Simulation Of Mono And Dual-Wavelength Airborne Radar Observations Of Precipitating Systems At Various Frequency Bands

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1. Introduction

Meteorological hazard in civil aviation is mainly due to convective precipitating systems, and particularly hail and strong turbulence areas. A radar located behind the radome, forming the noise of the plane, is the only tool used to detect these precipitations. The question of the most efficient couple (f, θ_{3dB}) has to be set for airborne radar precipitating system observations, where f is the microwave frequency and θ_{3dB} the beamwidth aperture at 3 dB ($\theta_{3dB} = 70\lambda/D$, D is antenna diameter). We also studied the interest of the dual-wavelength technic.

2. Method

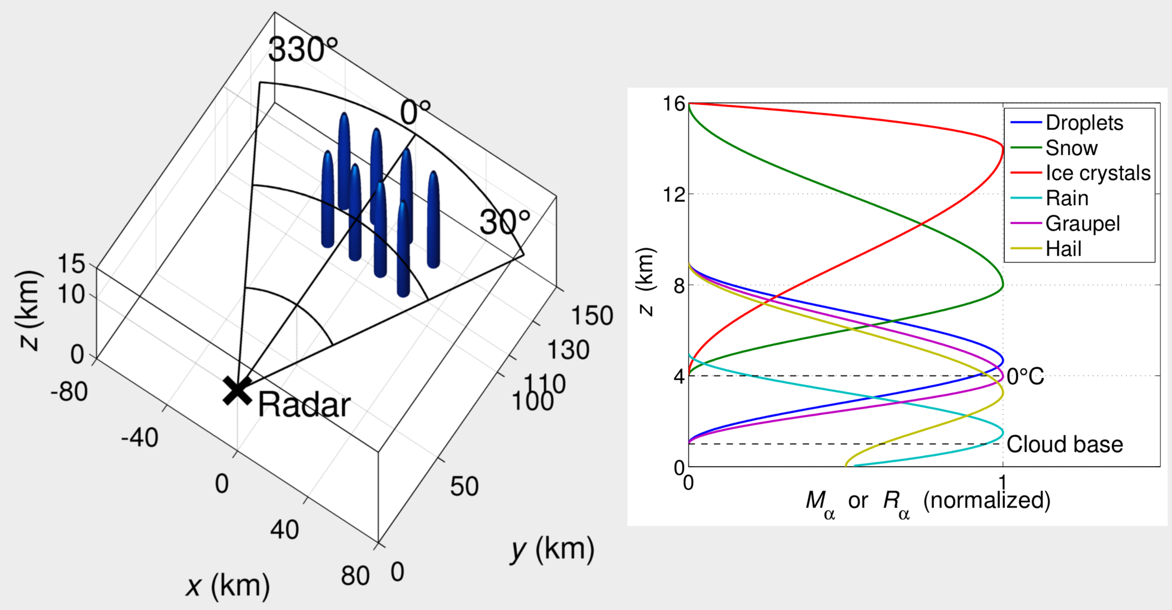

Figure 1: (a) System configuration. Convective towers are surrounded by a stratiform background (b) Hydrometeor normalized vertical distribution.

A realistic model of precipitating systems is used to perform simulations of airborne radar observations at the six meteorological frequency bands: S ($f \approx 3$ GHz), C (5.5 GHz), X (10 GHz), K_u (15 GHz), K_a (35 GHz), and W (94 GHz). The airborne radar is located at 10 km of altitude. Range bin spacing is set to 150 m. The electromagnetic energy is supposed to be uniformly distributed.

3. Frequency and θ_{3dB} comparison

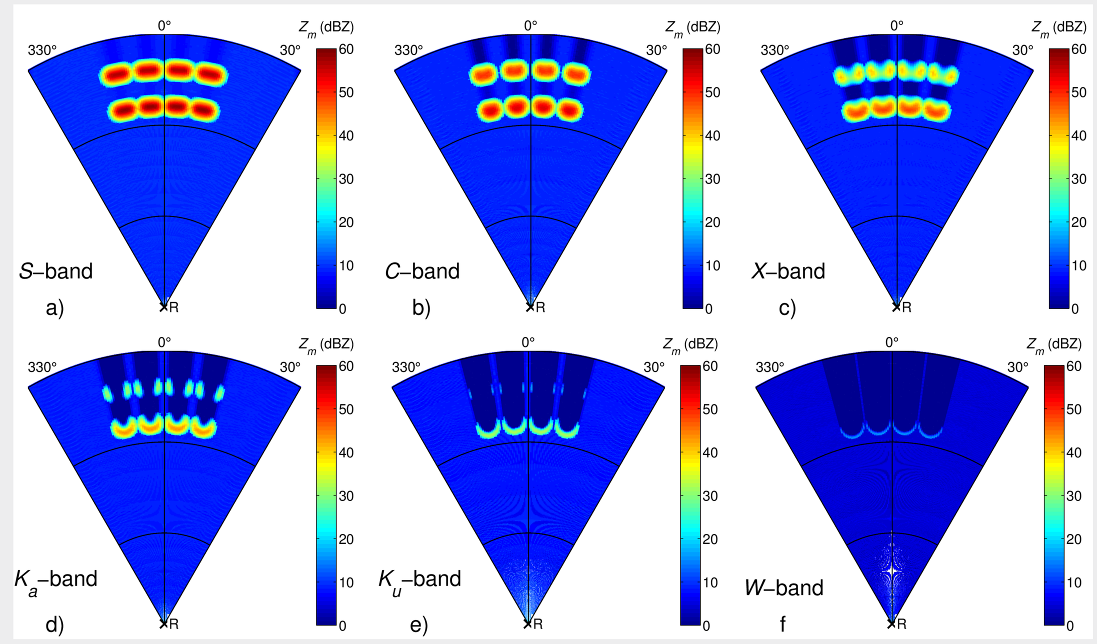

Figure 2: The frequency effect. (a,b) Antenna diameter $D_a = 2$ m, and (c,d,e,f) $D_a = 0.8$ m. All convective towers contain hail (here $R_h = 40$ mm h^{-1})

S and C-bands, two lines of convection are clearly visible. X-band the second row is attenuated and seems to be safe. K_u, K_a, and W-bands, the convective system is unobservable.

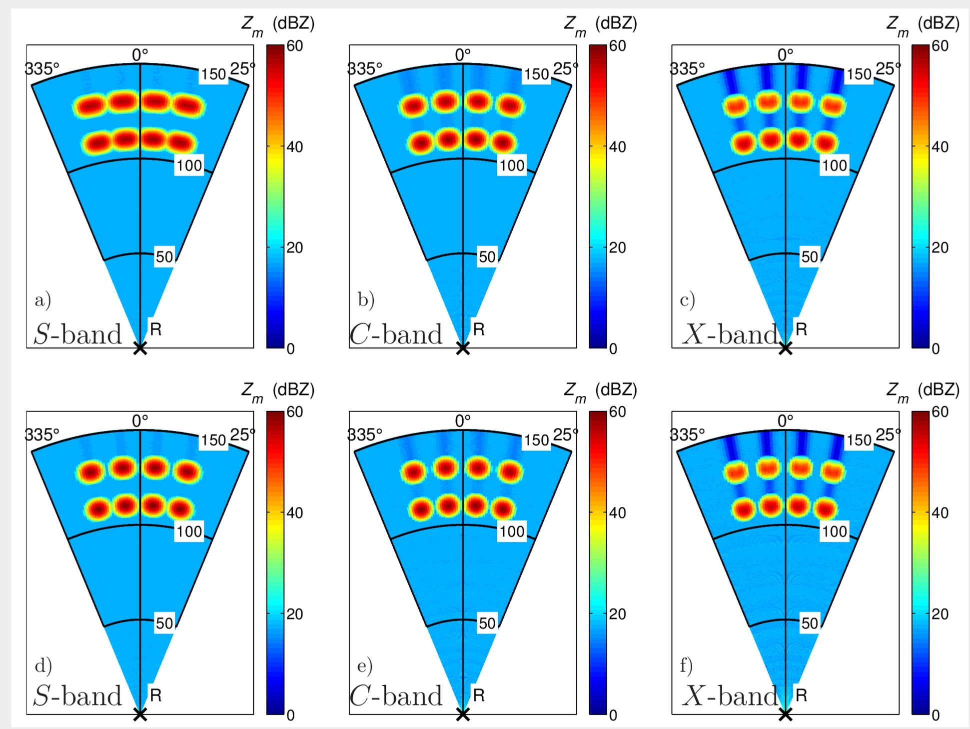

Figure 3: The θ_{3dB} effect. PPI view simulation of the measured reflectivity Z_m in a mesoscale system at various frequency bands: S(a,d), C(b,e), X(c,f), with a radar antenna size of 2 m (a,b,c) and of 4 m (d,e,f).

X-band presents a good improvement for D = 2m, since the convective towers are separated. For $D = 4$ m, convective towers are identifiable.

4. Dual-wavelength technic (DWT)

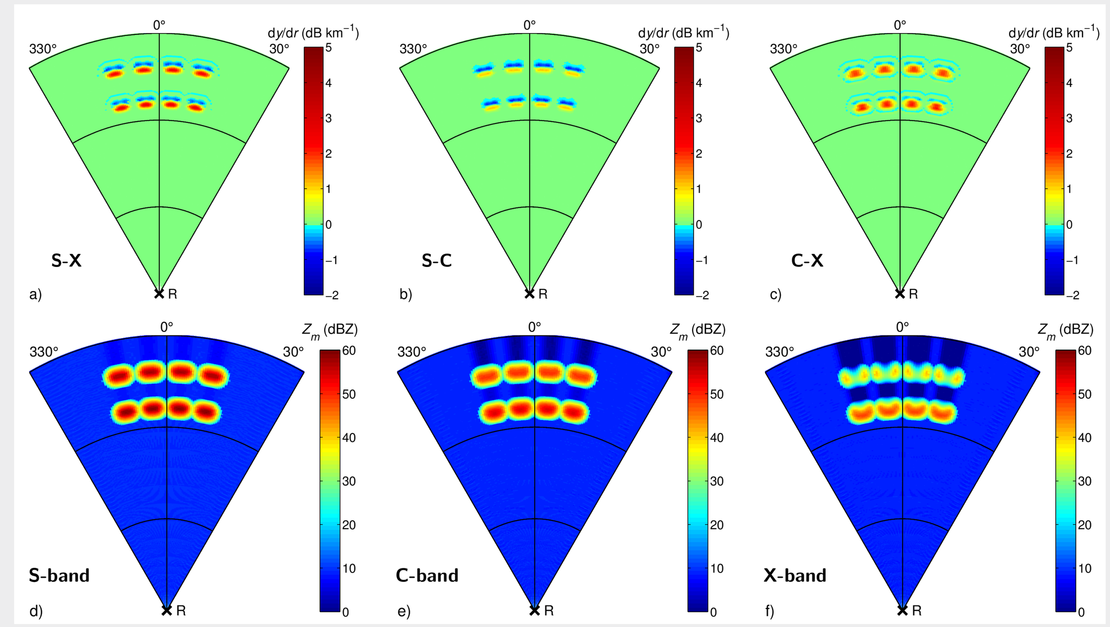

Figure 4: Gradient of the dual-wavelength reflectivity difference relative to the distance for (a) S-X, (b) S-C, and (c) C-X. Reflectivity field for (d) S, (e) C, and (f) X-bands for $\theta_{3dB} = 3°$.

The quantity studied is the dual-wavelength ratio (DWR) $\mathrm{d}y/\mathrm{d}r$:

$$\frac{\mathrm{d}y}{\mathrm{d}r} = \frac{\mathrm{d}}{\mathrm{d}r}[Z_{m,\lambda_l}(r) - Z_{m,\lambda_s}(r)]. \quad (1)$$

where Z_m is the measured reflectivity at a wavelength l or s (for large or small). It requires that the two radar beams illuminate identical volumes of resolution, the same value of $\theta_{3dB} = 3°$ has been considered at S, C, and X-bands. The use of the DWR is interesting because hail is the only non-Rayleigh scatterer at these frequency bands, and thus it implies that DWR is positive in front of a hail tower and always negative at the rear, and this can be used as .

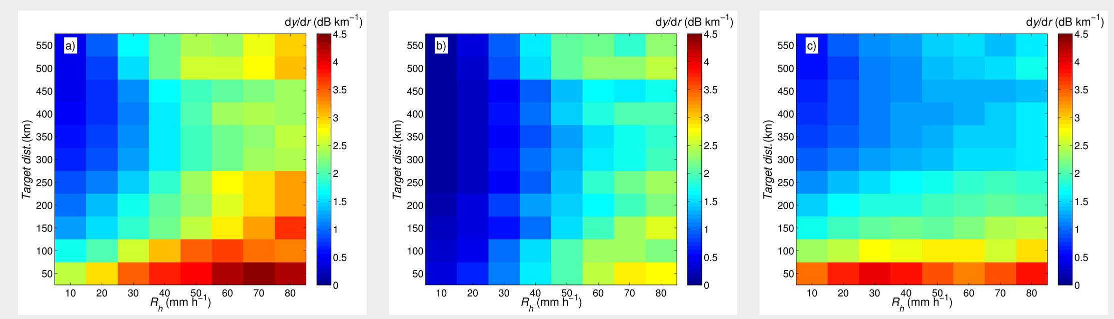

Figure 5: Gradient of the dual-wavelength reflectivity difference relative to the distance for (a) S-X, (b) S-C, and (c) C-X. Reflectivity field for (d) S, (e) C, and (f) X-bands for $\theta_{3dB} = 3°$.

$\mathrm{d}y/\mathrm{d}r$ increases with R_h, small variations are due to Mie modes.

5. Real mesoscale system

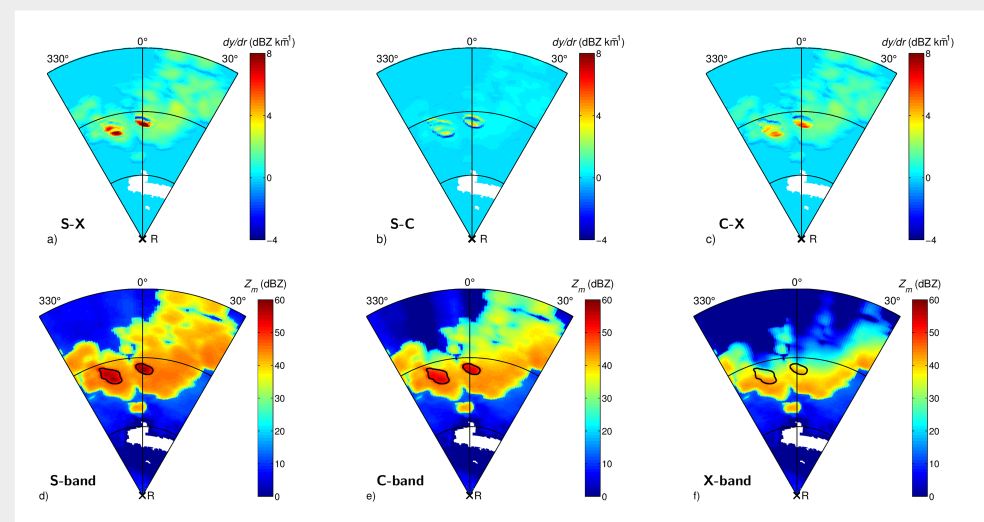

Figure 6: PPI field of $\mathrm{d}y/\mathrm{d}r$ of hailstorm for S-X (a), S-C (b), and C-X (c). Measured reflectivity in dBZ at S (d), C (e), and X-bands (f). CAPPI at 10 km of altitude of the mesoscale system of May 2003, 2nd, in Alabama (USA). R indicates airborne radar position. Data comes from NEXRAD network (S-band). Radar designation is KFCC. Black contours delimite possible hail area ($Z_m > 45$ dBZ). White zone between 30 and 50 km corresponds to an absence of data.

In order to illustrate the usefulness of the DWR to determine hail areas, let consider a real mesoscale precipitating system that occurs on May 2003, 2nd in Alabama (USA). Note that the area C does not contain hail, although it presents a reflectivity which is about that of areas A and B. It illustrates that a criteria based solely on reflectivity is not sufficient for hail detection.

References

[1] Valentin Louf et al. Simulation of airborne radar observations of precipitating systems at various frequency bands. *IEEE TGRS*, 2013.

[2] Valentin Louf et al. The dual-wavelength method for hailstorm detection by airborne radar. submitted to IEEE TGRS.

Conclusion and further studies

We have studied the effect of different parameters: f, θ_{3dB}, rainfall and hailfall rate, and DW configuration. For this, more than 400 systems (purely numerical or inspired from reality) have been computed. Due to the relation $\theta_{3dB} \propto \lambda/D$, decreasing θ_{3dB} implies decreasing λ and increasing D. The simulation presented herein on modelled precipitating systems shows that (1) S-band is the best one to distinguish hail from rain since it does not suffer attenuation, but a low θ_{3dB}-values implies using an important antenna diameter; (2) $X-$band is penalized by attenuation, but allows good θ_{3dB}-resolution; (3) $C-$band seems to be a good compromise. Therefore, C-X is the best couple for hail observations by dual-wavelength airborne radar.

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