

Towards improving high resolution NWP forecasts of convection using an explicit/ bin microphysics scheme to guide bulk microphysics scheme improvements

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1. Visit summary

Noémi arrived to NCAR at the middle of December 2017 and departed at the beginning of February, 2018. Most of the goals of the visit were successfully achieved, although some parts of the original research plan were not completed during the visiting time because of timing with other projects and code issues.

During the early summer of 2018 Noémi was able to visit the NCAR again secured by her own funding to support another 2-month visit. However, because of the fact that the abovementioned visit was related to another project limited time was available to work on previous missed points of the DTC project.

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) bulk microphysics scheme and also modify the detailed microphysical scheme to improve the aerosol-cloud interactions (this part of the work mainly was done by István Geresdi).

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. Explicit/bin microphysics scheme

Between 2012 and 2014, the explicit/bin microphysics scheme of I. Geresdi (c.f., Geresdi, 1998; Rasmussen et al, 2002, Sarkadi et al, 2016) was incorporated and extensively tested in WRF v3.4.1. The bin scheme offers a significant advantage over the usual bulk schemes. It makes no *a priori* assumption concerning a functional form of any water species and predicts the number and mass mixing ratio of 36 individual size bins explicitly. As such, it contains a proper spectrum of fall speeds of water and ice particles whereas the bulk schemes must assume that all particles (of single water species) fall at a mass-weighted or number-weighted mean speed. These assumptions may be critical in the growth phase of convective towers because whereas the bin scheme properly simulates that only the largest particles are falling downward relative to the updraft, the bulk schemes may be producing far too much downward moving rain that prematurely evaporates below cloud to create the cold pool that ultimately propagates large-scale convective systems. Most notably, for only the second time in the world, a 2-moment bin microphysics scheme with ice has been run in a fully three dimensional simulation of a squall line. The run was performed using

NCAR's Yellowstone computer in Sep. 2013 using idealized 3D conditions following Case#2 of the 2012 WMO Cloud Modeling Workshop. Because of the fact that bin schemes have explicit bins of particle size, they have hundreds of total predictive variables rather than roughly 10 used by a typical bulk scheme. Until computing power reached its current state, we could only run 2D idealized simulations or water-only bin microphysics schemes to reduce computational cost. Now we have run a state-of-the-art bin scheme in a real-world squall line and other 3D cases. During István Geresdi's 2014 visit, which was partially supported by DTC visitor funds, we encountered some code errors that took far longer to diagnose and correct and we were, therefore, unable to complete the task of fully implementing the bin scheme into a public release of WRF. These issues have now been resolved and we would like to update and adapt the code infrastructure to the most current WRF version (v3.8.1).

b. Test & Evaluation plan

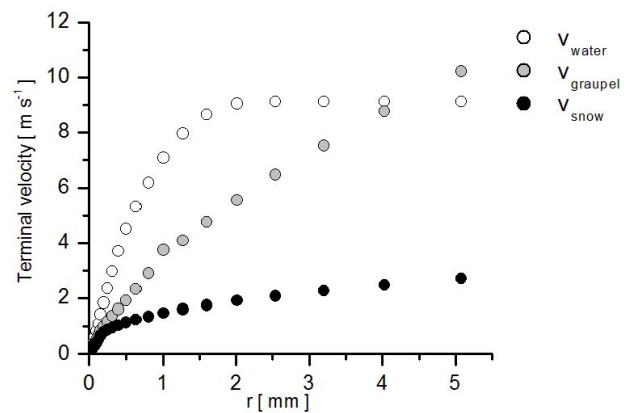
In this section originally the following plans were described:

1. Sensitivity experiment on aggregation of snowflakes within the melting layer, graupel/hail production and its subsequent fall velocity that brings it to the melting layer to create rain. Our aim was to compare the process rates and terminal velocities between the bin and bulk microphysics schemes.
2. Brief investigation on the model grid spacing similar to Bryan and Morrison (2012).
3. Convective cloud investigation: i) based on Fan et al (2017) and ii) a second type of convective cloud system from the most recent International Cloud

Modeling Workshop held at the UK Met Office in July 2016.

c. Realization of the research

Unfortunately, the delays discussed previously slowed progress in this area. Fig. 1 shows the terminal velocity of the different type of particles (dry snowflakes, water drops and dry graupel particles) in the case of the bin scheme.



Hki wt g" 30' Vgto kpcn' xgrqekf" qh' yj g" r ct vkengu" ft{ "
upqy hcnгу."ft{ "i tcwr gn' r ct vkengu."y cvgt "ft qru+lp" yj g"
dkp' uej go gO'

Previous study showed that the Thompson bulk scheme (see reference Sarkadi et al, 2016) is sensitive to the modification of the terminal velocity properties. Table from Sarkadi et al, 2016 added as reference.

Point 2 was investigated by Greg Thompson with bulk microphysics scheme because of the high needs of computer capacity of the bin microphysical scheme.

Because of these expensive run times only 3/ii) was made. The following table (see Table 2) contains the sensitivity runs of the COPE case study. The case studies were run of Cheyenne

supercomputer. One simulation took around 12 days to finish.

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Vcdng"30Tgwnu"qh'vj g'ugpukxkxk' 'yguu'qh'vj g'VJ QORUQP"cpf "DKP"uej go g'y kj 'fHtgt gpv'vgt o kpcn'xgrqek' "x'p"vj g" ecug'qh'vj g'Vj qo ruqp'uej go g'cpf 'y kj 'cpf 'y kj qw'eqnkukq/kpf weg' 'uj gf f kpi "x'p"vj g'ecug'qh'vj g'dkp'uej go g-0'

Crr nkgf "" o let qr j { uecni' uej go g"	Vqeni'co qwpv'qhi' nis wif "" rtgek'kevkq" Jo o _"	Cxgt ci g" f gr vj "" qhi' vj g" o gnkpi "" x{gt'Jo _"	Vqeni' f qo clp"" ceewo wrevgf "" upqy "" qp" vj g" umhcegJo o _"	Vqeni' f qo clp"" ceewo wrevgf "" i t cwr gn'kp'vj g" umhceg'Jo o _"	O czlo wo "" o lzlpi 't cvkq" qhi' upqy hcnngu' ji 'b /5 _"	O czlo w o "o lzlpi "" t cvkq" qhi' i t cwr gi' r ct vknngu' ji 'b /5 _"
DKP EKU'	4385"	8970"	208"	: 0"	2066"	2075"
DKP Y EKU'	4489"	8980 "	204"	408"	2066"	2084"
DWNM'	448; "	; 950 "	: 0 "	5: 0"	2085"	2047"
DWNMB"	; 58"	82808"	202"	: 05"	3047"	2044"
DWNM4"	444; "	: 2: 0 "	202"	570"	2082"	2048"
DWNM5"	438: "	; 7808"	608"	9406"	2073"	2055"
DWNM6"	4383"	9; 709"	202"	9202"	2073"	2055"
DWNM7"	4798"	9950 "	204"	6908"	2077"	204: "

DKP EKU-<qtiki kpcn'dkp'uej go g"

DKP Y EKU-<dkp'uej go g'y kj 'eqnkukq/kpf weg' 'uj gf f kpi "

DWNM<qtiki kpcn'Vj qo ruqp'dwm'uej go g="

DWNMB-<y g'vgt o kpcn'xgrqek' 'qh'vj g'o gnkpi 'upqy hcnngu'ku'gs wcn'v'vj cv'qh'f t { 'upqy hcnngu.'qy gty kug'wpej cpi gf 'Ht qo "DWNM="

DWNM4-<y g'vgt o kpcn'xgrqek' 'qh'vj g'o gnkpi 'upqy hcnngu'f gr gpf u'hkpgctn' 'qp'vj g'gp'xk'qpo gp'cn'vgo r gtcw'g0Cv2AE'k'ku'gs wcn'v'vj g'vgt o kpcn'xgrqek' 'qh'f t { 'upqy hcnngu'y j kn'cv'- 7AE.'k'ku'gs wcn'v'vj g'vgt o kpcn'xgrqek' 'qh'y cvgt 'f tqr u="

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DWNM7-<y g'DWNM6"o qf k'kecvkqpu'y cu'eqo d'kpgf "y kj "eqnkukq/kpf weg' "uj gf f kpi "hqt"i t cwr gn'tckpy cvgt "eqnkukq." qpn' "y j gp" vgo r gtcw'g"ku"i tgcvt'vj cp"2AE'lwu'cu"kp'DKP EKU.'vj g'uwteg"gs wcvkq'ht"pwo dgt "eqpegpvcvkq'qh'tclp'f tqr u'htqto gf 'Ht qo 'vj g" o gnkpi "qh'upqy hcnngu"cpf "i t cwr gn'r ct vknngu'cnngt'gf "v'q"t'gf weg'vj g'o gcp'uk' g'cpf "tclp'ug'n'eqn'evkq'cpf "dt gcn'w' j cu'c"nyj gt" eqpucpvr'tg/hcevt'v'q'ngugp'vj g'lo r cev'qh'o gnkpi "cpf 'tlo kpi 'r t qe'gu'guO'

¹ Vj g'tcpuhgt'hwpevkq'kp'DWNM'wugu'c'k'kpgct'tgrcvkq'ht qo '7'v'97' 'qh'tlo gf 'upqy "o cuu'eqpxgt'v'v'v'q' i t cwr gn'cu'vj g" tlo g'i t qy vj "v'xcr qt'f gr qukskq"i t qy vj 't cvkq'kpetgcugu'ht qo '7-3'v'52-30'k'vj g'DWNM5'g'zr g'tko gpv'c'k'kpgct'tgrcvkq' ht qo '7'v'; 7' 'qh'tlo gf 'upqy "o cuu'eqpxgt'v'v'v'q' i t cwr gn'cu'vj g'tlo g'i t qy vj "v'xcr qt'f gr qukskq't cvkq'kpetgcugu'ht qo '4-3'v'52-30

Table 2 shows the sensitivity simulation properties with bin microphysics scheme. The model setup was the following:

Time period: 3rd August 2013 06 UTC to 3rd August 2013 18 UTC

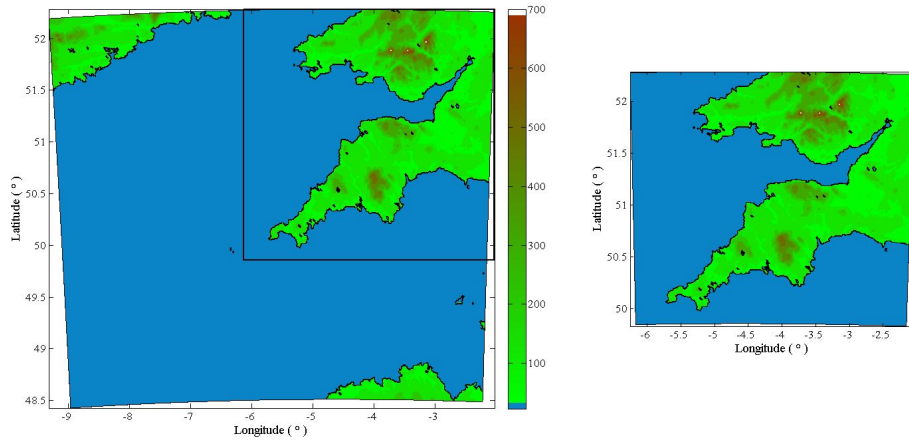
Domain centre (in Figure 2): 50.3928 °N and -5.6331 °E.

Fig. 2. shows the modeled domain and the smaller domain where the analysis was made (MODIS image also attached to the figure).

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Vcdrg"40Ugpubkxkxk' 'iko wrcvqpu't grxvgf 'vq'EQRG'ecug'lawf {0'

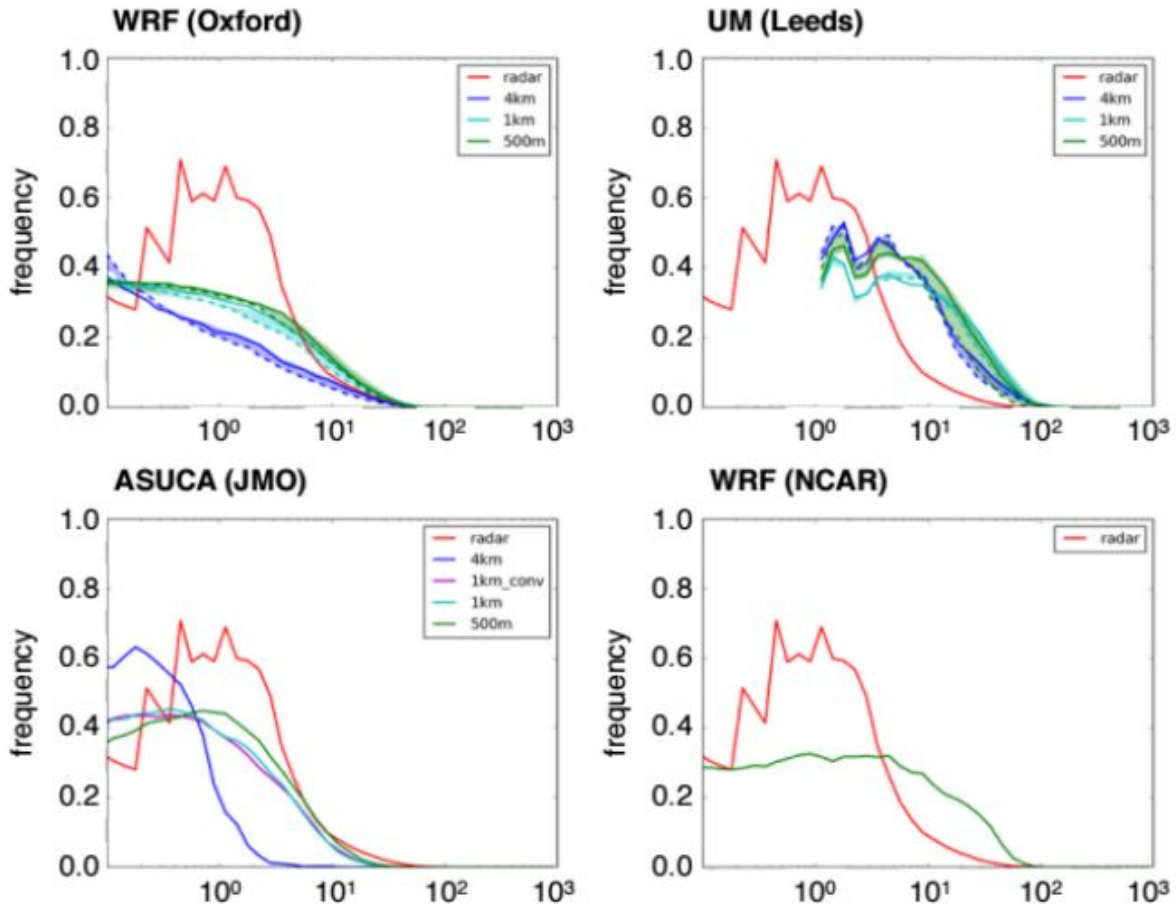
"	EVTN"EE+"	PQJO "EE+"	EVTN"FO+"
F qo clp'uk' g'lp'j qt'k qpvcn'	: 52z922"	: 52z922"	: 52z922"
J qt'k qpvcn't guqnwkqp"	822'o "	822'o "	822'o "
F qo clp'uk' g'lp'xgt'lecn'	93"%42'no +"	93"%42'no +"	93"%42'no +"
Xgt'lecn't guqnwkqp"	wt'gej gf 'i tlf "%67/922'o +"	wt'gej gf 'i tlf "%67/922'o +"	wt'gej gf 'i tlf "%67/922'o +"
Ulo wrcvqp'v'o g'"	34'j "	34'j "	34'j "
Vlo g'lvgr"	5'u"	5'u"	5'u"
O letqrj {ulecn't qeguugu"	CNN"o letqrj {uleu"	Y kj qw'J cngwO quqr 'ghgev'	CNN"o letqrj {uleu"
K'g'lp'k'le'v'qp'r't qeguug"	Eqqr gt.'3; : 8"	Eqqr gt.'3; : 8"	F gO qw'gv'c'0'4232"



*Hki wt g"40"Uo wrvfg "f qo clp"*qr" rgh±"cpf "uo cngt "f qo clp"*qr "t ki j v±lp"y j kej "j g" f qo clp/cxgt ci gf "xcwgu"y gt g" ecrewrvfg."cpf "O QF KUko ci g"qh36-22"WVE "dqwqo +"*

Comparison between results of different bulk models (see Fig. 3) with observations and comparison between bulk and bin (see Fig. 4) scheme shows large spread of data. Results of the bin scheme shows better agreement with the observations to catch the highest peak of light or moderate precipitation rates during the simulations. As Fig. 4 shows Hallett-Mossop

effect has large impact on domain average precipitation intensity. Without this effect (green line) underestimation of the intensity occurs.



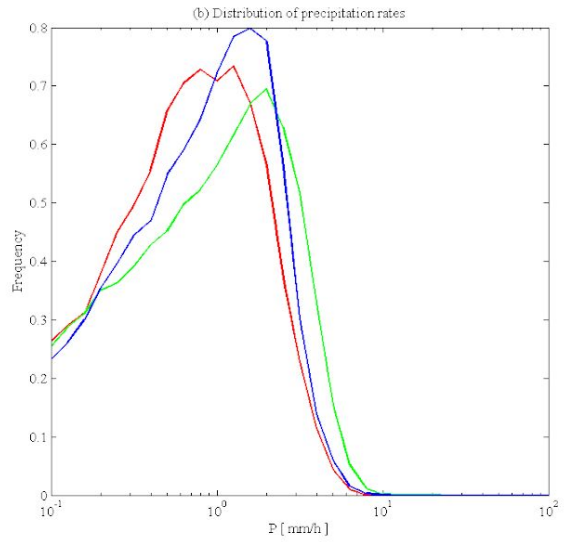
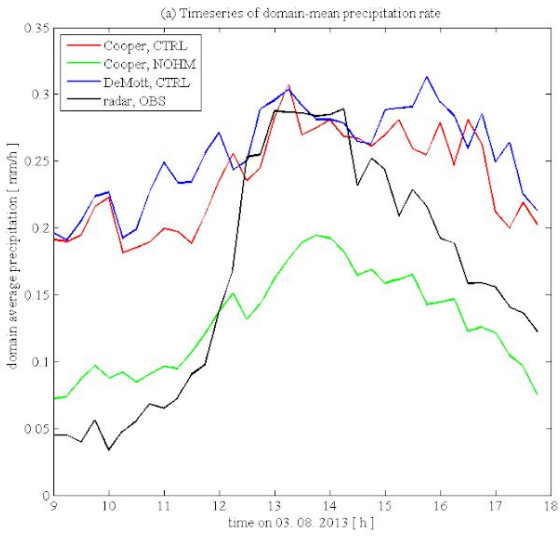
*Hli wt g"50Hqwt 'f lltgt gpv'o qf gn'uko wrvklpu'qh'lt gswgpe{ "qh'rt gekr kcvkqp"tcvg"*o o "j/3+'cu'eqo rct gf "vq'tcf ct'f cwO' Cn'l'o qf gnu'wpf gt/guko cvg'yj g'vki j v'vq'o qf gt cvg't ckp"tcvgu'cpf "o quw'qxgt/guko cvg'yj g"j gcvkgn'rt gekr kcvkqp"tcvguO' F lltgt gpv'eqrqt gf "ewt xgu't grt gugpv'o qf gnu'twp'y kj "f lltgt gpv'i tlf "ur celpi uO'Ko ci g'eqwt vgu{ "qhlCpPgwg'O lnxgpdgt i gt" *WpkxONgc f uO'*

This means that secondary ice production between -3 and -8°C plays an important role in surface precipitation formation.

Comparing the different bin schemes with observed radar reflectivity frequencies shows the model and measurements are in good agreement (Fig. 5 and Fig. 6).

Figures 7 and 8 show the simulated domain and time averaged microphysical profiles of different

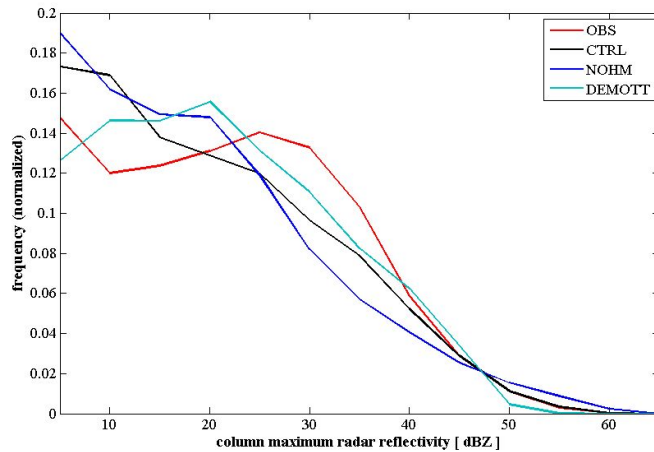
hydrometeors (water drops [both cloud water and rain], snowflakes, ice crystals, graupel particles). However, the different ice initiation schemes do not significantly affect the liquid water content in the clouds but have a large impact on the ice phase.



*Hli wt g"60'Vlo gugi kgu"qhl'f qo clp/o gcp"rt gekr kcvkqp"t cvg"*c+cpf'f kat kdwkqp"qhl'rt gekr kcvkqp"t cvgu"*d+"ht qo "o qf grl' uko wrcvqpu"*ugg'f Wlgt gpv'eqplki wt cvkqpu'kp'Vcdng"4+cpf't cf ct "qdugt xc vqpu"*drc em'kpg'kp"r ct v'c+0"*

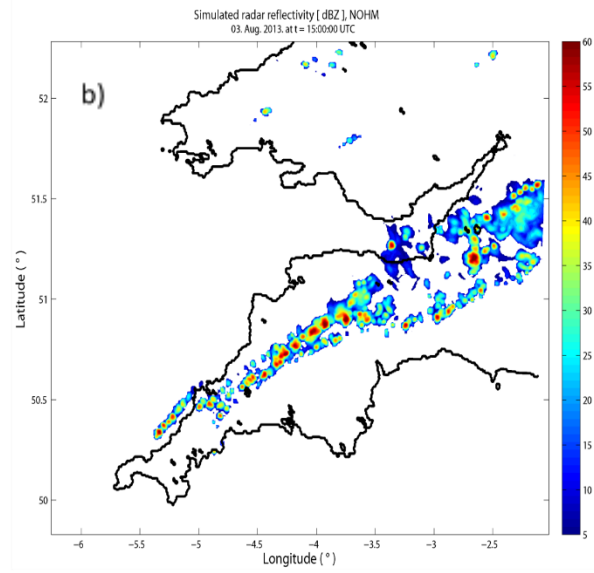
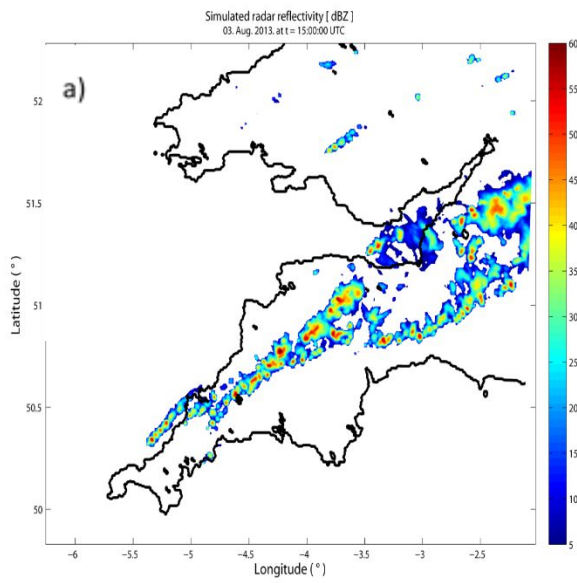
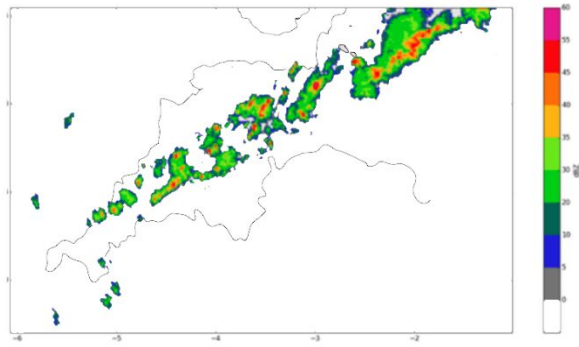
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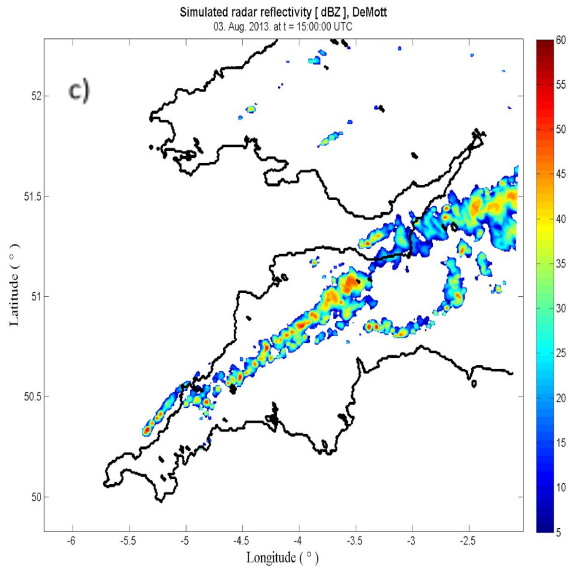
"



*Hli wt g'70F kat kdwkqp"qhl'eqno p'o czko wo "t ghgewkxk' "ht qo "t cf ct "qdugt xc vqpu"*drc em'+c'pf "o qf grl'uko wrcvqpu" *eqrqt u+0'*

"

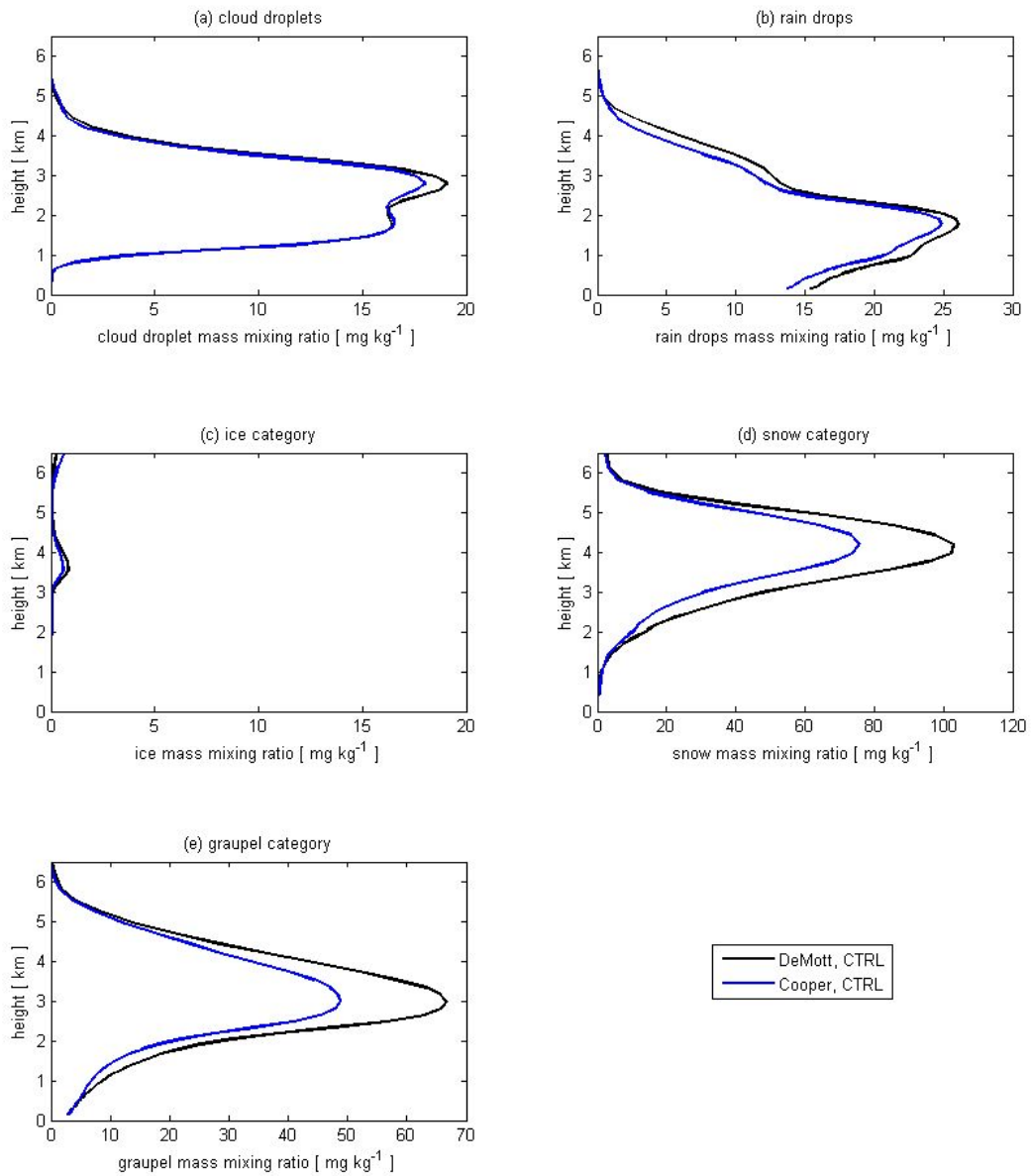




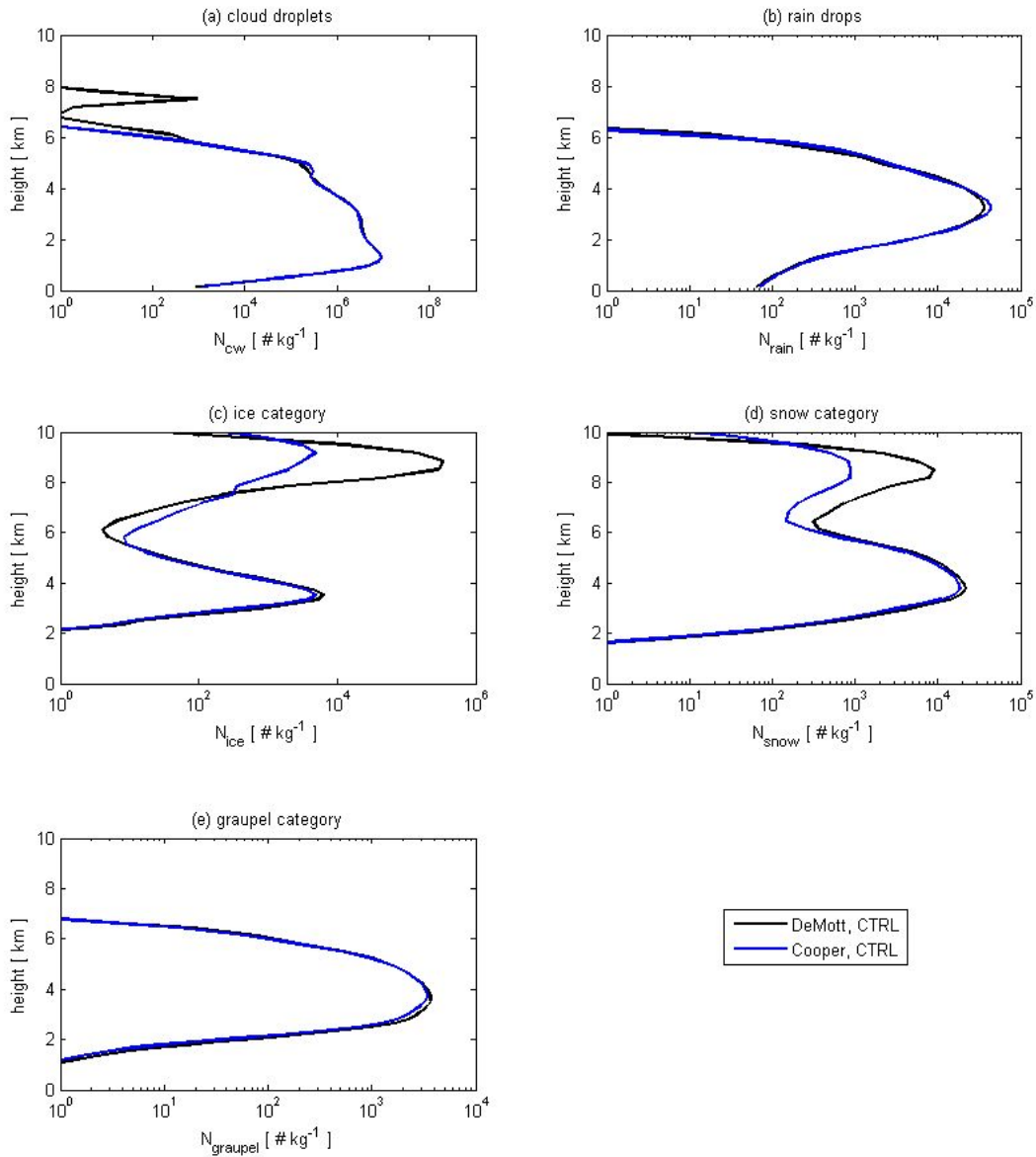
Hli wt g"80Qdugt xgf "qqr"o kf frg+"cpf"uko wrxvf"t cf ct "t ghgevkxkx/ "kgrf u"%c +Eqqr gt."EVTN."%d +Eqqr gt."PQJ O "cpf" %e +F gO qw."EVTN"cv'250Cwi 04235'37-22'WVE"%gcej "r cpgn0'

In the case of the ice crystals, the DeMott ice initiation scheme did not affect the mass of the formed ice crystals but did change the number concentration of ice. Because of a large change in the number concentration of the ice crystals, the number and mass of the generated

snowflakes also increased. An interesting result is that the number of the falling graupel particles did not change from the DeMott ice initiation scheme, but the mixing ratio of the graupel particles significantly increased.



Hki wt g"90'Rt qhkgu"qh'j {ftqo vggqt"o cuu"o k kpi "tcvku"cxgt ci gf "dgwy ggp"32/39-67"WWE"qxgt"cm'i tkf r qkpui"kp"vj g" uo cmgt 'f'qo clp<*&c +enqwf 'ftqrngv."%d+tckp'ftqru."%e+leg'et{ucnu."%f +lupqy hcngv."%g+i tcwr gilrct vkengu'kp"]'o i hi "_0'



Hki wt g': 0Uco g'cu'Hki 00dw'lqt 'pwo dgt 'eqepgt c'kqp0'

3. Original Expected Outcomes

A number of positive outcomes are expected from the planned research:

- 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.

Although not all of the planned tests were performed during the visit, the aforementioned outcomes favor considering

the project a success. The following work was done during the visit:

Implementation of a new ice initiation process (DeMott, 2010) into bin microphysics.

Implementation of more detailed aerosol – cloud interactions in the bin scheme is under development. The addition of aerosol particles into the bin scheme are in progress by István Geresdi based on DeMott simulations.

The bin scheme was successfully implemented into a newer version of WRF v3.7.1.

Radar reflectivity calculations were post-processing in previous version and also required high computational resources. The radar reflectivity calculation was implemented and coupled with the WRF and the bin scheme. As a result data analysis became faster.

Three different kinds of sensitivity studies were made by bin scheme and also with bulk scheme in COPE case study.

The final expected outcome will be a paper in high-ranking journal. The manuscript is being prepared, and the expected submission will be early summer in 2019.

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