

Evaluation of hydrometeor classification algorithms from multi-frequency dual-polarimetric radar observations collected during HyMeX

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1 - INTRODUCTION

One of the major outcome of dual-polarization radar is the ability to determine the type of hydrometeors within cloud systems. Météo-France, which owns and operate 15 polarimetric operational radars throughout mainland France, has developed a fuzzy logic hydrometeor identification (HID) algorithm, which allows to discriminate between five microphysical types regardless of the radar wavelength: Rain, Wet Snow, Dry Snow, Ice, and Hail (Al-Sakka et al, 2013). This hydrometeor classification algorithms is based upon combination sets of dual-polarimetric observables (horizontal reflectivity Z_h , differential reflectivity Z_{dr} , cross-coefficient correlation ρ_{HV} , specific differential phase K_{DP}) along with temperature data inferred from a NWP model outputs.

This study takes place within the framework of the Hydrological cycle in Mediterranean Experiment field phase (HyMeX-SOP1), which was conducted from September to November 2012 (Ducrocq et al. 2014). HyMeX is a 10-year research program focusing on the quantification and understanding of the water cycle in the Mediterranean at various time and spatial scales with particular emphasis on high-impact weather events (Drobinski et al. 2014). An important objective of this project is to achieve a better understanding of the dynamic and the microphysic of coastal orographic heavy precipitation events (HPE) that develop in the NW part of the Mediterranean basin. With this regard, the ability to map the three-dimensional structure of hydrometeors species within precipitating systems is essential and represents an important objective of HyMeX.

The present paper aims at evaluating the performance, and advanced utilization of an improved version of Meteo-France Hydrometeor Classification Algorithm (HCA) allowing for the identification of graupel in addition to the five original types. This HCA was specifically designed to process radar data collected in the frame of the HyMeX program and to achieve scientific objectives of the project.

2 - DATA AND METHODOLOGY

2.1 Radar and aircraft data

During HyMeX SOP1, a dense network composed of 20 operational and research radars at various kinds and frequencies was set up to collect observations of heavy precipitation events (HPE) developing in Southern France with emphasis on the Cevennes-Vivarais region (Bousquet et al. 2014). The core of this network was based upon an ensemble of seven operational and research dual-polarization radars deployed over an area of approximately 120,000 km². The radar covered area was regularly flown by a Falcon 20 (F20) research aircraft equipped with microphysical probes to gather additional microphysical measurements at high space-time resolution.

This particular study focuses on the analysis of dual-polarization measurements collected by the three operational radars respectively located in Montclar (MON, C-band), Nîmes (NIM, S-band), and Collobrières (COL, S-band). These three radars, owned and operated by the French Weather Service, provide coverage over the Tarn, Hérault, Gard, Bouches-du-Rhône, and Var administrative departments. The beamwidth is 1.1° for the C-band radar and 1.25° for the two identical S-band radars. All three radars are equipped with a radar processor developed by the French Weather Service (Meteo-France) and use a simultaneous transmission and reception (STAR mode) that provides horizontal (Z_h) and differential (Z_{dr}) reflectivity, cross-coefficient correlation (ρ_{HV}) and differential phase (Φ_{DP}) measurements. Furthermore the scanning strategy is radar-dependent and consists in three five-minute cycles that are repeated every 15 minutes. Each five-minute cycle is made of six radar scans performed at different elevations. The four lowest elevation tilts are repeated every 5 minutes and are interlaced with higher elevation scans in order to sample a larger bulk volume (Tabary, 2007).

2.2 - Cases studies

The work presented herein is based upon the analysis of radar data collected within two precipitation events that passed over the HyMeX radar network on 28 August and 29 September 2012. Among these two cases, the 28th August was characterized by the presence of deep, intense, convection, while the second (29 September) was associated with stratiform precipitation. An overview of the overall structure of these systems is shown in Figure 1. The August event (Figure 1a) was associated with the passage of a dynamic trough over France that led to deep convective developments over the radar network. The 29 September event (Figure 1b) is a frontal system. It is characterized by the presence of embedded convection and developed in connection with the propagation of a cut-off low over southern France.

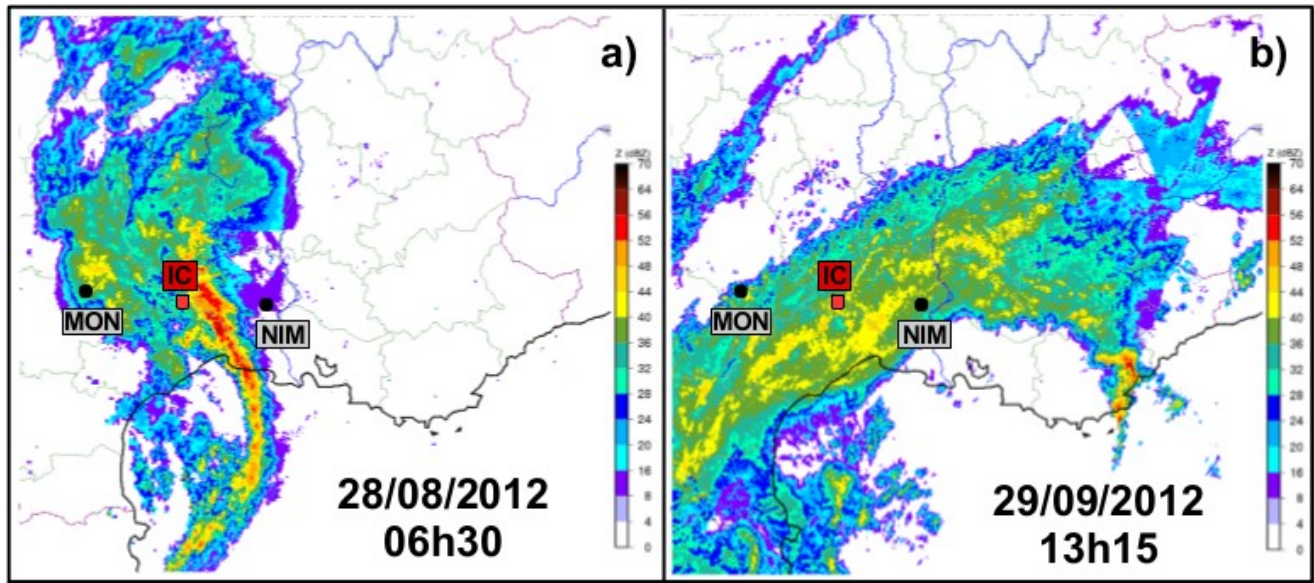


Figure 1: Operational reflectivity composite (dBZ) showing the overall structure of the two weather events investigated in this study: a) 28 August 2012 and b) 29 September 2012. MON and NIM boxes correspond respectively to Montclar and Nimes radar, whereas IC red boxes coincide with the inter-comparisons area. Times are in Universal Time Coordinated.

3 – HYDROMETEOR CLASSIFICATION ALGORITHM AND VERIFICATION METHODOLOGIES

3.1 Hydrometeor classification algorithm

The processing of dual-polarimetric raw radar data is based upon the procedure described in Figueras et al. (2012). It consists of five main steps given hereafter: i) correction for potential Z_{dr} miscalibration as implemented by Illingworth et al. (2002) and Gourley et al. (2006); ii) discrimination between meteorological and non meteorological echoes (Gourley et al. 2007); iii) estimation of the 0°C isotherm altitude from polarimetric data (Giangrande et al. 2008) and operational model analyses; iv) estimation of the specific differential phase K_{dp} , and v) correction of signal attenuation (Tabary et al. 2009). Once pre-processed, radar data are passed into the HCA.

The core of the HCA is based on the fuzzy logic operational algorithm described in Al-Sakka et al. (2013), which allows for the discrimination between five hydrometeor types [rain (R), wet snow (WS), dry snow (DS), hail (H), and ice (I)] at both S- and C-band. This method relies on a unique equation to calculate the probability scores and adopts the same formulation at all wavelengths without using of empirical weights. The calculation of the probability is given in Eq. (1) hereafter:

$$P_F^i = F^i(T) F^i(BB) [F^i(Z_h, Z_{DR}) + F^i(Z_H, K_{DP}) + F^i(Z_H, \rho_{HV})] \quad (\text{Eq. 1})$$

,where i refers to the hydrometeor type and F^i represents the membership function. In Eq (1), one-

dimensional membership functions of temperature (T) and bright band (BB) are used as multiplicative terms, whereas bivariate membership functions are applied as additive terms.

The membership functions are established empirically for each bandwidth from T-matrix simulations and human expertise (Al-Sakka et al. 2013). The choice to discriminate between only a limited numbers of hydrometeor species is motivated by operational constraints and allows to improve the robustness and the efficiency of the algorithm. . In order to allow for a more comprehensive description of the cloud microphysics, the graupel category, which is critical to both investigate cloud electrification processes (Takahashi, 1978) and evaluate microphysical parameterizations used in numerical weather predicting (NWP) systems , was thus implemented into this HCA.

Graupel identification is achieved by using the definitions proposed by Marzano et al. (2007), for C-band, and by Park et al. (2009), for S-band. Since the outcome of HID methods is generally both radar- and area-dependent, some parameters were adjusted to achieve consistency at both wavelengths. A bivariate (Z_h , ρ_{hv}) and a trapezoidal membership function for temperature, which are not included in Marzano et al. (2007), are also introduced at C-band in order to use the same parameter for all radars. The graupel probabilities are also weighted to obtain a coherent range of results.

Another improvement of the original algorithm of Al-Sakka et al. (2013) was achieved by identifying a distinction between convective and stratiform precipitation such as suggested by Park et al. (2009) and Dolan et al. (2013). In the present study, the method for discriminating between convective and stratiform echoes follows the recommendations of Park et al. (2009). It is based on both the identification of the 0°C isotherm and the detection of high values in observed vertical reflectivity profiles. When the maximum reflectivity Z_H within a given vertical column is higher than 45 dBZ, or if it is higher than 30 dBZ at a height higher than 1.6 km above the 0° isotherm, the echo is classified as convective. This partitioning restricts the presence of given hydrometeor types into specific area of the weather system so as to mitigate the risk of misclassification. When an echo is classified as “convective”, dry snow (DS) and wet snow (WS) are not allowed within a whole vertical column. Conversely, when an echo is classified as “stratiform”, graupel (GR) and hail (H) are excluded.

3.2 HCA evaluation principle

The performance of the HCA is first evaluated by inter-comparing Plan Position Indicator (PPI) of retrieved hydrometeor fields inferred from the analysis of data collected within overlapping areas of different radars. The rationale for this approach is that two neighboring dual-polarization radars should detect the same hydrometeor populations within their common sampling areas regardless of their wavelength and of their overall characteristics. The analysis framework is described hereafter:

- i) Pairs of neighboring dual-polarization radars, separated by distances comprised between 100 km and 180 km, are selected independently of the wavelength and scanning strategy of the instruments. Based on this criterion, two pairs are selected: Montclar (C-band) / Nimes (S-band).
- ii) A domain of intercomparison of 5 km (x-direction) x 5 km (y-direction) x 10 km (z-direction) centered on the middle of the radar baseline (the imaginary segment joining the pair of selected radars) is defined.
- iii) For each pair of radar tilts intersecting within the intercomparison area, HCA outputs inferred from the analysis of near-simultaneous observations made by the two instruments are compared (Fig. 2). While the sampling volumes are nearly similar, the differing scan patterns of the two radars may

yield time differences. To mitigate errors resulting from temporal mismatch only tilts belonging to the same five minutes cycle are compared. A difference of $\Delta h = \pm 250\text{m}$ (horizontal plan) and $\Delta z = \pm 100\text{m}$ (vertical plan) between the center of each pair of intersecting radar beams is also permitted to allow for more data in the statistical analysis. The quality of the radar measurements is also taken into account by discarding radar data when the signal-to-noise ratio (SNR) is lower than 15 dB or when partial beam blockage (PBB) is higher than 10%.

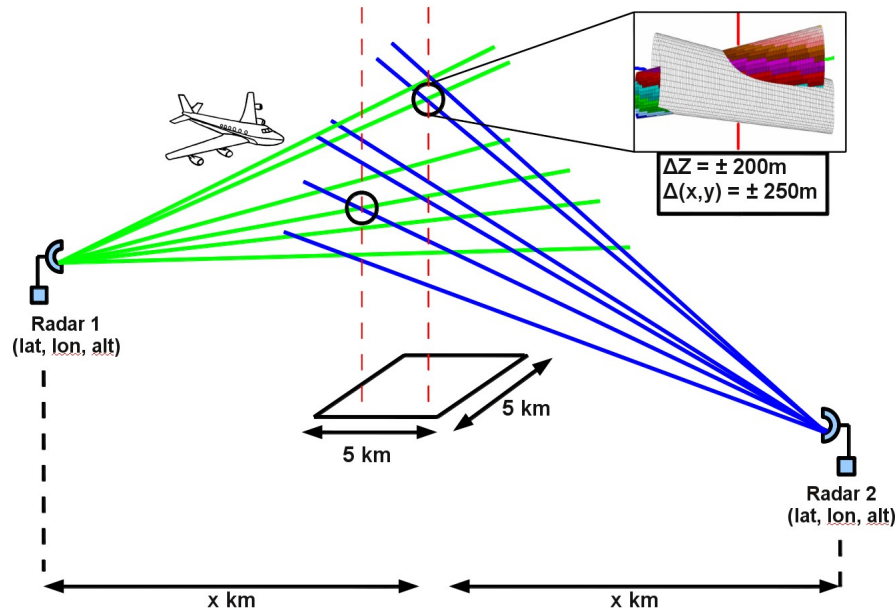


Figure 2 : Inter-comparison method using a pair of neighbouring radar and/or in-situ restitution from radar and aircraft.

4- RESULTS

4.1 – Intercomparisons at C- and S-band

According to the comparison method described in Section 3.2.1, the volume coverage pattern resulting from the scanning strategies of the MON and NIM radars offers the possibility to compare HCA outputs at three different levels: 3km, 7km, and 9km.

Figure 3 presents the percentage of hydrometeor species retrieved during the 29 September 2012 stratiform event (Figure 3a) and the 28 August 2012 convective case (Figure 3b). The agreement between the two datasets is superior in the stratiform regime, as illustrated by the roughly equivalent proportions of retrieved hydrometeor types at all levels (notice the lack of data at 9 km AMSL due to the limited vertical extension of the system). The results are less consistent in the convective case for which identified hydrometeor species differ from one radar to the other at the lowest level. Indeed, one can notice the existence of wet snow in MON-derived hydrometeor data that is not present in NIM observations. A smaller proportion of hail is also obtained with MON data although the overall proportion of frozen hydrometeor (graupel + hail) is relatively steady from one radar to the other.

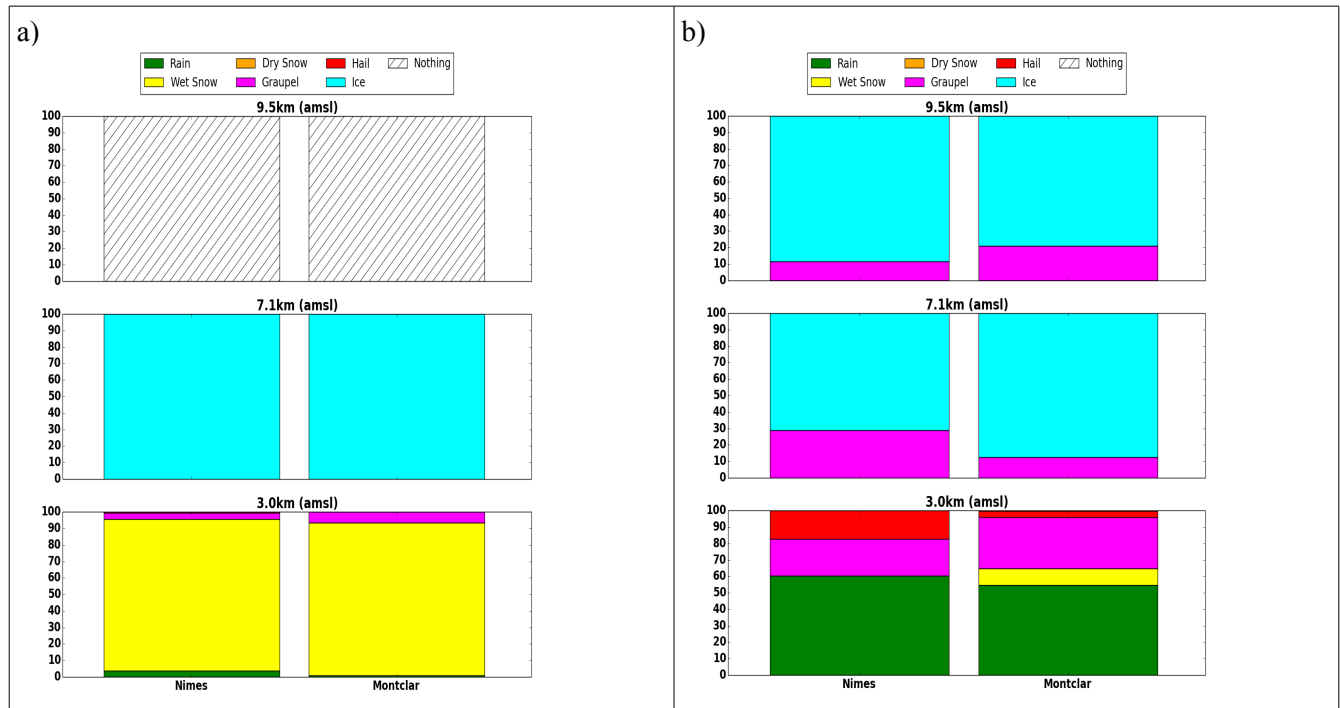


Figure 3: Percentages of hydrometeor species between Nîmes and Montclar radar, integrated over the full area of interest on the: a) 29 September 2012, b) 28 August 2012

The performance of the algorithm as a function of time is also investigated by looking 15 minute time windows of retrieved hydrometeor types. In the stratiform case (Figure 4b), results obtained with the two radars are again in excellent agreement. At the height of 3 km, the two radar beams intersect within the bright band region resulting in high percentages of wet snow. The simultaneous presence of wet snow and graupel at given periods likely suggests the presence of embedded convection. The main differences occur between 13 and 14 UTC, possibly resulting from the slightly different beamwidth of the two radars or from slight time shifts between observations. In the convective situation (Figure 4a), the HID algorithm produces equivalent proportions of frozen particles but higher quantities of hail are systematically generated from NIM data. The proportion of graupel at midlevel altitudes are also significantly higher as long as NIM data are considered. The comparison of attenuation corrected horizontal reflectivity values measured by the two radars in the common sampling area indicates a mean bias of ~ 4.5 dBZ in favor of the S-band radar at heights of 3 and 6 km levels and a bias of less than 0.5 dBZ at 9 km (not shown). In the stratiform case, the difference between the two radars is much less pronounced and is limited to approximately +0.8dBZ at all heights. These observations suggest that differences in hydrometeor fields retrieved from NIM and MON radars are likely related to an imperfect correction of attenuation at C-band.

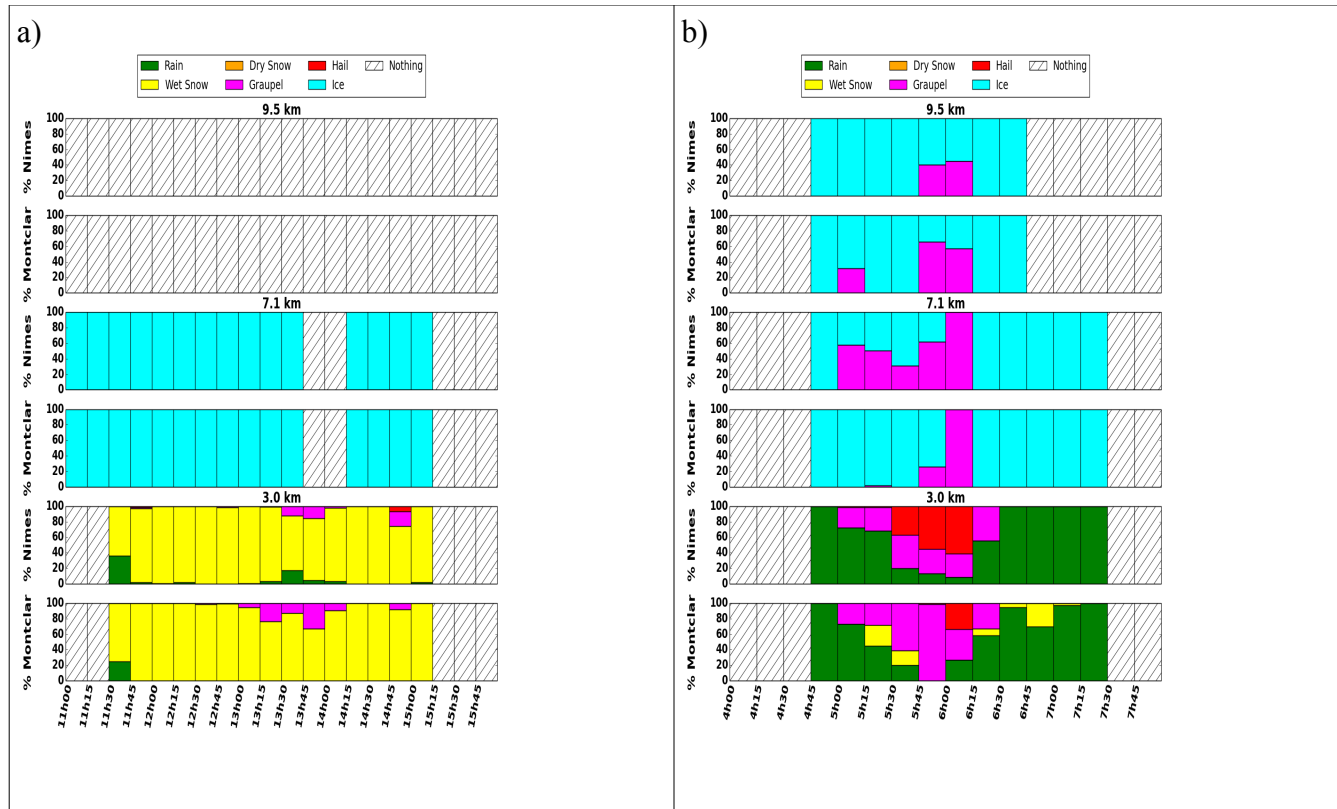


Figure 4: Time series plots of the percentages of hydrometeor species between Nîmes and Montclar radar, integrated over the full area of interest on on the: a) 29 September 2012, b) 28 August 2012.

4.2 – Comparisons against in-situ data

Comparing HCA outputs achieved from collocated radar measurements is an original approach to roughly evaluate the overall performance of HID techniques. This method is however not sufficient to objectively validate the performance of the algorithm as it only allows to infer the relative consistency of the results. Validation of HCA outputs remains a hard challenge due to the scarciness of in situ observations via aircraft measurements. The extensive in situ dataset collected by the F20 research aircraft during HyMeX thus represent a remarkable opportunity to further evaluate the performance of this algorithm. On 29 September, the F20 flew across the observed cloud systems at various heights and for several hours, allowing sampling the microphysical properties of this weather system with a high level of details. From each F20 data measurements at a given time, a location in space is specified using its latitude, longitude, altitude. Similarly the exact space and time locations of each radar pixel is given by the same coordinates information. Thus by combining both F20 and radar pixel center locations, it is possible to assess the performance of hydrometeor discrimination from in-situ observations. Example of radar-derived /aircraft comparisons, in the vicinity of Nîmes radar, are shown in Figure 5.

The precipitation imaging probe (PIP) data shows big drops at an altitude of 2100m AMSL, while the region is classified to hail according to the S-band radar. The distance between the nearest radar pixel center and the F20 measurement is 1849m. However a misclassification might be the reason of this

discrepancy. Indeed melting hail and big drops have the same signal signature with high Z_h and low Z_{dr} values according to Bringi et al, 1991, Schuur et al, 2001, Ryzhkov et al, 2005, Ryzhkov et al, 2008, among others. F20 observation detects aggregates particles at 4500m above the mean sea level, where the region is classified to dry snow for Nimes radar. This discrepancy is due to the limited number of microphysical species take into account by the HCA. However, as both snow categories signal signatures represent a kind of aggregate, this comparison might be considered as correct. At 13h42UTC, graupel particles were identified at ~3800m by both the F20 and the radar. This shows the consistency of precipitation regime (stratiform vs convective) used in the HCA. Finally in-situ probes detected ice at 6000m and 14h18 UTC. Although the distance between F20 and the nearest radar pixel center is quite high (3213m), the identification from dual-polarization radar is again consistent with aircraft data.

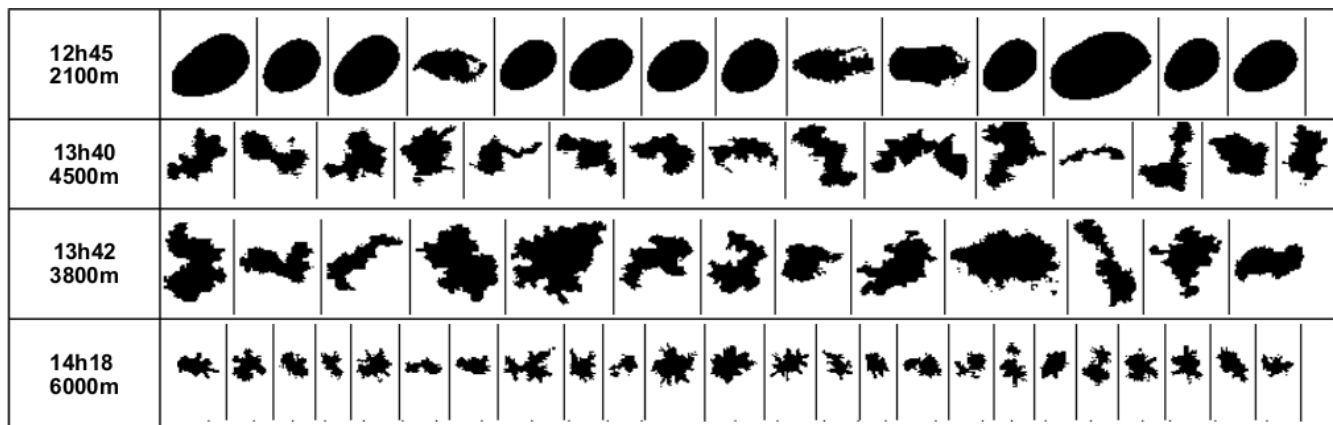


Figure 5 : Falcon 20 aircraft observations on 29 September 2012.

5 - CONCLUSIONS

The evaluation of hydrometeor classification algorithm outputs at C- and S-band showed good consistency at both wavelengths. The analysis showed the robustness of the proposed HCA, according to about 9 hours of intercomparisons data recorded during the HyMeX-SOP1 project. As one would think, comparisons are more consistent during stratiform events comparing to convective events. Radar-derived hydrometeor data are also in agreement with in-situ observation from F20 aircraft. This work will be completed by the analysis of radar data collected during other HPE and new results will be presented during the conference.

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