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Use of a mesoscale model and a radar simulator to analyze the feasability of x-band radar retrieval algorithms

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1 Introduction

An X-band polarimetric radar, with coherent reception has been developed in our laboratory. This radar has been designed for hydrological applications such as the monitoring of rain events and quantitative precipitation estimate above small watersheds. This research radar will soon be involved in an experiment in Africa, as part of the international program for African Monsoon Multidisciplinary Analysis (AMMA). Fig. 1 present a schematic of the site, situated in northern Benin (near 2° E, 10° N, see also Fig. 5 which gives a general view of West Africa and the window over which the mesoscale model was run). The radar will be located in Djougou, in the Upper Valley of the Ouémé River in Benin. From that location the radar will have a good coverage of the Donga Basin, a 600 km^2 watershed already well equipped with a good network of rain gages and a variety of hydrological sensors to measure river outflows, ground water levels, soil humidity and even geochimical methods to trace the origin of the water. The radar will be operating for the 3 years of the AMMA Enhanced Observation Period (EOP) from 2005 to 2007. Unlike in the Sahelian zone where extensive studies were already carried out (EPSAT Niger, Hapex Sahel experiments) the variety of rain events in the soudanese region has not been studied yet. However the few data gathered thanks to raingages on the ground or an analysis of the satellite images reveals that the precipitations in these region are quite complex, with fewer organized squall lines then in the Sahel but a richer variety of situations.

The objectives of the radar experiment are :

– to provide the hydrological models with good spacial and temporal resolution maps of precipitation, in order to study the impact of rainfall variability on the hydrological response and to get an insight in the processes involved.

– To derive statistics on the 3D structure of precipitation in that region. This is important, for example, to feed precipitation downscaling methods, used to force hydrological models with precipitaion field derived from spaceborne estimators or large scale meteorological models. Such statistics linked with satellite observations of the dynamics and spatial extension of the precipitation systems, are also important to adjust locally the algorithms used to estimate rain from satellite data. Such statistics are also very important to understand which parameters are important for rainfall efficiency.

– To carry out case studies on a variety of systems and understand what microphysical processes are at stake in these systems. One of the important parameters to be studied are the vertical profiles and the occurrence of rain evaporation.

To achieve the above objectives the scanning strategy planned for our radar, Xport, consists in a combination of volumetric scans (12 PPIS) associated with fixed vertical pointing mode to allow a fine resolution of the vertical profiles. Several polarimetric based algorithms, will be used to insure attenuation correction and give an estimate of rain. (Matrosov 2002, Testud 2000, Sauvageot 1996).

In order to prepare the above experiment, to optimize the scanning strategy and select and pre-tune the algorithms, a realistic radar simulator, mimicing the characteristics of Xport has been coded. This tool is useful to carry out sensitivity tests and have a mean to compare algorithms performances for different space and time resolution (see examples in Gosset and Zawadzki, 2001, and Gosset 2003). The simulation are also useful to study the effects of the natural variability of rainfall characteristics on the retrieval. The simulator and the models chosen to account for the natural variability in rainfall characteristics and noise measurement are described in Sect. 2.

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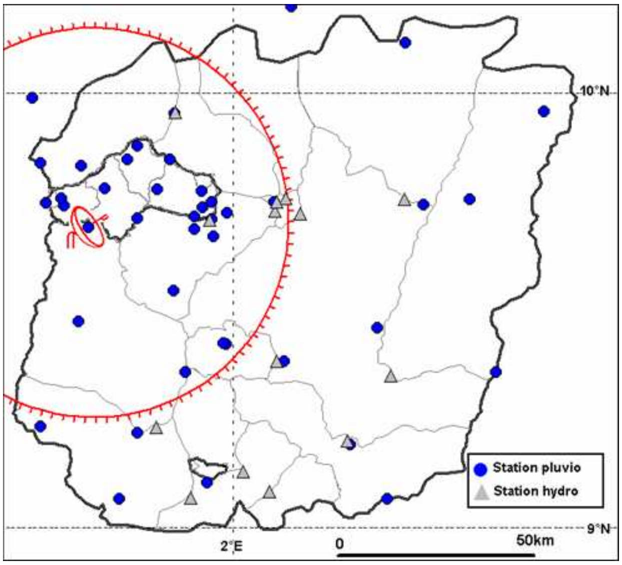

Fig. 1. Schematic of the Ouémé upper Valley hydro-meteorological observatory, in Norther Benin, West Africa, showing the planned position of the Xport radar, the contour of the small Donga catchment basin and the rain gages network (dark).

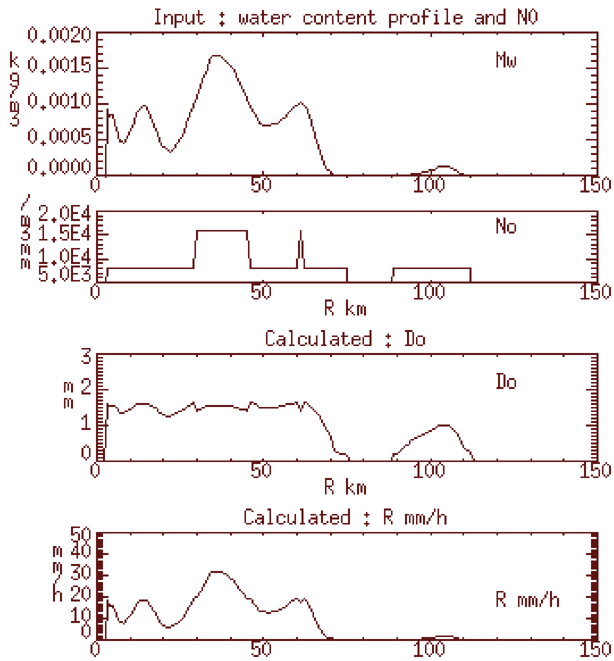

Fig. 2. Example of a profile (steps 1 and 2) with input and calculated parameters, for the DSD at each range gate. In this example, mu=0, but the parameter No varies with water content.

An important issue for such simulations is to use realistic fields as an imput. In our case, we chose to input the radar simulator with fields generated with a mesoscale atmopsheric model. An interpolator was coded inside the atmospheric model so that radar scans can be simulated for any position of a radar and any scanning strategy.

The reference mesoscale runs are described in Sect. 3. In Sect. 4 we present example of the radar scans simulated for african rain events and some preliminary results of our sensitivity study.

2 The radar simulator

The core of the simulator is a T-matrix code which is used to calculate the relevant radar parameters both for propagation (Attenuation Ah, differential attenuation Ah-v, specific phase shift Kdp) and back-scattering (Reflectivity Zh, differential reflectivity Zdr, back scattering phase shift Delta δ). This code is input with the equivalent spherical diameter and number density for each class of diameters, the value of the shape factor a/b for drops considered as oblate spheroids, the temperature of the medium and radar wavelength.

The simulations are run through a 4 steps processes

1. Input a profile of Water content, along the radial derived from the model fields.

2. Derive the drop size distribution for each range gate: The DSD are normalized gamma distributions such as in (Testud 2000) with a choice for the parameters "mu": and No. The minimum and maximum diameters to be considered for the integration are also choosable, as these parameters are quite important for some of the radar parameters (such as delta...). An example is given in Fig. 2 below.

3. Derive the radar "intrinsic" parameters (Zh, Zdr, Ah, Ah-v, Kdp, delta) for each gate, using the T-matrix code and the previously calculated DSD, with the relevant value of wavelength and temperature, a given formula for the a/b aspect ratio vs diameter function.

4. Derive the "measured" radar parameters : attenuated reflectivities and differential reflectivity, differential phase shift PHIdp (range integrated kdp + delta). At this stage optional random fluctuations and a minimum detectable signal can be considered to account for measurement noise, and a formula based on the SN ratio is used to calculate a RHOhv parameter for each gate. Examples are given in Fig 3 and 4.

3 The meso-NH model and its use to generate African squall lines

Data used as input to the radar simulator derived from numerical simulations of African mesoscale convective systems. These simulations have been carried out with the Meso-NH model (Lafore et al., 1998) run over three nested domains with a 2.5 km horizontal resolution for the finest grid. Figure 5 below gives an overview of the area covered by the model.

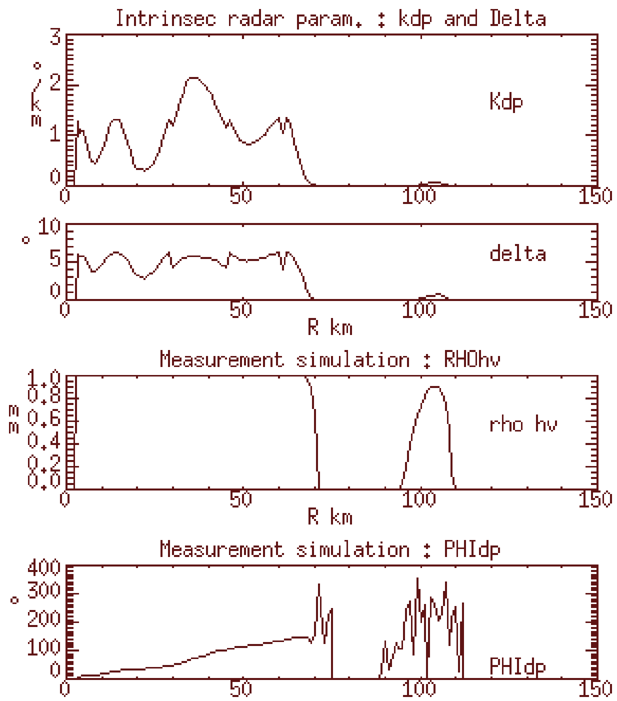

Fig. 3. "Intrinsec" and "measured" radar parameters. Calculated by the simulator, for the profile of Fig 2. A measurement noise, dependant on the SNR ratio, I considered both for the reflectivities and phase measurements. See text for steps 3 and 4.

Only highlights of this model will be given here. Meso-NH is a non-hydrostatic and three dimensional cloud resolving model. At high resolution, convection is explicitly resolved, meaning that clouds and precipitation (cloud ice, cloud water, rain, snow and graupel) are entirely represented through additional prognostic equations which account for the microphysical and thermodynamical transformations associated with water phase changes.

The case modeled is the 21–22 August 1992 squall lines observed during the program HAPEX (Hydrological Atmospheric Pilot Experiment) – Sahel 1992 in Niger (West Africa). This MCS was largely analyzed and simulated by Redelsperger et al. (2002) and Diongue et al. (2002) respectively. Another Meso-NH simulations have been made and were initialized with ECMWF ERA-40 re-analyses which appeared, in this case, better than ERA-15 one used for previous runs.

The simulation's large domain extension (800 km×800 km) and the fairly realistic results led us to document many MCS as pointed out on the figure. In this present study, we use results of SL2 squall lines which is localized in the sahelian region of Aïr (Fig. 5).

These simulations will now be used as a reference data base to carry out sensitivity test with our "virtual" radar. In order to evaluate the realisme of the generated rain field some statistics of the model rainfall were compared with observations in the region. One of the parameters to be checked was

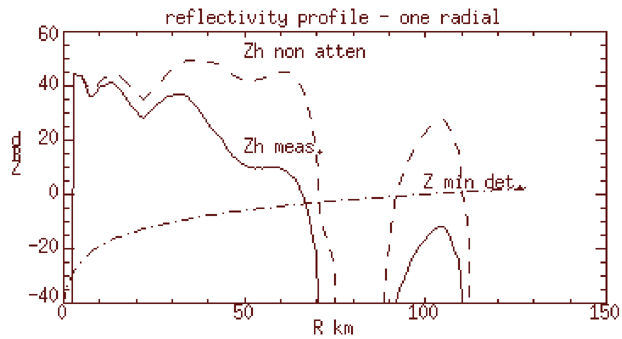

Fig. 4. Zh, attenuated + noisy Zm, and MDS.

the probability distribution function (pdf) of the instant rainfall for a given accumulation. This is important when calculating attenuation for example. The results of these comparison were very satisfactory.

In order to feed the radar simulator with the mesoNH simulated fields, an interpolation scheme was developed within the atmospheric model. The scheme is based on the code developed by Caumont et al. (2004). The necessary variables (mixing ratios of the various type of hydrometeors, air density and temperature) are provided for each radar radial, on a polar grid (distance to radar, elevation, azimuth) consistent with the radar characteristics.

4 Examples of synthetic radar scans and rain retrievals, and perspectives

Results examples are presented in Figs. 7 and 8.

The simulator is now fully operational and the tests themselves can be refined. The next step is to carry out an extensive set of virtual experiments with the available reference data set. In addition, further studies are also planned :

- Disdrometer measurements gathered in African precipitation will be used to provide a more representative model for the variability of drop size distributions at different scales.

- So far the virtual radar is scanned only at lower elevations where only rain and no other type of hydrometeors are present. The next step is to add other type of particles in the simulations to test the possibility to use hydrometeor classification scheme at attenuated frequencies.

- A further application planned for the simulator is to use it to optimize the scaning strategy. For that, a stochastic dynamical rain model, available in our group, will be used in order to study sampling and advection issues.

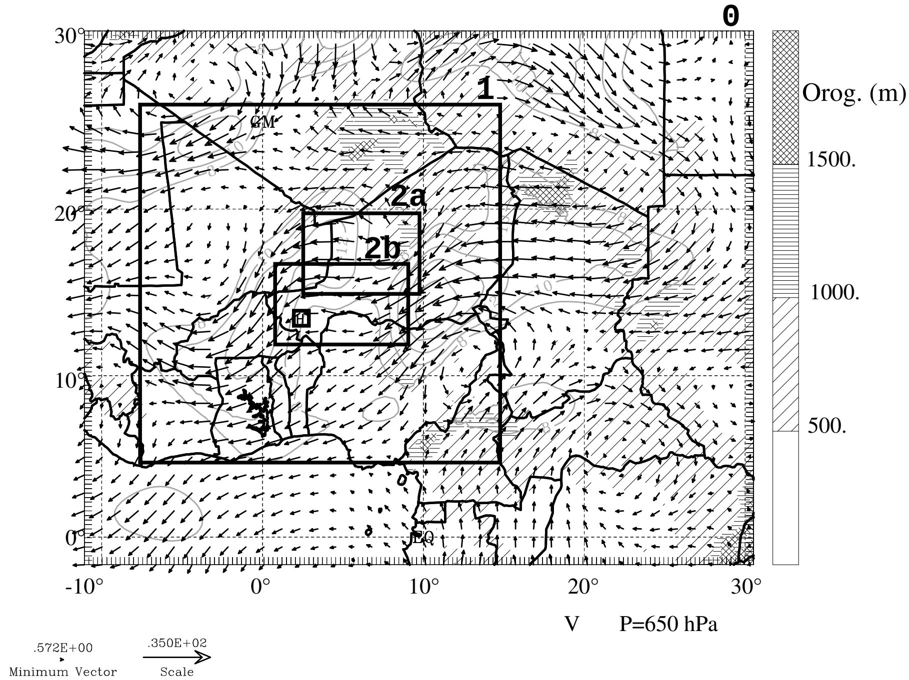

Fig. 5. The West African windows (grid nesting) used to generated the mesoscale simulations with meso NH.

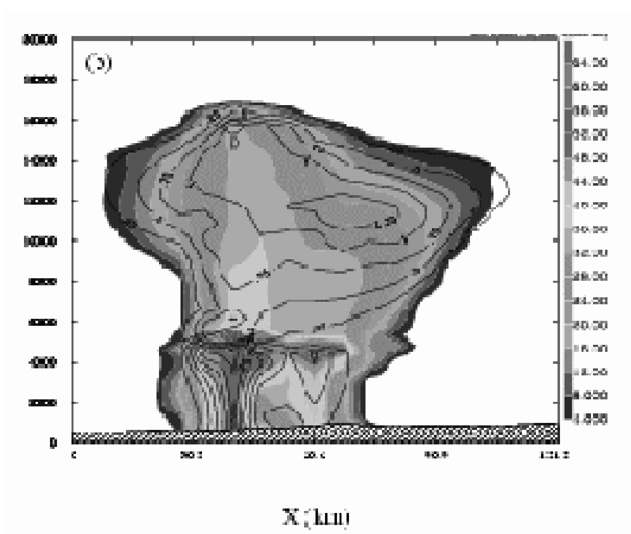

Fig. 6. Example of a vertical slice in an African squall line generated by mesoNH. It illustrates the fine resolution and the fine details of hydrometeor type and concentration which is provided by the model.

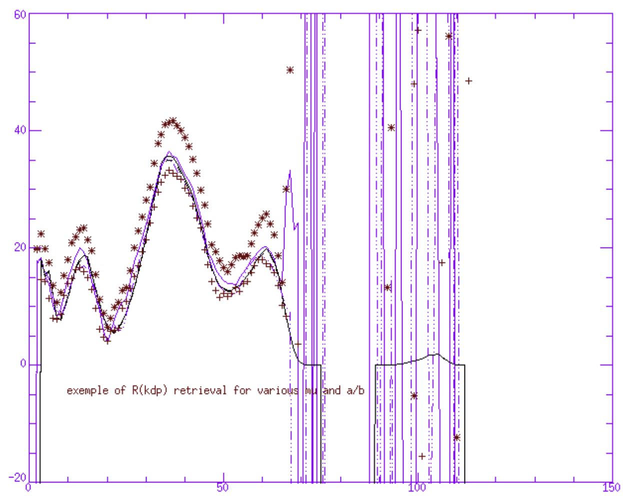

Fig. 7. Rain rate retrieval along a given radial. For this example a simple R(kdp) algorithm was used. Kdp is derived from the "measured" PHIdp, using a least square fit over 5 gates. A rhohv threshold is used Asa quality check to allow or not rain rate derivation. The R(kdp) formula used in the algorithm was derived assuming, exponential distribution, with No=8000 and a shape parameter as in Andsager . The thick line is the inpiut rain rate. 2 different profiles (crosses and dots) are for different "direct" models with different shape parameters (such as the mean shape given by a linear formula). The thin line is for a DSD "mu" parameter set to 4. This preliminary result illusrates the sensitivity to the mean aspect ratio formula and a lesser influence of the mu parameter, for a simple R(kdp) algorithm.

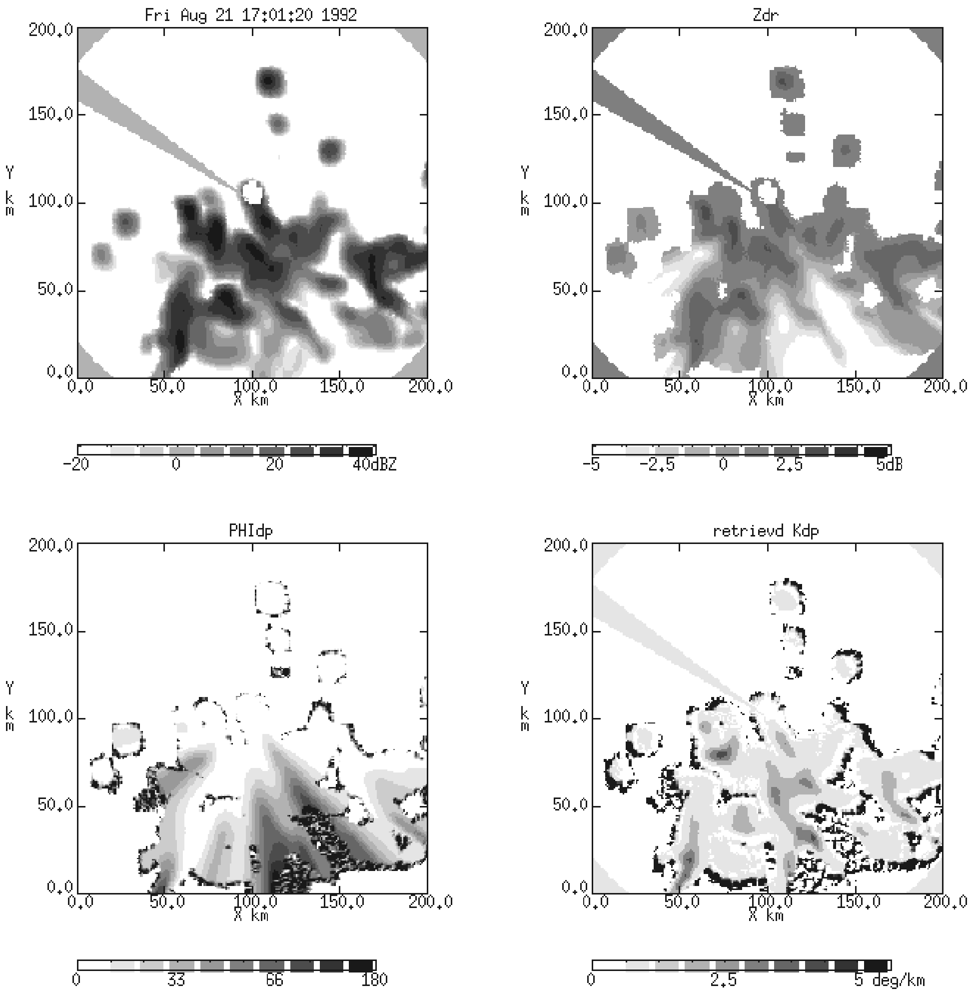

Fig. 8. Examples of output field from the simulator for the 21 August 1992 at 16:00, African rain system. The radar position was at latitude 18.6 and longitude 8.17, in the Sahelian zone. The fields are : attenuated + noisy reflectivity (top left), attenuated Zdr (Top right), PHIdp (bottom left) and Kdp (bottom right) retrieved from PHIdp using a least square scheme with a weigh constrained by RHOhv.

References

Caumont, O., Ducrocq, V., Delrieu, G., Gosset, M., du Chatelet, J. P., Pinty, J. P., Andrieu, H., Lemaitre, Y., and Scialom, G.: A radar observation operator for high-resolution non-hydrostatic numerical weather prevision, This proceeding, paper ERAD3-P-00043, 2004.

Diongue, A., Redelsperger, J.-L., and Roca, R.: Numerical study of a sahelian synoptic weather system: Initiation and mature stages abd its interactions with the large-scale dynamics, Quart. J. Roy. Meteor. Soc., 128, 1899–1927, 2002.

Gosset, M. and Zawadzki, I.: Effect of Nonuniform Beam Filling on the Propagation of the Radar Signal at X-Band Frequencies, Part 1 : Changes in the k(Z) Relationship, J. of Atm. And Ocean. Tech., 18, 1113–1126, 2001.

Gosset, M.: Effect of Nonuniform Beam Filling on the Propagation of the Radar Signal at X-Band Frequencies, Part II : Examination of differential phase shift, J. of Atm. And Ocean. Tech., 21, 358–367, 2004.

Lafore, J. P, Stein, J., Asencio, N., Bougeault, P., Ducrocq, V., Duron, J., Fisher, C., Héreil, P., Mascart, P., Pinty, J. P., Redelsperger, J. L., Richard, E., and Vilà-Guerau de Arellano, J.: The Méso-NH atmospheric simulation system, PartI: Adiabatic formulation and control simulations, Ann. Geophys., 16, 90–108, 1998.

Matrosov, S. Y., Clark, K. A., Martner, B., and Tokay, A.: X-band polarimetric radar easurements of rainfall with polarimetric X-band radar, Journal of Applied Meteorology, 41, 941–952, 2002.

Redelsperger, J.-L, Diongue, A., Diedhou, A., Ceron, J. P., Diop, M., Gueremy, J. F., and Lafore, J.-P.: Multi-scale description of sahelian synoptic weather system representative of west African monsoon, Quart. J. Roy. Meteor. Soc., 128, 1229–1257, 2002.

Sauvageot, H.: Polarimetric Radar at Attenuated Frequencies as a hydrological sensor, J. Atmos. Oceanic Technol., 13, 630–637, 1996.

Testud, J., Bouar, E. L., Obligis, E., Ali-Mehenni, M.: The rain profiling algorithm applied to polarimetric weather radar, Journal of Atmospheric and Oceanic Technology, 17: 332–356, 2000.