Towards improving representation of convection and MCC longevity in high-resolution WRF and NEMS-NMMB model forecasts

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1. Visit Summary

Istvan made prior arrangements to visit NCAR-RAL with funding support from his own university together with the DTC visitor program. He arrived at the start of March, 2014 and departed at the end of July. The most immediate and important goals of the visit were successfully achieved, although some parts of the original research project plan were not completed due to timing with other projects and code issues uncovered during simulation and testing. A number of specific code problems diagnosed during his visit were investigated by Istvan and his PhD student, Noemi Sarkadi, in the subsequent six to ten months. Furthermore, Noemi secured her own European funding to support her 3-month visit to NCAR between April and June 2015. Therefore, all prior known code issues are now completely and effectively discovered and fixed, leading to a much more robust, efficient, and capable bin microphysics scheme than at the end of 2014. While this did mean that not all portions of the original research plan were finished, the opportunity to move ahead with those plans and the lessons learned in the process have already led to substantive changes to the Thompson et al (2008) and Thompson and Eidhammer (2014) bulk microphysics schemes.

This document is organized as follows. The primary sections of the original research plan are briefly revisited in subsections below and details of 12-month progress are noted. Then, the expected outcomes of the original plan are discussed in the context of what was partly or fully successful versus what work could be pursued in the future to achieve these outcomes.

2. Research Plan

a. Upgrading Thompson BMP: 3−moment graupel

We will extend the existing Thompson scheme in WRF and NMM-B models to forecast three moments of the graupel distribution in a manner similar to Milbrandt and Morrison (2013). It was explicitly mentioned in the original plan that: "this effort will be leveraged with another NCAR-RAL funding source: STEP, led by Sarah Tessendorf." Unfortunately, other priorities within the STEP project essentially did not permit this activity to be started in a meaningful manner. Since the STEP project is composed of only two persons qualified to code these additions, and both Sarah and Greg had too many competing demands for their time and insufficient funding to pursue to date, this activity remains as future work.

However, the existing bulk microphysics scheme did receive a set of relatively minor changes and additions based on findings related to Istvan's DTC visit and other work. Specific changes made to the bulk scheme includes the treatment of rain drop break-up and self-collection as well as the number of rain drops created during graupel and rain collisions. Also, as mentioned in the original research plan, the bulk scheme was used in the OU-CAPS Spring Experimental Forecast program at NOAA-NSSL-SPC and we were verbally informed that the Thompson scheme in general out-performed all other microphysics sensitivity experiments (ensemble members) on a consistent basis in both 2014 and 2015 (Clark, A.; Coniglio, M; Kong, F., personal comm.).

If STEP and other future funding for upgrading the bulk scheme is identified, then this activity will become a top priority to meet the original objectives. A more coordinated effort with OU-CAPS for Spring 2016 could be highly leveraged to achieve this goal and would represent an excellent research-to-operations activity together with NCAR-RAL and NOAA-NSSL (and other collaborators).

b. Explicit/bin microphysics scheme

The explicit/bin microphysics scheme of I. Geresdi (c.f., Geresdi, 1998; Rasmussen et al, 2002) was incorporated in WRF v3.4.1. While the bulk microphysics scheme mentioned above has on the order of ten hydrometor variables to consider, the bin scheme has nearly 500 individual variables. This is one of the most advanced mixed-phase bin microphysics schemes in the world and obviously has a very high computational cost.

During Istvan's 2014 visit, WRF simulations using this bin scheme on an idealized three-dimensional squall line tested the limits of this code. Extensive tests were previously performed on events with weaker vertical velocities, but the strength of mid-latitude convective squall lines is, in general, far greater than any prior tests performed with this scheme. Therefore, new unexpected problems were encountered. Most importantly, the treatment of water drop collisions with other water drops or graupel had to be simulated with a tiny time step to remain numerically stable. This greatly delayed the progress we had planned and forced us to investigate a new technique to simulate these processes more efficiently. As an example, the dynamics and microphysics time step was previously about 1-2 seconds but this had to be reduced by a factor of nearly 100 (only for some microphysics processes) to keep the simulation from failing. This became a severe limitation in 2014 and greatly limited the activities of other portions of the original research plan. However, since 2014, Istvan devised an adaptive time step approach that triggers only when necessary due to intense vertical updrafts and the modified code was tested more extensively (along with other changes mentioned below) by Noemi during her 2015 NCAR visit. By the end of June 2015, it appears the code change effort was entirely successful and the bin scheme is now stable with the prior time step of 1-2 seconds. Better yet, the new methodology has only a small impact to total WRF model run time since adapting to the rapid time step is only required in the most extreme but rare circumstances.

Numerical simulations with prior versions of the bin scheme overestimated the size of the rain drops formed due to the complete melting of graupel particles. In our earlier version of the code (Geresdi et al, 2014) it was assumed that the melted water remains on the surface of melting graupel particles. This description agrees with the laboratory observations (Rasmussen et al, 1984), but incorrectly simulates the evolution of the size distribution of the water drops. The concentration of the larger water drops formed after the complete melting is significantly overestimated. Numerical simulation accomplished in a box model shows that the latent heat released during the evaporation of the water drops is sensitive to the size distribution of the water drops (Fig. 1). Fig. 1 shows how the amount of evaporated water depends on the mean size of water drops.

The sensitivity of the evaporation rate to the drop size distribution is a critical issue, because the propagation of squall lines is governed by the cool pool formed due to the evaporation of water drops. Theoretical considerations showed that the collision that occurs between the melted graupel particles and water drops can reduce the mean size of the water drops by limiting the accretion of the graupel particles and by generating small water drops. The effect of the collision induced shedding is presented in Fig. 2.

The importance of specific microphysical source-sink processes such as these water and drop collisions can impact simulations of any weather situation. Noemi performed sensitivity experiments with the proposed changes to test their efficacy in a winter storm case that is very dissimilar to the squall line. This activity resulted in a journal manuscript nearly ready to submit (Sarkadi et al, 2015) and will lead to a second journal manuscript when time permits the analysis of the sensitivity with these changes in the DTC-supported squall line case. These two outcomes were not originally planned but the discovery of code issues has led to important microphysical process studies worthy of description in the literature.

c. *Test & Evaluation plan*

The effort originally described in this section of the research plan was a best-case scenario of the bin scheme working reliably at the earliest date possible and Noemi would have had the time to begin collecting the test cases. Unfortunately, the delays discussed previously prevented any true progress in this area. However, with leveraging of the STEP project and interactions with OU-CAPS and NOAA-NSSL researchers, we

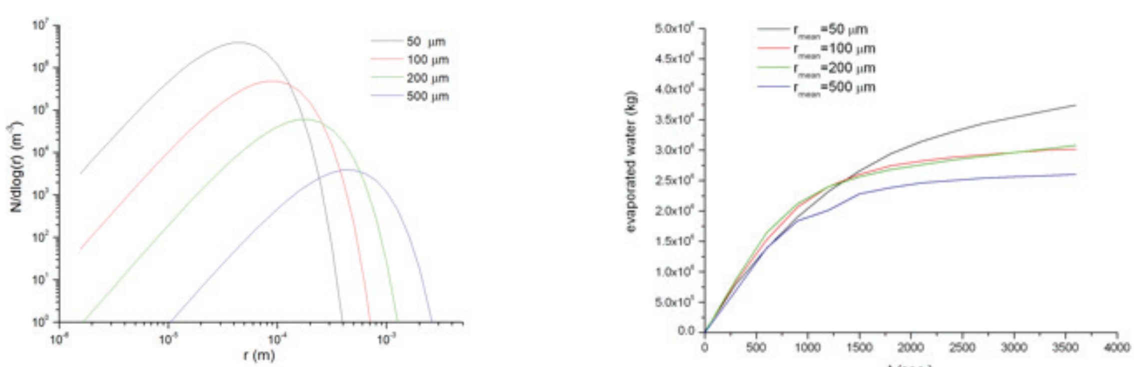

Fig. 1: Different initial size distributions of the rain drops (left), and the time evolution of the amount of the evaporated water in a 2 km deep downdraft region (right).

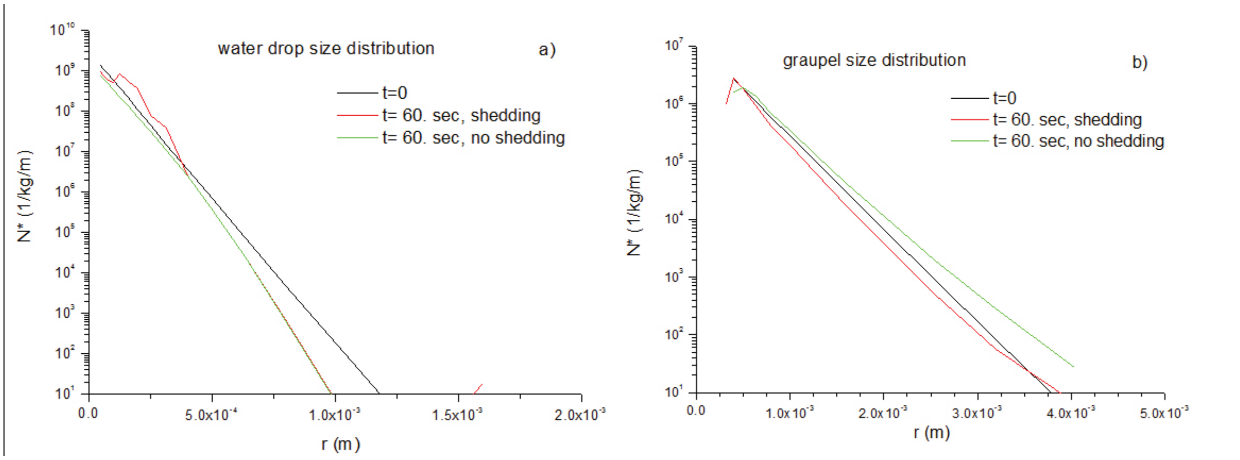

Fig. 2: Time evolution of size distribution of water drops (a) and that of graupel particles (b) calculated by an idealized box-model simulation with collision-induced and without collision shedding.

could assemble a sizable test suite of cases and attempt running WRF simulations to test incremental improvements to the bulk microphysics scheme now that the bin scheme is producing sensible results. In the meantime, by comparing results of each scheme in the idealized 3-D squall line case derived from actual observations of 2007Jun20, we now find excellent correlation between the bin and bulk schemes that has never occured in prior versions of these schemes. Therefore, we believe the stage is set for future work related to test and evaluate the existing Thompson bulk scheme in squall line and other convective events before proceeding to the newer treatment of graupel/hail mentioned in subsection (a).

The following series of graphics is expected to show the results of the bin and bulk microphysics schemes in the same WRF simulated environment. When compared to prior simulations of the same type and reported at the WMO Cloud Modeling Workshop in Warsaw, Poland (2012), these new simulations have characteristics that match more closely than ever before.

Particular features to note are the bin scheme reflectivity seen in cross section and near-surface altitude (Fig. 3) versus the bulk scheme (Fig. 4). Besides the general appearance and minima and maxima values, the total covered region and the placement towards the right in the X-direction indicate that the driving force, the cold pool, is simulated very consistently between the two simulations.

This conclusion is further supported by viewing the cross-section of vertical velocity between bin and bulk schemes (Fig. 5) as well as the cross-section of theta perturbation (Fig. 6). Lastly, in numerous previous times attempting to compare the bin and bulk schemes, the surface precipitation found in the bulk scheme was nearly always significantly larger than in the bin scheme. Furthermore, the distribution from starting convective location (center of domain) versus the region towards the right showed significant differences. With the latest

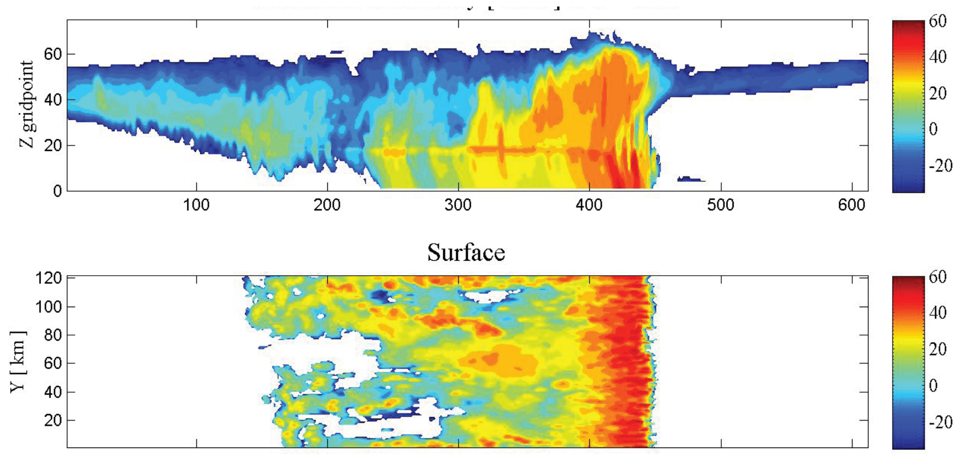

Fig. 3: Simulated radar reflectivity using the bin microphysics model of the squall line after 8 hours. The top panel shows the vertical cross-section and the bottom panel shows the near-surface reflectivity (dBZ).

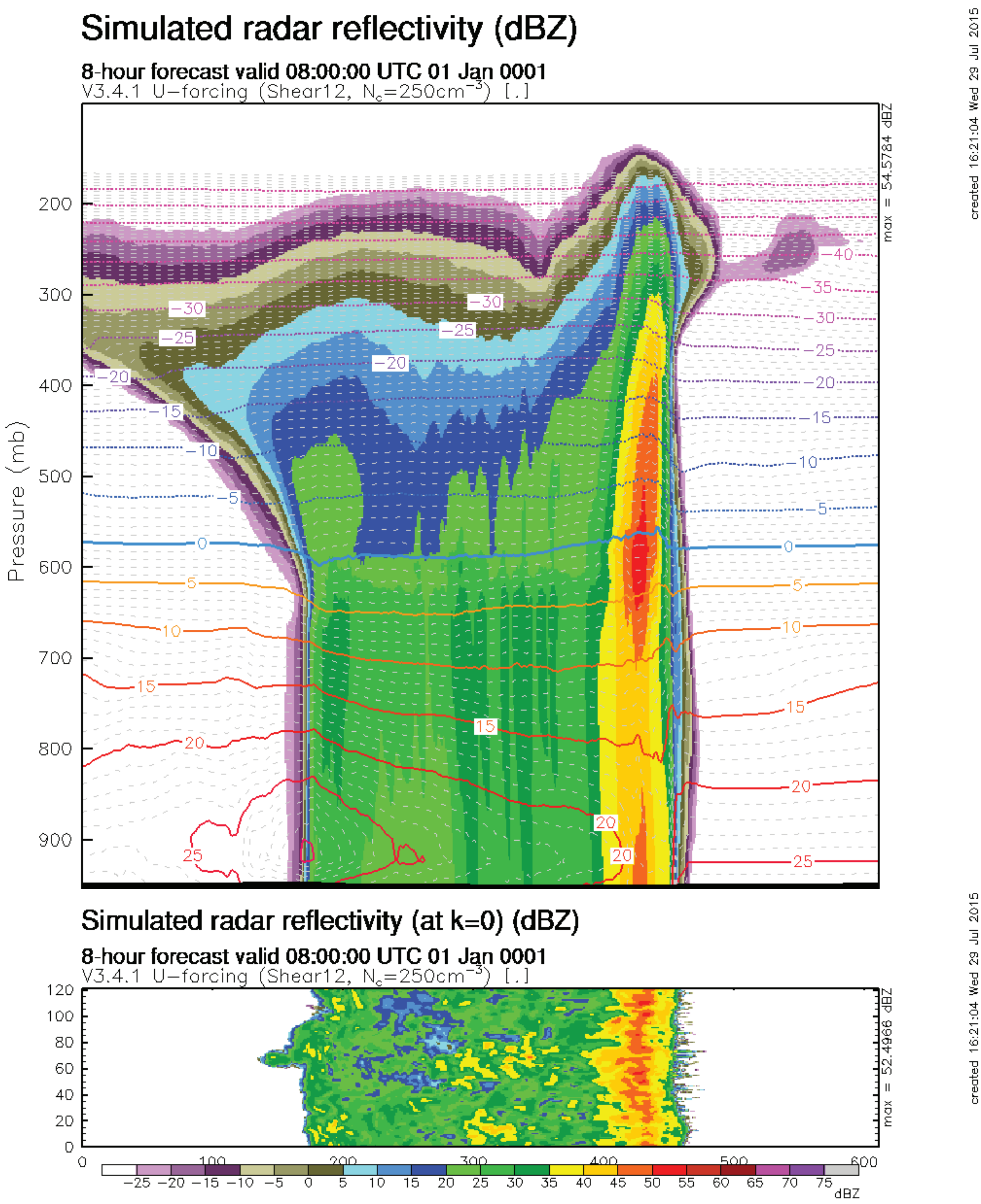

FIG. 4: Same as Fig.3 except results from the bulk (Thompson) microphysics scheme.

changes to both bulk and bin schemes, the correspondence between the two simulations is striking (Fig. 7). We interpret this very positively since the aim of using a bin microphysics scheme is to identify issues and try to improve the bulk scheme mostly due to computational cost of the bin scheme and inherent improvements in explicit microphysical source-sink processes by a bin scheme. Therefore, we are thrilled to be seeing evidence

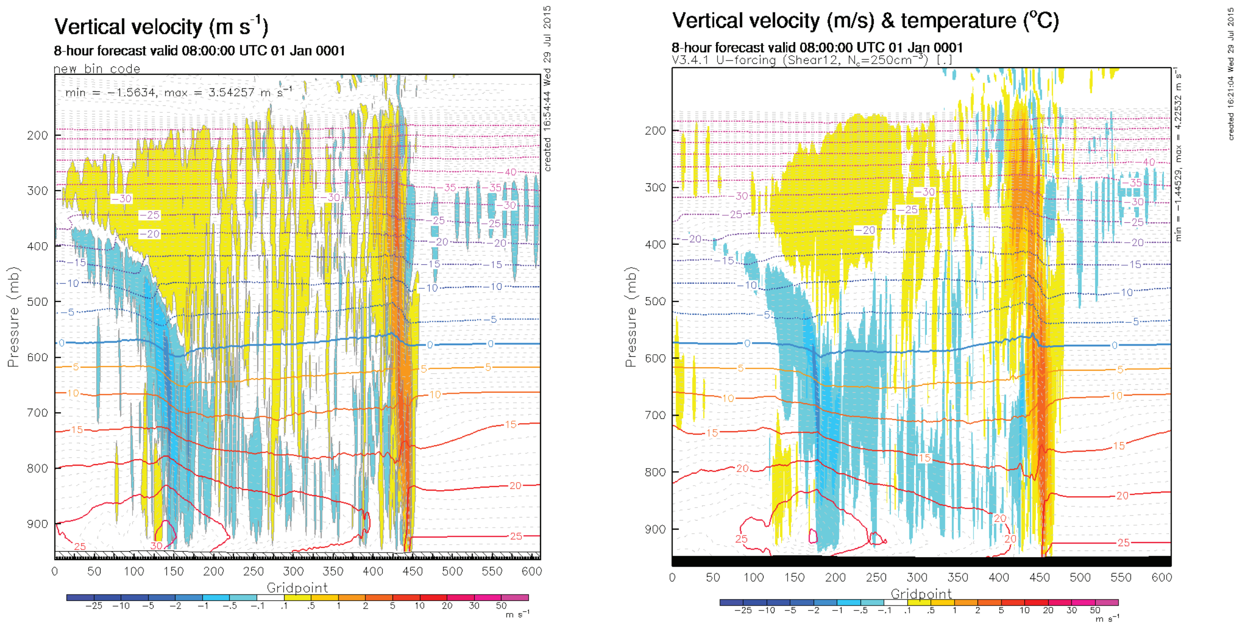

Fig. 5: Cross-section of vertical velocity predicted in the bin scheme (left) versus bulk scheme (right).

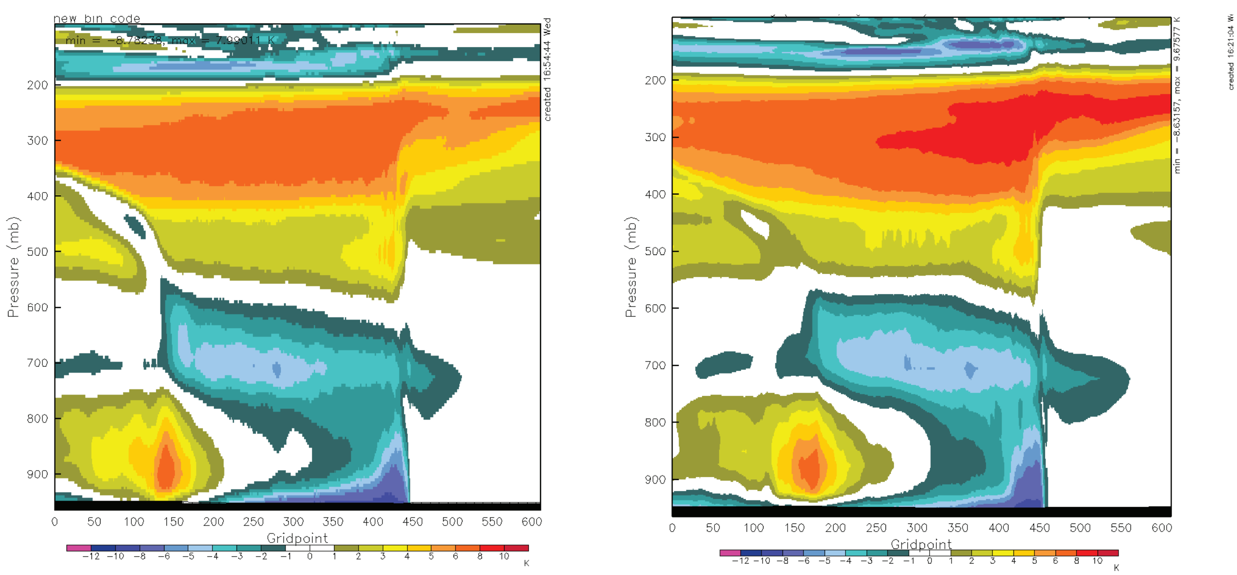

Fig. 6: Cross-section of theta perturbation predicted in the bin scheme (left) versus bulk scheme (right) clearly showing the horizontal and vertical extent as well as the strength of the cold pool in each. This is striking correspondence as compared to simulations done a couple years ago.

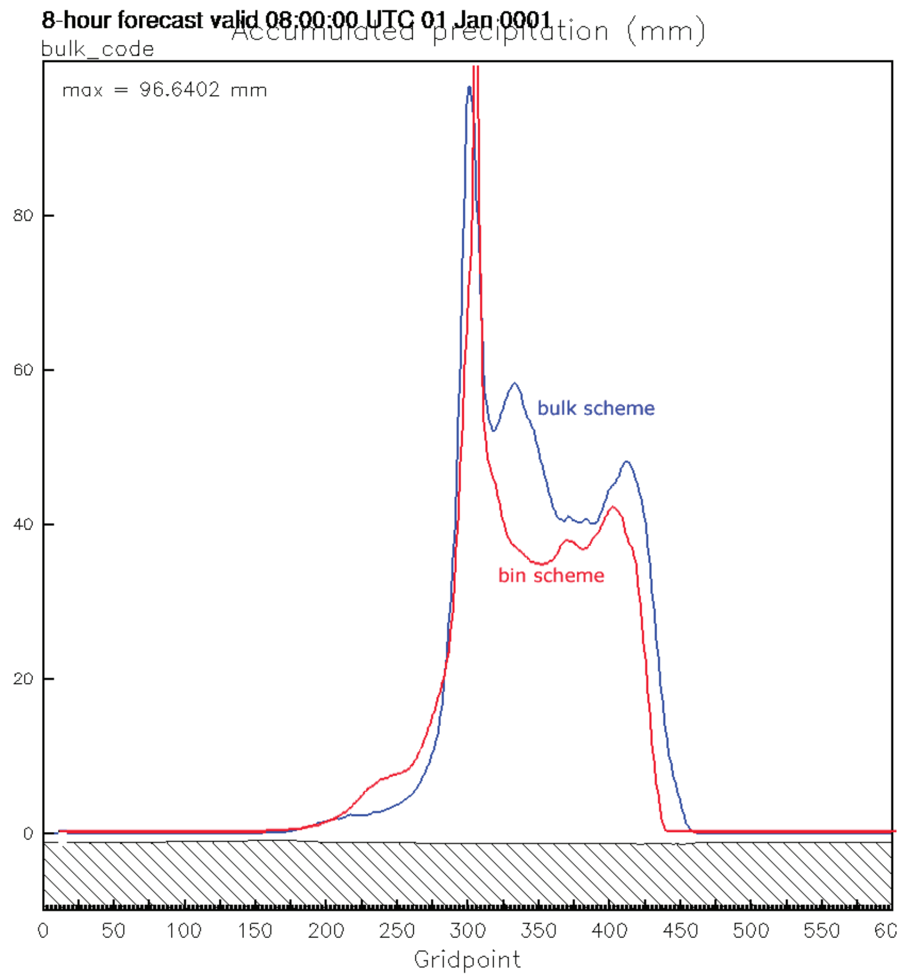

FIG. 7: Total accumulated precipitation after 8 hours in the X-direction predicted by the bin scheme (red) and bulk scheme (blue).

that the two schemes are converging towards the same results now more than ever before.

3. Original Expected Outcomes

- *A rapid research to operations pathway because the Thompson scheme is already available within the NMM-B model.*
- *A state-of-the-art bin microphysics scheme with ice will be available to the WRF-ARW research community to serve for future improvements to bulk microphysics schemes.*
- *Improvements of high-resolution, high-fidelity convective forecasts.*

The first bullet above is considered a success because the lessons learned from the implementation and testing of the bin microphysics scheme has already led to some changes to the bulk Thompson microphysics scheme in WRF. At this time, a transfer of those changes from WRF-ARW to the NEMS/NMM-B model is relatively trivial to complete the path to operations.

The second bullet above is considered partly successful. Due to work two years prior to this DTC support, Istvan's code was ported to v3.4.1, which is now getting out-dated. However, the initial transfer of code with over 500 new variables as compared to original WRF-ARW was far from trivial so the delays in getting the code running stably in the squall line case prevented our group from fully transitioning this software from v3.4.1 into a more recent version, such as v3.7. We are now at a stage where the final steps towards a public release of the bin microphysics scheme is possible and desireable. There is no current schedule for such delivery due to time constraints, but we will investigate the level of effort needed for updating/migrating the code, potentially for a v3.8 WRF release.

The final expected outcome list above has also been achieved to a satisfactory level, given the current state of the art. Both the bin and bulk microphysics schemes are producing very similar appearing squall line structures to each other and to known characteristics of natural squall lines. One remaining concern to mimic nature better is the representation of the "transition region" behind the leading convective edge and before the "trailing stratiform." This complete trifecta remains rather elusive and we conjecture that additional complexity of a high-density ice category (hail) may be needed to fully capture all three features.

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