meteorological analyses are modified and applied to a numerical model grid. Dynamical imbalances between the wind and mass in the model initial field initiate spurious gravity waves at the start of a model forecast. These waves can seriously contaminate the model's solution during the first few hours causing inaccurate circulations resulting in numerical instabilities, forecast degradation, unrealistic precipitation, and damage to any subsequent data assimilation through first-guesses containing spurious features. Digital filter initialization (DFI) is one of the available methods to remove or reduce these initial imbalances (Lynch and Huang, 1992). It has been shown to produce meteorological fields (e.g., cloud water content and vertical velocity) that are balanced more consistently within the context of the forecast model's dynamics than would otherwise be the case if the analysis were used without modification (Huang and Lynch, 1993; Huang and Sundqvist, 1993; Chen and Huang, 2006).

## 2. DFI Development in WRF

One of the initial developments of DFI in the WRF model was conducted at NCAR. This early adaptation required the output of a restart data file at the end of each integration period as well as separate executions for each phase of the DFI application. This DFI methodology allowed for flexibility in the DFI run-time procedure as well as several choices in DFI filter window options.

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Retrospective simulations using this DFI configuration were conducted for a 4-day period. The results showed a reasonable amount of noise reduction and simulation spin-up time reduction, as well as improvement to conventional observation verification and precipitation scores (Huang et al., 2007).

DFI was implemented in the Rapid Update Cycle (RUC) model (Benjamin et al., 2004) about 10 years ago, and used since then, with several modifications, in the operational RUC cycle at NCEP. The use of DFI has been critical to the success of the 1-h cycling in the RUC forecasts as it reduces the initial imbalances and spurious gravity wave amplitude. In addition, the DFI was applicable to the hydrostatic, hybrid-isentropic-vertical-coordinate used in the RUC model.

Whereas an earlier decision had been made to replace the current RUC model with the WRF ARW for use as the operational forecast model for the Rapid Refresh (RR) forecast at the National Centers for Environmental Prediction (Benjamin et al., 2007), it was considered essential to have the DFI into WRF. The RR is planned to replace the RUC in NCEP operations in 2010. It will also operate on a one-hour cycle, wherein the previous 1-h forecast is used as the first guess for the next analysis. Therefore, given the importance of the DFI to the success of the RUC forecast, once the decision was made to use the WRF ARW, a separate effort took place at NOAA/ESRL to add DFI to the developmental version of WRF. An operational constraint in the DFI usage is that it must use a minimal amount of computational resources in a single executable code that is called from a batch job submission. Therefore, the DFI needed to be flexible in its choice of filtering methodology, run using a single job submission, and not to use temporary data files. At NOAA/ESRL - the ARW WRF model was modified through the addition of DFI namelist variables to the registry along with DFI routines and their associated calls in higher-level routines. The resulting changes differed from the NCAR DFI methodology in that the ESRL DFI executable was able to run from a single batch queue submission and subsequently produce a simulation using a single executable and namelist input file.

### 3. Results

Examination of real time forecasts made at ESRL using the ARW WRF with and without DFI show very satisfactory results. For example, mean surface pressure tendency in simulations for the CONUS domain (the contiguous 48 states) without using DFI show a significant decrease over the first two hours of the simulation (Fig. 1). When the twice-DFI option (Lynch et al. 1997, Huang and Yang 2002) is used for same forecast period, the initial mean surface pressure tendency shows only small variations during the first two hours. Therefore, the DFI has produced an initial field that is much closer to being in balance with

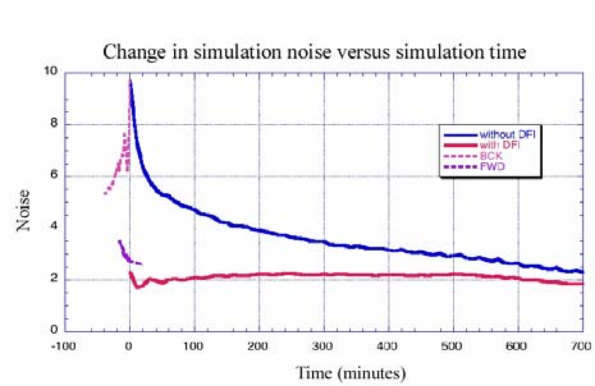


Figure 1. Change in simulation noise, in this case the mean surface pressure tendency versus time. The blue line shows the forecast noise over time without DFI. When using twice-DFI, the model noise is reduced from the initial analysis state during a backward adiabatic integration (lavender dashed line). And starting from a filtered state, the noise is again reduced during a forward diabatic integration (purple line). The forecast starts at the analysis time from a filtered state resulting in a much smaller noise amplitude (red line). Data used for the noise calculation were obtained from a 13-km WRF Rapid Refresh forecast using the twice-DFI option and a DFI time interval of 40 minutes.

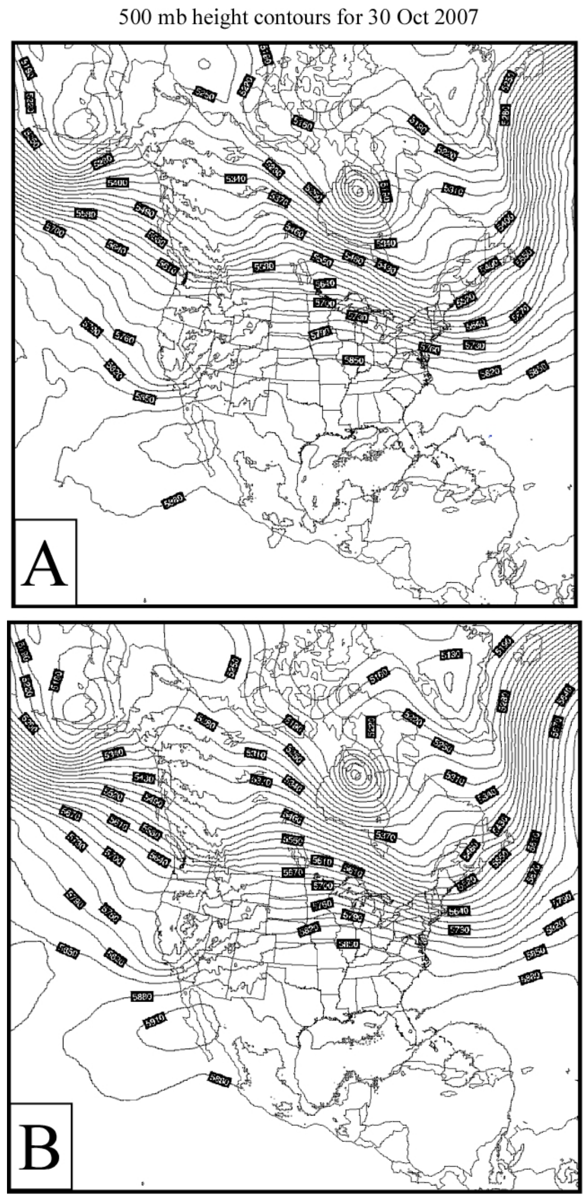


Figure 2. Figures showing a 3-h 500 mb forecast for 30 Oct. 2007 using the WRF model without (A) and with (B) the DFI (TDFI option) . The 500 mb height contours using the DFI shows less small-scale features away from high-elevation regions indicating that the DFI has greatly reduced the noise in the model initial fields and subsequent gravity wave generation during the simulation.

the model numerical structure resulting in a significant reduction in unrealistic features during the first hours of the calculation.

Figure 2 provides an example field from one of the simulations: 500 hPa height contours. Figure 2A shows the results from a test simulation using WRF ARW over the Rapid Refresh domain for 30 Oct 2007 in which the DFI was not applied. The same simulation in which the DFI (option 3) is used for a cycle period of 80 minutes (40min backward integrating the adiabatic, reversible terms in the equations only, followed by 40min forward using full physics and mixing/dissipation terms) is shown in Figure 2B. The use of DFI clearly reduces the high-frequency noise produced in the initial fields away from the high terrain of the Rocky Mountains. In addition, the production of gravity waves during the first hours of the forecasts results in a more realistic cloud and precipitation pattern development (not shown). In addition, DFI has been found to be a very efficient and convenient vehicle for a new radar reflectivity initialization methodology in which diabatic effects are included (Weygandt et al. 2007).

During collaborative discussions between ESRL and NCAR, it became evident that the two different DFI systems contained very similar components. It was decided that the two groups would combine the two methodologies to provide a single executable DFI system that would maximize both the flexibility in the DFI run-time options and filter choices in addition to eliminating the use of intermittent data output. The results of the combined efforts have been made available in WRF version 3.0. While applicable for the ARW core at this point, the DFI implementation have been introduced at the WRF driver layer and, therefore, potentially applicable to other dynamic cores.

## 4. Current DFI developments in cycled ARW-based Rapid Refresh

Additional functionality is under development at ESRL/GSD to use either DFI filtered states or the analysis fields for the initial post-DFI time step, respectively, for various fields (e.g., cloud hydrometeors, land-surface fields). In the WRF version 3.0 and recently released 3.1, the standard option is to use DFI filtered states when DFI option is selected. However, since cloud/hydrometeor assimilation (with satellite and METAR) and radar reflectivity assimilation included within the Rapid Refresh (WRF and GSI), it is preferable to combine use of analyzed fields for moisture variables with the DFI filtered states for the rest of the atmospheric variables. To provide this option, an additional switch was introduced in the WRF model namelist to the ARW registry to include or exclude hydrometeor variables from the DFI methodology. For the RR, initial relative humidity field and saturation conditions for 3-d grid points with non-zero cloud water or ice is also restored after the DFI integrations.

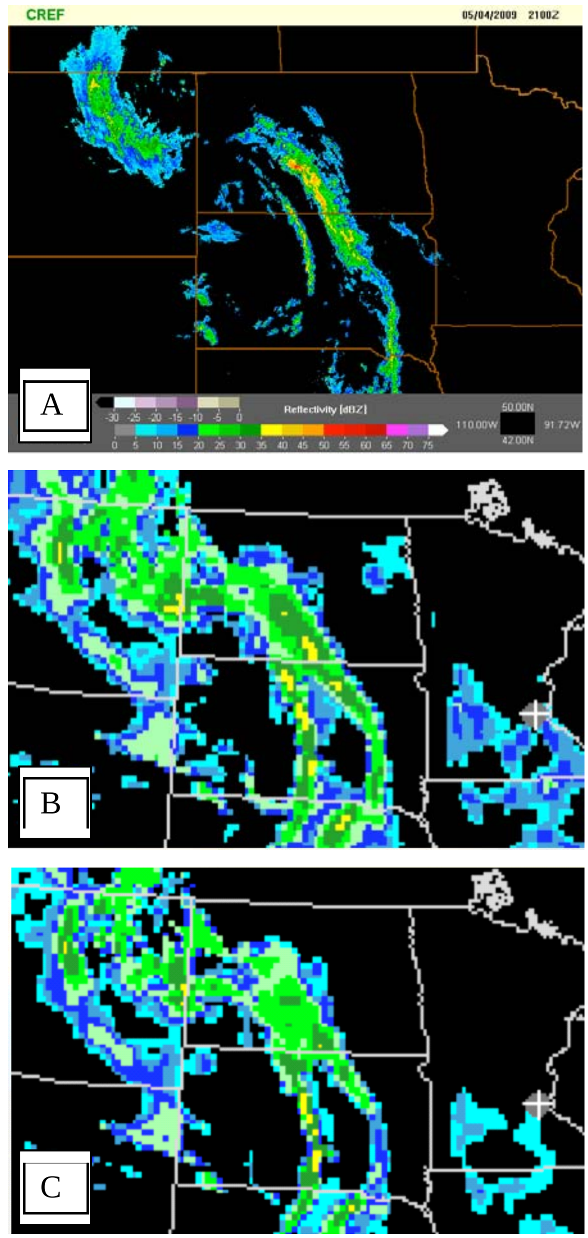


Figure 3. Observed composite radar reflectivity (A) and Rapid Refresh 1-h forecast using WRF ARW with DFI modifications (B) and without modifications (C). Valid at 2100 UTC 4 May 2009.

The positive effects of these recent DFI modifications in WRF are especially important in the first hours of integration reducing spin-up in cloud, reflectivity, and precipitation forecasts. Figure 3 demonstrates stronger echoes in 1-h composite reflectivity forecast from the Rapid Refresh system with DFI modifications (Fig. 3B) compared to the run without DFI modifications (Fig. 3C), the former being in better agreement with observed radar data (Fig. 3A).

Another development of WRF DFI at ESRL/GSD includes specification of different time step in DFI integrations than in the post-DFI forecast integration. Also, several other minor modifications were made to give users more options for DFI in WRF ARW model.

WRF DFI developments were extensively tested in the real-time Rapid Refresh cycle using WRF version 3.0. As of this writing, these developments are now under testing with WRF version 3.1, and it is planned to make this increased capability available to WRF users in the near future.

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