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Precipitation sensing experiment with a prototype dual-polarization weather radar for civil aircraft

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Abstract

The European Commission initiative CleanSky launched several project activities aimed at improving flight route planning in the presence of unforeseen events, such as rapidly evolving thunderstorms occurring along the route, both to increase the safety and comfort of flight and to keep emissions as low as possible. Improving meteorological instrumentation onboard and supporting the pilot in interpreting such goals are important to achieve this goal. Potential improvements to aircraft weather radar related to the use of dual opalization technology were investigated along several CleanSky projects. Two experimental campaigns, were carried out in 2016 within the X-WALD project with a prototypal radar using a low-power X-band dual-polarization radar mounted in the nose of two different aircrafts in the Netherlands and in Italy. Results from these campaigns and comparison of data collected on board with ground-based instrumentation are presented.

1. Introduction

Aircrafts (both civil aviation airplanes and military transport aircrafts) are usually equipped with an airborne weather radar (AWR) mounted in the nose of the aircraft. Its task is to scan ahead of the aircraft for early detecting dangerous meteorological phenomena along the route and to allow pilot to make proper decision, such as a change in the route to mitigate risk related to weather. For this reason, sometimes these devices are indicated as airborne weather avoidance radar. They operate at X-band (C-band for larger aircraft) with a coarse angular resolution to keep the physical size of antenna compatible with mounting. Most of these AWRs have Doppler capabilities, providing also forward looking windshear and turbulence detection within some range limits. Measurements of reflectivity are displayed with few levels and most of their interpretation is left to pilot's experience. Polarimetry has not been adopted in commercial weather radars for aircrafts and, its potential advantages for airborne weather radar are still mostly unexplored [1].

Instead, the experience gathered from research and operational radar at ground has proven several advantages of polarimetry that can be of interest of avionic application. In particular, the dual-polarization technique in particular provides a reliable correction of X-band attenuation [2] and a quite precise classification of the precipitation type [3].

Figure 1. Installation of radar in the two aircrafts used in X-WALD campaigns, namely Diamond DA42 (left) and and Piaggio P-166 (right).

In the framework of the CleanSky Joint Undertaking (JU) European program and, specifically, in the CleanSky Systems for Green Operations (SGO) Integrated Technological Demonstrator (ITD), the use of a weather radar for civil aircraft improved by dual-polarization, has been proposed in the Management of Trajectory and Mission (MTM) study to make available to the pilot more precise information about not forecasted weather phenomena along the route. Also automated tool to handle the richer information obtainable from dual-polarization radar measurements, eventually merged with other information on no-flight zone or weather forecasts from off-board sources have been investigated with the goal to make optimal decision during flight [4]. In the context of CleanSky SGO the project CLEOPATRA has developed an avionic polarimetric radar signal simulator named CleoSim to support design phase of an airborne dual-polarization weather radar. The project KLEAN has developed basic signal processing and trajectory optimization algorithms, the latter to be run on the pilot's EFB (Electronic Flight Bag), while issues related to optimal fusion and display of heterogeneous information from different sources has been the goal of a project called WinFC. The X-WALD [5] project was funded with the main objective of planning and performing ad-hoc experimental airborne polarimetric radar measurements to make available of real data is of great importance to test the quality of the simulator as well as the capability of the algorithms. This short summary, presents relevant outcomes of X-WALD project. In particular, it will discuss the results of the two measurement campaigns carried out in the Netherlands and in Italy, respectively, using a low-power X-band radar mounted on two different aircrafts.

2. The X-WALD prototype dual-pol radar

X-WALD project aimed at run specific experiments to test, validate and optimize, for a dual-polarization radar, i) signal processing for avionic applications and ii) weather classification algorithms implemented by KLEAN project iii) the radar signal simulator named CleoSim developed along the CLEOPATRA project [6]. Planning of the experiment required the accomplishment of several tasks concerning the prototypal dual-polarization radar, such as to draft specifications to make radar suitable to be mounted on the airborne platforms affordable for the experimenta. A survey of the off-the-shelf technology was carried out, and it was then decided that a customized version of a radar manufactured by MetaSensing BV (Noordwijk, The Netherlands) would meet X-WALD specifications. Table 1 summarizes the main characteristics of the radar. The adopted polarization scheme allow for quite complete set of output sual polarization measurements.

Adaptations of the radar system included:

i) implementation of a pulsed transmission scheme, with the use of a single antenna replacing the existent FM-CW scheme using 2-antennas;
ii) increase of maximum transmit power; *iii)* choice of an off-the-shelf antenna with optimal radiation characteristics and minimal physical dimensions;
iv) implementation of a scanning mechanism;
v) re-engineering of the system for withstanding with typical aircraft space and weight limitations.

Concerning *v)*, the two platforms to be used for the two campaigns, as shown in Fig. 1, namely the Diamond DA42 (left) and the Piaggio P-166 (right) needed to be taken into account.
An important aspect to be tested was the processing of collected data to mitigate the influence of ground clutter and for compensating motion of platform. The algorithm proposed is a combination of ground clutter mitigation and a two-step motion compensation. In particular:

1. Ground clutter mitigation: it is performed in the frequency domain applying interpolation of weather spectrum.
2. Removal of the first motion compensation: after the clutter mitigation, the first motion compensation is removed.
3. Motion compensation for the weather target: finally, the platform compensation is performed along the boresight direction of the antenna.

After motion compensation and clutter mitigation are performed, the Doppler-polarimetric moments are estimated in the frequency domain. In particular, the power spectral density is estimated over the four dual-polarization channels (HH, HV, VH, VV), and the estimation of the cross-power spectral density (CPSD) is computed over all the channels pairs (HH-VV and HH-HV, HH-VH, …). A spectral integration is then performed and the elements of the polarimetric covariance measurement matrix are returned. Then, starting from the PSD estimated from the HH samples, the Doppler centroid and the spectrum width are computed.

Table 1. Characteristics of X-WALD radar

Parameter	Value
Frequency	X Band (9.6 GHz)
Transmitted Power	5 W
Pulse Repetition Frequency	Up to 10 kHz
Transmitted Bandwidth	1 MHz
Min. Operational Range	100 m
Max. Operational Range	100 km
Range Resolution	150 m
Max. Unambiguos Velocity	125 km/h
Transmitter Polarization	Alternate H/V
Receiver Polarization	Simultaneous H/V
Antenna Type	Parabolic Reflector Dish
Beamwidth (- 3dB)	5° (Both Polarizations)
Elevation Operating Range	± 10°
Azimuthal Scan Range	± 60°
Antenna Scan Speed	Up to 30°/s

3. The X-WALD campaigns

The first measurement campaign was conducted in the Netherlands in December 2016. The Diamond DA42 was based at the Teuge airport (52.244° N, 6.046° E, 5 m ASL) with goal of exploiting ground based instrumentation for atmospheric remote sensing of the Cesar Observatory located in the western part of the Netherlands in Cabauw (51.971° N, 4.927° E, -7 m ASL). In addition to the available instrumentation, an OTT Parsivel2 disdrometer was installed at CESAR observatory. Due to the short time allocated to the campaign (one week) and to the lack of significant precipitation, the campaign provided important feedbacks on hardware and signal processing performance, but not on the quality of dual polarization measurements collected in precipitation.

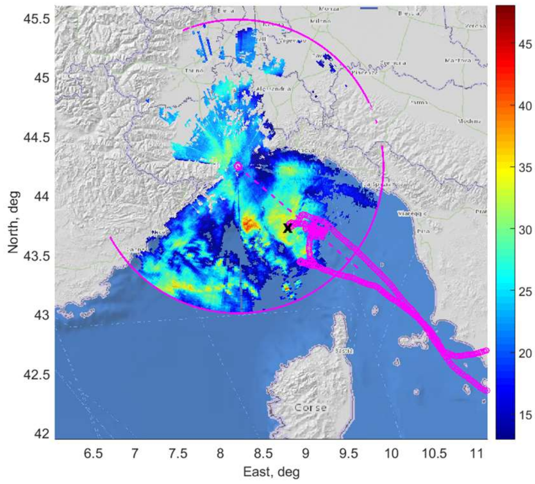

Figure 2. Radar coverage from Monte Settepani and the route of the flight performed on 16 March 2016. Range ring is at 136-km distance from the radar.

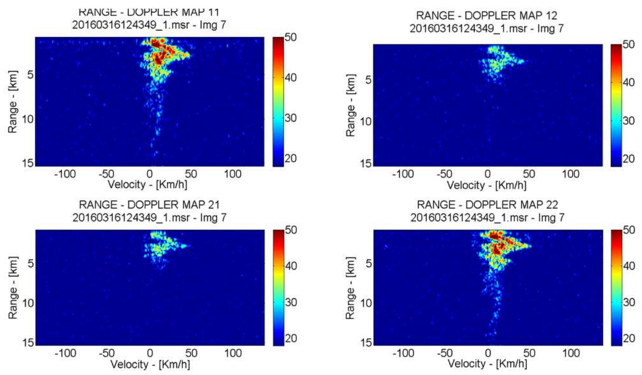

Figure 3. Range-Doppler maps represented in an arbitrary logarithmic scale of 4 polarimetric channels (clock wise: HH, HV, VV, VH) from measurements collected on the 16th of March over the Ligurian Sea.

A second campaign of two weeks was conducted in Italy in March 2016 with a different aircraft, a Piaggio P166C based at the Aviosuperficie Leonardi in Terni (Lat 42.573 N Lon 12.584E, 114 m ASL). Again, the disdrometer was installed at the Aviosuperficie Leonardi to collect eventual precipitation. Routes of the flights were decided depending on the occurrence of precipitation, the vicinity of regions observed by operational dual-polarization radar facilities, and the maximum range of the aircraft. Typically, radar performed sector sweeps between -15° and 15°. Three significant measurement sets were collected. A first one was collected on March 11th over the Tyrrhenian Sea. Radar reflectivity measurements from this flight were the highest recorded for the Italy campaign. The second set was collected on March 15th above Southern Tuscany. The third dataset was collected March 16th in Gulf of Genoa, when intense storms were occurring. This case is of extreme interest because the same precipitation phenomenon was being scanned also by the operational dual-polarization weather radar located in Monte Settepani, allowing for a comparison. Figure 2 shows the flight track superimposed to a reflectivity map collected by the Settepani radar during the X-WALD flight. The circle represents the maximum range of 136 km. Figure 3 shows an example of range Doppler representation of the collected data. A precipitation event is clearly distinguishable between 1 km and 10 km in slant range. As expected, the cross polar channels are characterized by a lower SNR with respect to the co-polar channels. A comparison between the two radars is shown in Fig. 4. Aspects related to the different geometry views, time difference (the Settepani radar performs a 5-minute volume scan) and possible wrong calibration of the X-band radar makes difficult a quantitative comparison. A simple analysis among the different measurements collected during the same day reveals some degree of consistency of measurements with expectations. Considering data with a sufficiently high copolar correlation coefficient, say greater than 0.7 (no data masking has been applied to Figure 5), increase of differential phase is consistent with the presence of precipitation. The cross-range behavior of the differential reflectivity requires investigations.

4. Conclusions

Dual-polarization potential has not yet applied for weather avoidance radars used by civil aircrafts for avoiding dangerous weather. A prototype of a polarimetric weather radar has been deployed on two different airborne platforms for two different campaigns. Some radar measurements collected during the most significant flight of the campaign in Italy have been shown. Data collected in the presence of medium-intense precipitation are still under investigations both to assess the quality of data given the instrumental limitations posed by the airborne deployment and, to demonstrate the advantages of dual-polarization for radar for commercial aircrafts.

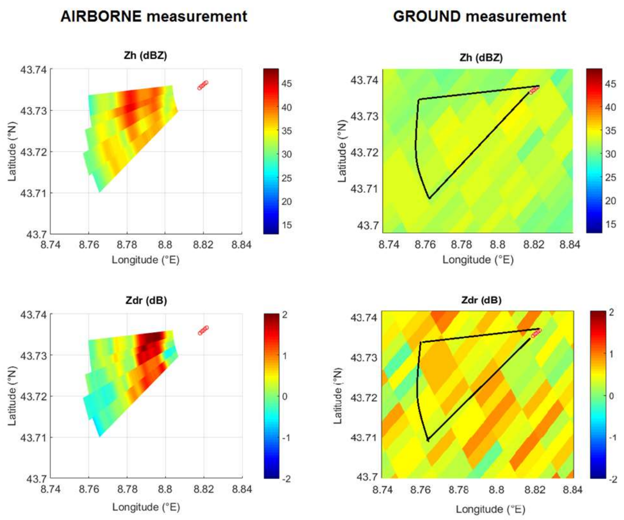

Figure 4. Comparison between radar maps of Z_h (on the top) and Z_{dr} (on the bottom) measured by airborne radar (on the left) and the radar of Settepani (on the right).

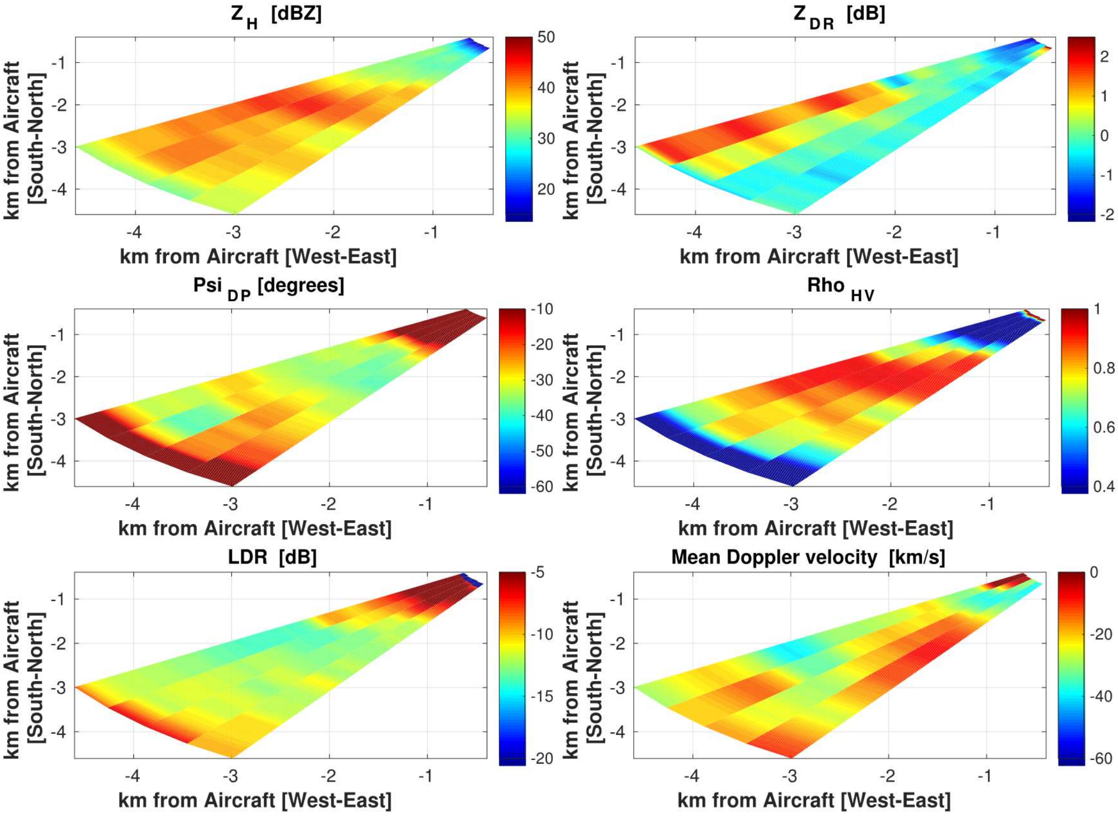

Figure 5. Example of measurements collected on 16 March 2016 at 10.33 UTC. Top, from left to right: Z_h (dBZ), Differential reflectivity (dBDifferential phase shift (degrees). copolar correlation coefficient, and linear depolarization ratio (dB), and mean Doppler velocity (m/s).

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6. References

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