# Simulations of X-band thunderstorms radar observations

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## I. INTRODUCTION

Thunderstorms are the most dangerous convective systems of the atmosphere. Their very large vertical extension and their extreme intensity in terms of precipitation are a serious problem for civil aviation. In tropical latitude, organization of several thunderstorms in mesoscale convective systems like squall lines is also of a great interest for pilots. To quantify the hazard and avoid such extreme precipitating systems, X-Band airborne radar are currently used. However, this frequency domain ($f$ = 10 GHz, $\lambda \approx 3.2$ cm is problematic due to attenuation. It is thus important to know what a radar would really see and consequently indicate to pilots.

In this paper, we present a static model of thunderstorms to simulate the observations of an airborne X Band radar. The modeled thunderstorms are first summarized and then various features of the radar observations in X Band are discussed. Final section indicates further scientific directions.

## II. MODELING OF A THUNDERSTORM

The present model is an extension to ice phases of the model used by Pujol et al. (2007a, b) to study liquid clouds. Thunderstorms contain all types of hydrometeors : ice crystals, snow and large aggregates as graupel, hail, supercooled water, rain and cloud droplets. In our model, each of these kinds of particles are characterized by a two dimensional physical variable $X(x, z)$, where $x$ is an horizontal variable and $z$ the vertical one, and a hydrometeor size distribution. $X$ is chosen to be water content $M$ (in g m$^{-3}$) for non precipitating particles (ice crystals and cloud droplets) and precipitation rate $R$ (in mm h$^{-1}$) for the other hydrometeors. Geometrically, the modeled thunderstorm are symmetric with respect to its vertical axis; one can write $X(x, z) = X_z(z)G(x)$ where $X_z(z)$ is the vertical profile of $X$ at the centre of the modeled thunderstorm and $G(x) = \exp(x^2/L^2)$ represents the horizontal dependence of $X$ - at a given altitude $z_i$, $X = X_z(z_i)G(x)$ - with $L$ the horizontal extension of the modeled thunderstorm. Hydrometeors microphysical characteristics is chosen to be a gamma modified distribution:

$$N(D) = N_0 D^{\mu} \exp(-\Lambda D) \qquad (1)$$

| | $D_{min}$ | $D_{max}$ | $\rho$ (g cm$^{-3}$) |
|---|---|---|---|
| Ice crystal | 0.1 | 2 | 0.9 |
| Snow | 1 | 5 | < 0.2 |
| Graupel | 0.5 | 5 | 0.2-0.8 |
| Hail | 5 | 50 | > 0.8 |
| Rain | 0.5 | 5 | 1 |
| Cloud droplet | 1 | 50 | 1 |

TABLE I: Various physical characteristics of the different particles considered in this study. First and second columns are the minimum and maximum diameters (in mm) of the hydrometeor size distributions; for the last line, diameters are given in $\mu$m. Third column is the density, which is necessary for computation of refractive index and then for radar reflectivity and attenuation (see following section).

where $D$ is the equivalent diameter from 5 mm to 5 cm and $N_0$, $\mu$, and $\Lambda$ are three parameters which can be determined using $X$ or other physical variable. For example, for hail, which is the most dangerous precipitation, $\mu = 0$, and (Cheng and English 1983, Sauvageot 1992):

$$N_0 = 115\Lambda^{3.63} \quad \text{and} \quad \Lambda = \ln(88/R)/3.45 \qquad (2)$$

with $R$ in mm h$^{-1}$, $N_0$ in m$^{-3}$ mm$^{-1}$, and $\Lambda$ in mm$^{-1}$. First and second column of Table I summarizes the minimum $D_{min}$ and maximum $D_{max}$ equivalent diameters of the different kinds of particles. It is noteworthy indicates that all the values in our model are based upon observations referenced in many accepted and recognized studies (e.g. Sauvageot 1992, Pruppacher and Klett 1997).

## III. SIMULATION OF RADAR OBSERVATIONS

Radar observations of the modeled thunderstorms are performed at frequencies of 3 and 10 GHz with a radial resolution of about 100 m and a beamwidth approximated at a 3dB aperture of 1°. Then, in each radar sample volume $\mathcal{V}$, the backscattering cross section $\sigma$ and the attenuation (diffusion + absorption) cross section $Q$ of each hydrometeor can be computed by means of the Mie theory, and then added and averaged over $\mathcal{V}$ to finally obtain the reflectivity $Z$(dBZ) and attenuation $A$(dB km$^{-1}$) fields in S and X Bands. Since the S Band is less attenuated and presents a first Mie mode for larger backscatterer diameters, the comparison between the $Z(A)$-fields in S and X Bands should illustrate and quantify the differences and the problem of the X Band.

## IV. RESULTS AND CONCLUSIONS

Two main results emerges from these simulations of radar observations of thunderstorms:

- Reflectivity field is degraded by hydrometeor attenuation in X Band. A particular point concerns attenuation by cloud droplets which is a non negligible source of attenuation although droplets are undetectable compared to the precipitating particles. This point has been already underlined and investigated by Pujol et al.(2007a) for cumulus clouds; this problem is all the more important that, contrary to precipitation, there does not exist a corrective method for cloud attenuation with a single radar.

- Hail detection is limited in X Band. Indeed, the most dangerous hailstones have diameters which are larger than the first Mie mode. In such a situation, hailstones have a radar reflectivity in X Band lower than the radar reflectivity in S Band. Thus, hailstones can be assimilated to very heavy rain which is less dangerous than a hail area. This problem is particularly important since a pilot would then underestimate the hazard of the region where he conducts its plane and many people.

Although simple, but reasonable and realistic, our model indicates clearly that hail detection is problematic in X Band. Either many effort are required to improve hail detection or X Band should be avoided and advantageously replaced by S Band radar.

## V. FURTHER WORKS

This works suggest other ones. First, it appears necessary to propose an efficient method for hail detection if X Band continues to be used for civil aviation. Second, organization of thunderstorms in squall lines or other mesoscale convective systems should be studied. These tropical precipitating systems, which are of an extreme intensity in terms of convection and precipitation are of considerable importance for pilots. Finally, our model should not stay in a static mode and a time component seems to us necessary to take into account lifecycles of one or many convective cells. The authors are conscious that the study presented here is theoretical and need some real data for validation.

## VI. REFERENCES

Cheng L. and English M., 1983: A relationship between hailstone concentration and size. *J. Atmos. Sci.*, 40, 204 - 213.

Pruppacher H. and Klett J.D., 1997: Microphysics of clouds and precipitation. Kluwer Academic Publisher 943 pp.

Pujol O., Féral L., Sauvageot H., and Georgis J.F., 2007a: Degradation of radar reflectivity by cloud attenuation at microwave frequency. *J. Atmos. Oceanic Technol.*, 24, 640 - 657

Pujol O., Sauvageot H., and Georgis J.F., 2007b: Influence of drizzle on $Z$-$M$ relationships in warm clouds. *Atmos. Res.*, in revision.

Sauvageot H., 1992: Radar Meteorology, Artech House, 366pp.