SENSITIVITY OF QUANTITATIVE PRECIPITATION FORECAST TO SOIL MOISTURE INITIALIZATION, MICROPHYSICS PARAMETERIZATION AND HORIZONTAL RESOLUTION

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I. INTRODUCTION

A major debate in the atmospheric mesoscale modelling community is associated with the strong deficiencies in several aspects of the quantitative precipitation forecast (QPF), despite a continuously improving representation of the physical processes and improving numerical techniques. The scope of the present research is to gain insight in how operationally feasible modifications to aspects of the QPF interrelate and if current insights for mainly idealized experiments could be confirmed for real case simulations. We performed a number of sensitivity experiments, including modified soil moisture content, more realistic microphysical size distribution assumptions and enhanced spatial resolution. Two cases of extreme convection were selected, one having strong vertical wind shear conditions and modest thermodynamic instability and a second having almost no vertical shear and strong thermodynamic instability.

II. MODEL SETUP

In order to assess the impact of the sensitivity experiments we employed the Advanced Regional Prediction System (ARPS - Xue et al. 2000 and Xue et al. 2001). The model was applied using one-way grid nesting with two levels. Analysis data on a 0.25° horizontal resolution from the global operational model operated by the European Centre for Medium-Range Weather Forecasts (ECMWF) were used as initial conditions and as 6-hourly lateral boundary conditions for the model integration with a 9-km grid spacing and a domain size of 1620 km × 1620 km. Within this domain, a smaller domain, centred over Belgium and covering 540 km × 540 km with a 3-km resolution was nested. Cloud microphysics was parameterized following Lin et al. (1983 further referred to as LFO83), including five water species (cloud water, cloud ice, rain water, snow and hail).

III. EXPERIMENTAL DESIGN

A series of five sensitivity experiments has been designed to compare the impact of modifications to soil moisture content, size distribution assumptions and enhanced spatial resolution. A first set of two experiments consisted of a decrease of the initial soil moisture to the lowest recorded value by Nachtergaele and Poesen (2002) over one year in a Belgian loam area (DRYSOIL) and an increase to saturated volumetric soil moisture content (WETSOIL).

In a second set of experiments we applied more realistic size distribution assumptions for the precipitating hydrometeors. All precipitating hydrometeors in the LFO83 scheme are represented by exponential size distributions of the form:

$$N_x(D) = N_{0x}\exp(-\lambda_x D_x), \quad (1)$$

where N is the number of particles per unit volume per unit size range, D is the maximum dimension of a particle and N_{0x} and λ_x are the intercept and slope of the exponential size distribution respectively. While the intercept parameter of all hydrometeors is assumed constant, slope parameters, assuming all hydrometeors to be constant density spheres, are determined by

$$\lambda_x = \left(\frac{\pi\rho_x N_{0x}}{\rho_{air} q_x}\right)^{0.25}, \quad (2)$$

where ρ_x is the hydrometeor density, q_x the hydrometeor mixing ratio and ρ is the air density. From many observational data it is clear that intercept parameters are not constant, but vary over many orders of magnitude. Therefore we diagnosed the intercept parameter of rain using a mixing ratio dependent relation (Zhang et al. 2008) and the snow intercept parameter of snow using a temperature dependent relation (following Houze et al. 1979). Further, the constant density sphere relation for snow is found to be problematic in a number of studies to mainly cold season stratiform precipitation. Hence we calculated the slope parameter and terminal fall velocity of snow using V-D and m-D relations found by Locatelli and Hobbs (1974) for graupellike snow as proposed by Woods et al. (2005)

$$\lambda_x = \left(\frac{a_m N_{0x}\Gamma(b_m+1)}{\rho_{air} q_x}\right)^{1/(b_m+1)}, \quad (3)$$

Last, Gilmore et al. found a strong sensitivity of the surface precipitation to the way the hail/ graupel variable was parameterized in idealized cases of extreme convection. The two microphysical size distribution experiments we conducted had all modifications previously mentioned, but one experiment having the original formulations of large hail, (MIRSH) while in a second experiment we replaced these formulations with those typical for small graupel. We increased the constant intercept parameter and used the m-D and V-D relations found by Locatelli and Hobbs (1974) for lump graupel in the calculation of the slope parameter and the terminal fall velocity (MIRSG).

A last experiment was conducted to investigate the influence of enhanced horizontal spatial grid spacing (GR1500) by decreasing the grid spacing to 1500 m as compared to the 3000 m of the CONTROL experiment.

III. RESULTS AND CONCLUSIONS

Table 1 summarizes the surface precipitation statistics and a number of thermodynamic and heat balance statistics for all experiments and both cases. During the shear-driven case surface precipitation is mostly improved in the DRYSOIL and the MIRSH experiments. The main reason for the improvements in the DRYSOIL experiment is the decreased buoyancy leading to lower precipitation values. In the MIRSH experiment increased depositional growth of snow leads to more snow at the expense of cloud water and hail and hence slower precipitation fallout despite stronger updrafts. Replacing large hail by small graupel (MIRSG) did not decrease the precipitation further, contradicting the results of Gilmore et al. (2004). Increasing the horizontal resolution makes the precipitation fields very noisy with widespread precipitation due to grid-scale storms.

Shear	**CONTR**	**MIRSH**	**MIRSG**
Mrr	3.1	2.6	2.7
Xrr	47.8	46.7	49.9
CAPE	387.3	403.2	400.7
LCL	505.8	516.4	518.3
Xw	10.5	11.0	12.4
Xcp	6.9	8.1	6.6
	GR1500	**DRYSOI**	**WETSOI**
Mrr	5.3	2.7	2.9
Xrr	53.3	40.9	54.4
CAPE	343.1	312.1	413.4
LCL	480.8	592.9	480.9
Xw	11.8	9.3	11.8
Xcp	5.7	7.3	6.7
Buoyancy	**CONTR**	**MIRSH**	**MIRSG**
Mrr	11.1	11.1	13.7
Xrr	198.7	179.8	130.9
CAPE	816.1	986.0	683.8
LCL	400.8	435.3	415.9
Xw	16.2	18.3	19.9
Xcp	4.3	5.2	5.3
	GR1500	**DRYSOI**	**WETSOI**
Mrr	10.0	9.6	11.1
Xrr	139.7	190.2	206.0
CAPE	765.7	785.5	866.9
LCL	448.2	459.0	396.5
Xw		16.0	16.9
Xcp		5.2	4.5

TABLE I: Precipitation and (thermo)dynamic statistics of all model experiments (Mean surface precipitation (Mrr), Maximum surface precipitation (Xrr), Convective Available Potential Energy (CAPE), Lifted Condensation Level (LCL), Maximum vertical velocity (Xw) and Maximum cold pool temperature deviation from domain average temperature (Xcp)).

In the buoyancy-driven case, the DRYSOIL experiment yields similar improvements of the moist processes and the surface precipitation, but the MIRSH experiment does not yield clear improvements. There is a clearly increased vertical velocity as buoyancy increases associated with the increased depositional growth of snow. CAPE is indeed the only driver of the convection in this case and hence the increased buoyancy compensates for slower precipitation fallout. The MISRG experiment in this case leads to a decreased peak precipitation but a strongly increased mean surface precipitation. Due to enhanced collection of snow by graupel as compared to CONTROL graupel volume and maximum graupel amount grow to much larger values. This leads to much broader precipitation swaths and larger accumulated surface precipitation. Increasing the horizontal resolution in these cases clearly improves the surface precipitation as convection was forced on more realistic scales.

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V. REFERENCES

Gilmore, M.S., J.M. Straka, E.N. Rasmussen, 2004: Precipitation uncertainty due to variations in precipitation particle parameters within a simple microphysics scheme. *Mon. Wea. Rev.*, 132, 2610-2627.

Houze, R.A., P.V., Hobbs, P.H. Herzegh, D.B. Parsons, 1979: Size distributions of precipitation particles in frontal clouds. *J. Atmos. Sci*., 36, 156-162.

Lin, Y.-L., R.D. Farley, H.D. Orville, 1983: Bulk parameterization of the snow field in a cloud model. *J. Climate Appl. Meteor.*, 22, 1065-1092.

Locatelli, J.D., P.V. Hobbs, 1974: Fall speeds and masses of solid precipitation particles. *J. Geophys. Res.*, 79, 2185-2197.

Nachtergaele, J., J. Poesen, 2002: Spatial and temporal variations in resistance of loess-derived soils to ephemeral gully erosion. *European Journal of Soil Science*, 53, 449-463.

Woods, C.P., M.T. Stoelinga, J.D. Locatelli, 2007: The IMPROVE-1 storm of 1-2 February 2001. Part III: Sensitivity of a mesoscale model simulation to the representation of snow particle types and testing of a bulk microphysical scheme with snow habit prediction. *J. Atmos. Sci*., 64, 3927-3948.

Xue, M., K. K. Droegemeier, V. Wong, 2000: TheAdvanced Regional Prediction System (ARPS) – A multi-scale nonhydrostatic atmospheric simulation and prediction model. Part I: Model dynamics and verification. *Meteorol. Atmos. Phys.*, 75, 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, D. Wang, 2001: The Advanced Regional Prediction System (ARPS) – A multi-scale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. *Meteorol. Atmos. Phys*., 76, 143-165.

Zhang, G., M. Xue, Q. Cao, D. Dawson, 2008: Diagnosing the intercept parameter for exponential raindrop size distribution based on video disdrometer observations: model development. *J. Appl. Meteor. and Climatology*, 47, 2983-2992.