J1.5 A THEORETICAL STUDY OF THE IMPACT OF ANTHROPOGENIC CCN ON THE DYNAMICS OF DEEP CONVECTIVE CLOUDS IN THE EPIC REGION

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1. INTRODUCTION

Clouds are important components of the climate system as they affect the Earth's albedo and they participate in the hydrological cycle. One of the largest uncertainties in climate modeling is the parameterization of convective processes, in particular, the question of how anthropogenic emissions affect the different types of clouds is still open. Most research has been devoted to warm stratocumulus clouds, and only recently have some studies incorporated changes in cirrus and mixed phase clouds. Emissions of gases and particles in industrial and urban regions may affect the microphysics and dynamics of clouds developing near as well as downwind of such emissions.

In this study we have introduced changes in the parameterization of the autoconversion and accretion processes in the Advanced Regional Prediction System (ARPS). The CCN used in the model were obtained from in situ observations by the instrumented C-130 (NSF, operated by NCAR), during the East Pacific Investigations of Climate (EPIC). Two cases were selected, one of them with evidence that the CCN were modified by anthropogenic influence. The spectra were then incorporated as initial droplet distributions for the simulations. The main goal was to study the response of mixed-phase clouds to enhanced ambient CCN over this area.

2. THE MODEL

We used the numerical model Advanced Regional Prediction System (ARPS, Version 4.5.1), a 3-dimensional, non-hydrostatic, compressible model valid for scales of a few meters to hundreds of kilometers (Xue et al. 1995). ARPS was developed at the Center for the Analysis and Prediction of Storms, University of Oklahoma and has been used in a variety of numerical studies (Xue et al., 1996; Fovell and Tan, 1998, Xue et al. 2001, 2002, 2003).

The bulk microphysical parameterization in the model is in Lin et al. (1983) for mixed phase processes. That includes a modification of Berry's (1967) parameterization for rain autoconversion. We have modified these parameterizations in order to incorporate the effect of increased ambient CCN and therefore, activated droplets. The methodology proposed by Liu and Daum (2004), based on gamma functions for cloud droplet distributions, was incorporated.

The parameters in the gamma distribution are obtained from observations made in the regions of EPIC, for clean and polluted cases.

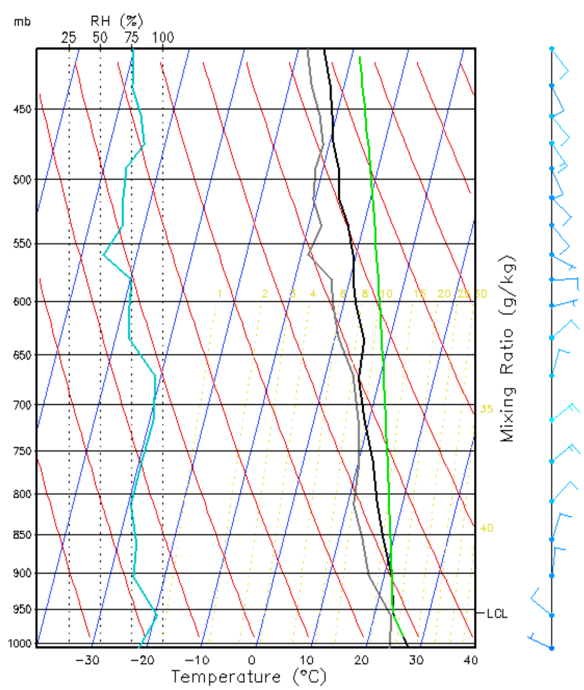

Fig. 1 Thermodynamic sounding at 10 N and 95 W.

A set of simulations was performed with the new autoconversion parameterization. Two of these

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simulations will be shown: using a clean (29 September, 2001) and a polluted (16 September, 2001) spectrum. Both were initiated with the same thermodynamic sounding (Fig1), obtained from a radiosonde deployed from the Ron Brown oceanographic ship stationed at 10 N and 95 W, during EPIC. An initiall perturbation in potential temperature (0.75) was placed at the center of the domain to trigger convection.

3. RESULTS

The analysis of the processes that give place to the formation of precipitation, showed that, in the clean case, the autoconversion of qc to qr (900s of simulation) occurs first, and once there is a certain content of precipitation this iniciates the accretion of qc by qr, Fig. 2a. This is in agreement with fig. 2b where precipitacion (qr>10^{-5} kg kg) appears at 1000s. The warm processes are the main contributers to the rain until the 2000s, even though, the melting of snow and hail starts since 1400s. After 2000s it is the melting of hail what contributes most to precipitation (fig. 2a and 2b).

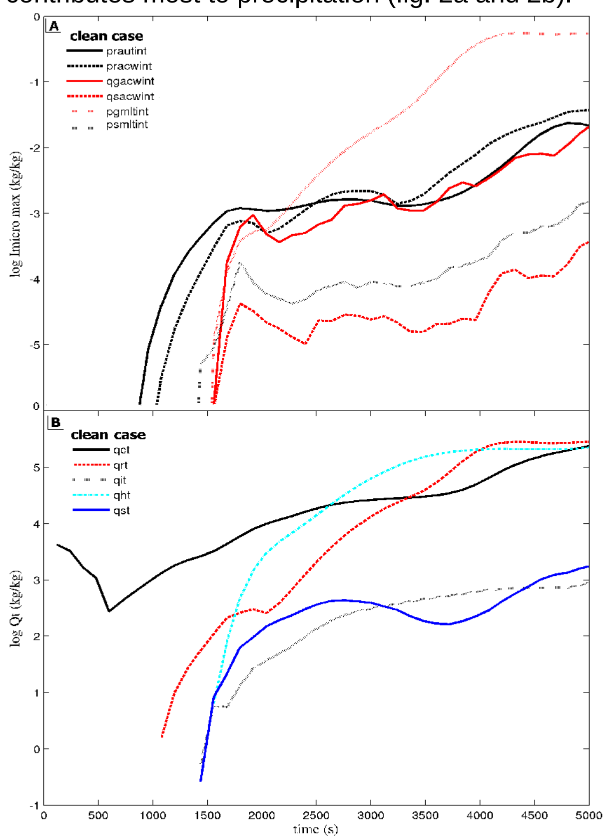

Fig. 2. Clean case processes that produce precipitation (A) and total amounts of hydrometeors(B), calculated every 120s for the whole domain.

In the polluted case the autoconversion is inhibited and precipitation is started by the melting of snow, (which appears for the first time due to the Bergeron processes) and accretion of qc by snow and hail, Fig 3a. From 2000s on, hail melting becomes the most important process in the production of precipitation. Fig. 3b shows a clear correspondence between the total content of qr and this process. A delay can also be seen in the appearance of solid hydrometeors with regard to the clean case because hail had formed earlier there by the freezing of qr.

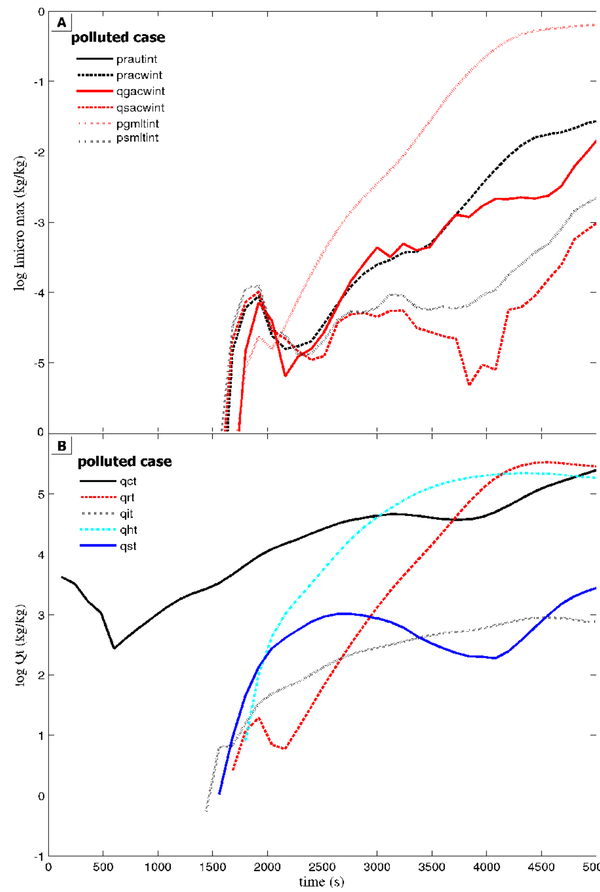

Fig. 3. Polluted case processes that produce precipitation (A) and total amounts of hydrometeors(B), calculated every 120s for the whole domain.

Figs. 4a and b show that the content of qr over the whole volume, from 4200 s on, is larger for the polluted case as well as the accumulated precipitation between 4500 s and 5700 s (Fig. 4b). In this interval the maximum of qr at the surface is also bigger since there is a larger concentration of qc, qi and qs, that in the first place produce a greater quantity of hail, which upon melting contributes to produce more of qr, and also accelerate their accretion by qr once its content is different from 0. This behavior of qr can be unrealistic as the parameterization of the solid phase processes do not take into account the effect of increasing aerosol number.

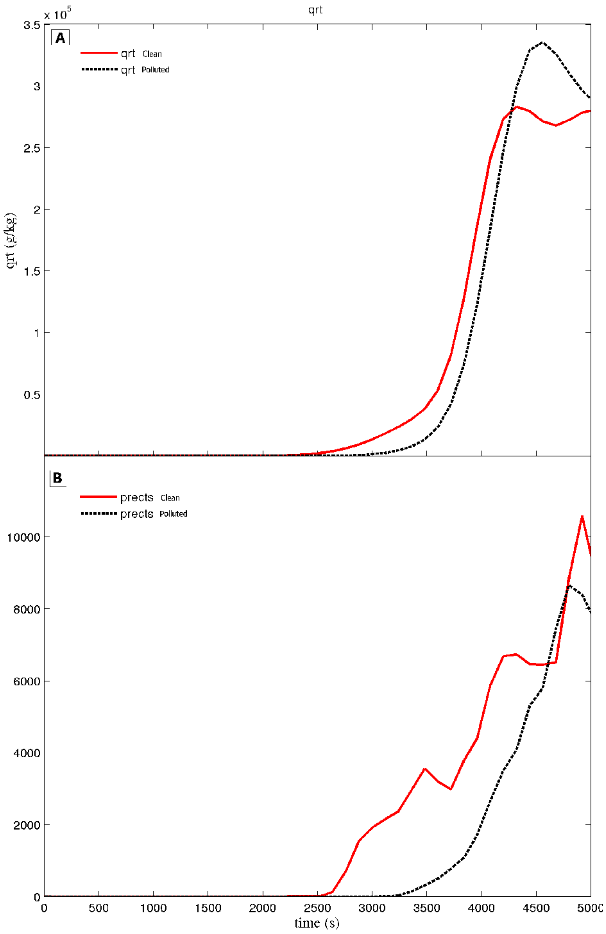

Fig. 4. Total amounts of qr, for the whole domain (A) and accumulated precipitation at the surface level (B), calculated every 120s for clean (solid red) and polluted (dashed black) cases.

Overall, the amounts of qc, qi, and qs were greater in the polluted case (Fig 2b). The total values (volume and time) of these variables are: 18.6x10^6, 11.0x10^4 and 19.2x10^4 respectively vs 16.6x10^6, 10.0x10^4 and 15.2x10^4 for the clean case. There was, however, much more precipitation at the surface for the clean case if the whole life span of the cloud is considered (Fig. 4b). The values of the areas under the curves on this figure are 3.8x10^5 for the polluted case and 4.6x10^5 for the clean case. The area of precipitation and the precipitation accumulated at the surface are also affected as the effect of an increase in the initial number of particles is incorpotared.

Cloud precipitation eficiency (CPE), defined as the ratio between the amount of accumulated precipitation at the surface and the total amount of qc for every 120 s time slice is shown on Fig. 5a for the clean and polluted cases. The polluted case CPE amounts to only 25% of the clean case.

All of this is in agreement with the hypothesis that precipitation is inhibited when there is a very large amount of CCN.

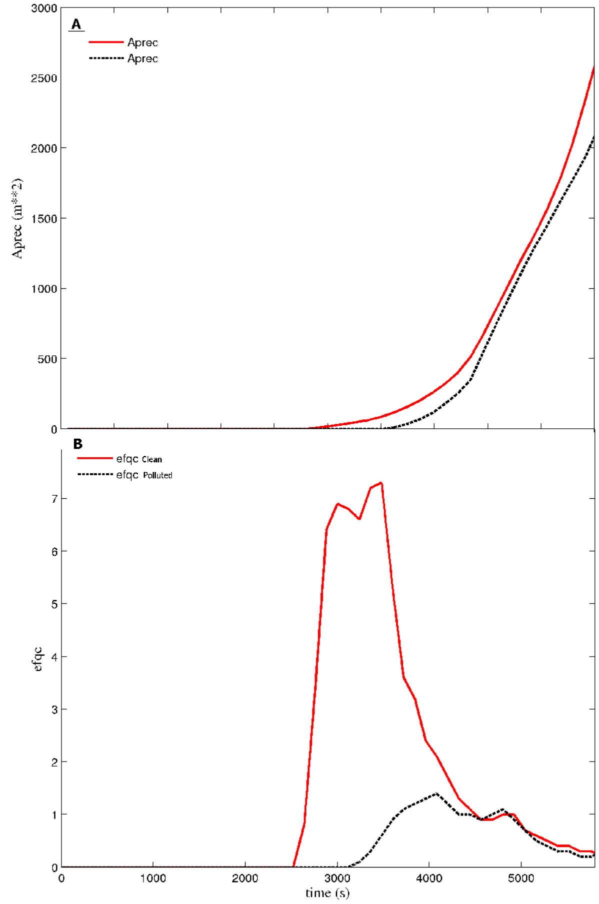

Fig. 5. Total precipitation area (A) and precipitation eficiency (B), calculated every 120s for clean (solid red) and polluted (dashed black) cases.

4. CONCLUSIONS

This study evalutes the response of mixed-phase clouds to enhanced ambient CCN. The Liu and Doun autoconversion scheme was introduced in ARPS to account for the presence of enhanced cloud droplet concentrations.

The results indicate that the dynamics of the deep, mixed phase clouds simulated is sensitive to the input of large concentrations of anthropogenic CCN. The precipitation development is delayed and reduced in the simulations when more CCN are included though larger amounts of qc, qi and qs are generated. These results are in agreement with observations of the precipitation spectra from the C-130, that had indicated the absence of large droplets in the most polluted situation.

The fact that precipitation eficiency decreases in the polluted cases proves the important role of warm proceses in the precipitation production even for mixed phase clouds. In other cases of polluted spectra, where the clouds do not reach the freezing level there is no precipitation at the surface. Nevertheless, some other simulations with higher instability in the environment and strong dynamics indicate a substantially reduced sensitivity.

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REFERENCES

Fovell, R. G., and P.-H. Tan, 1998: The temporal behavior of numerically simulated multicell-type storms. Part II: The convective cell life cycle and cell regeneration. Monthly Weather Review, v. 126, p. 551-577.

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

Liu, Y. and Daum, P. H., 2004: Parameterization of the autoconversion process. Part I: Analytical formulation of the Kessler-type parameterizations. J. Atmos. Sci. 61, 1539-1548.

Xue, M., K.K. Droegemeier, V. Wong, A. Shapiro and K. Brewster. 1995: ARPS Version 4.0 User's Guide. Available from Center for Analysis and Prediction of Storms, University of Oklahoma, Norman OK 73072. 380pp.

Xue, M., K.K. Droegemeier, D. Wang, and K. Brewster, 1996: Prediction and simulation of a multiple squall line case during VORTEX-95. Preprint: 18th Conf. on Severe Local Storms, 19-23 Feb., Amer. Meteor. Soc., San Franciscon, CA.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part I: Model dynamics and verification. Meteor. Atmos. Physics., 75, 161-193.

Xue, M., K. K. Droegemeier, V. Wong, A. Shapiro, K. Brewster, F. Carr, D. Weber, Y. Liu, and D.-H. Wang, 2001: The Advanced Regional Prediction System (ARPS) - A multiscale nonhydrostatic atmospheric simulation and prediction tool. Part II: Model physics and applications. Meteor. Atmos. Physics., 76, 134-165.

Xue, M., D.-H. Wang, J.-D. Gao, K. Brewster, and K. K. Droegemeier, 2003: The Advanced Regional Prediction System (ARPS), storm-scale numerical weather prediction and data assimilation. Meteor. Atmos. Physics, 82, 139-170.