Formation of big and giant drops inside mediterranean convective cells

J. L. SANCHEZ[1], E. GARCIA[1], J.L. MARCOS[1], J. DESSENS[2]

[1] Lab Física de la Atmósfera. Universidad de León. 24071 León.Spain e-mail dfqjsg@unileon.es
[2]Lab. d'Aérologie. UMR CNRS/UPS 5560 Université de Toulouse III. France

ABSTRACT

During the summer of 1997 a campaign was carry out in the Ebro Valley (Spain). Its main aim was the analysis of supercooled drops during in-flight icing conditions. A C-212 aircraft with cloud physics instruments on board was used. Among the scientific flights carried out, were those that provided new information about the formation of drops and graupel inside Mediterranean storms cells. It was determined that in the most vigorous cloud turret rising on the flank of warm-based storms, the growing processes by means of collision-coalescence were so active that regions of large drops and giant raindrops at negative temperatures close to 0ºC were found. Around these areas there were other zones were graupel was detected.

1. INTRODUCTION

The ice crust formed on the surface of an airplane while flying offers a great hazard. Icing reduces the aircraft lift. Also it hinders the flight operations, it increases the vibration and reduces the propeller efficiency. There are potential hazards of flying in icing in supercooled clouds regions, since ice is left on the airframe elements after the drops impact on the aircraft. After a few incidents, the National Transport Safety Board (NTSB) determined the need to improve the knowledge of clouds regions with high concentrations of Supercooled Large Droplets (SLD).

The EU program named as EURICE, financed research on the aircraft icing, having as the main aim, the analysis of supercooled regions of clouds and their influence on air safety. This program financed the use of several aircraft with cloud physics instruments on board, so that experimental data could be obtained in different Europeans regions, under meteorological conditions that cloud favor icing on the aircraft.

With this program a Campaign was carried out in the Ebro Valley (Spain), during the summer of 1997. Air traffic is very important in this region, especially during the summer seasons. One of the planned objectives was the establishment of the formations and growth processes of supercooled drops in the interior of storm cells. The proximity of the Mediterranean means that in conditions of thermodynamic instability, moisture spreads very quickly through the Valley. The mountains meanwhile, favors rising air currents, and as a result, both the orography and the climatology of the region provide favorable conditions for the development of storms (Castro et al., 1992), most of the times of the type multicell.

In this area, the temperature at the cloud bases of storms tends to be several degrees above 0ºC. It should be emphasized here that a warm-based cloud with vigorous cloud turret has a greater potential for producing a significant amount of liquid water content. Under favorable conditions of high LWC and strong updraft velocity, it has been shown that drizzle drops or in extreme cases giant raindrops can indeed from the embryonic droplets. (Beard et al., 1986, Rauber et al., 1991). When these drops reach zones with temperatures below 0ºC, SLD are formed.

Nevertheless, it should be remembered that the apparition of giant raindrops is not common as a natural phenomenon, except in tropical areas. This fact was analyzed in the Hawaiian Rainband Project (Smolarkiewicz et al., 1988, Szumoswski et al., 1997).

It is well known that drizzle drops are common inside storms cells. But it is unusual to find supercooled giant drops with diameters of more than 4 mm a few hundred of meters above the cloud base in geographical regions where there are no tropical storms. The results found in Nelspruit (South Africa) are very interesting: Mather (1990) discovered that inside the storm cells of that region, the SLD (sometimes of gigantic size) appeared grouped together forming accumulation zones. It is important to highlight that the detection of this type of zones is essential, since they contribute to aircraft icing. It would thus be convenient to determine the areas in the world where these processes are likely to take place.

This paper states the detection of big and giant supercooled drops, and in some cases giant raindrops with a diameter of several millimeters, forming accumulation zones in some regions inside the feeder cells of the Mediterranean storms.

2. EXPERIMENTAL DESCRIPTION

2.1 Flight Procedure

An indication of the presence of an accumulation zone with big and giant SLD in clouds seems to be given by the detection of strong updrafts currents, which make for difficult flying conditions. For this reason the following steps were followed for planning flight operations:

- To identify the cells, information was provided by Interprise radar on Band C, with data processing carried out by the TITAN system (Dixon and Wiener, 1993).
- The evolution of “radar variables” was determined from the Operation Center through analyzing radar images, in an attempt to identify and characterize the development of storm cells in real time.
- When the “feeder area“ on the flank of a multicell was identified, the trajectory was tracked and communicated to the pilot. So that the C-212

platform could enter and cross those “feeder” zones of the main cell with safety, at a temperature below 0ºC. The cruising speed of the C-212 was fixed at 80 m/s.

2.2. Aircraft Instrumentation

Among other equipment, the C-212 had the following installed:

- Two ‘Rosemount’ temperature sensors
- An FSSP 100 probe with a range of 5 to 95 µm.
- A CSIRO King LWC probe.
- An OAP 2D-C probe providing 30 size channel.

The information from a GPS installed on board the aircraft was joined to all the above.

The 2D-C particle image data were processed following standard artifact rejection techniques to eliminate streakers, zero images, images with gaps and invalid time words (Cooper 1978, Mather 1989). This allows to discriminate between drops, graupel and ice crystals following a classification method based on roughness criteria. Using the 2D-C images and a circle-fit procedure (Heymsfield and Parrish, 1978, Mather 1991), water content in drops and raindrops were calculated.

2.3 Mission Flights

The flight operations were designed to enter the Cb by the cloud turrets flanking it, which is where the unstable air feeding the storm cell enters. These cloud turrets have a diameter of about 4 to 5 km and it may be assumed that they are symmetrical. The flights were carried out at levels slightly below 0ºC, trying to detect SLD accumulation zones.

More than one hundred flights were carried out during the campaign analyzing Mediterranean storm cells. In most cases the storms were multicellular, and the data obtained by the C-212 platform were taken in different stages of the evolution of the storms. The typical storm in the study zone develops very quickly, making it often difficult to arrive in time to carry out the aircraft during the initial stages of the formation of the storm cells. The operations were made during in-flight icing conditions, at altitudes of approximately 4000 meters, and it was not always possible to identify the cloud turrets visually.

On 17 occasions the cloud turrets were identified and the data collection was carried out successfully by the C-212 instrumentation. All cases refer to storms in an early stage of their formation, which means that the intensity of their reflectivity had not yet reached its maximum. It is necessary to highlight that in all 17 cases the storm cells reached a reflectivity of more than 50 dBZ. Thus, all these storms caused heavy precipitation.

3. RESULTS

It is necessary to clarify some of the concepts that are used in this paper. The terminology adopted. So, the definition adopted throughout this paper is:

Droplets < 50 µm in diameter

1000 µm > Drops > 50 µm in diameter

1000 µm > Large drops > 100 µm in diameter

800 µm > Big drops > 400 µm in diameter

1000 µm > Giant drops > 800 µm in diameter

Raindrops are > 1000 µm in diameter

The flight trajectories were designed to carry out microphysical measurements in the cloud turrets feeding the storm cells. Thus, the flights were carried out within the updrafts and at temperatures near 0ºC. The updraft speed was divided into 3 categories:

Class a: updraft > 10 m/s

Class b: 10 m/s> updraft > 5 m/s

Class c: updraft < 5 m/s

In most of the cases in which SLD (of the type we have called big or giant drops) were detected, they tended to appear in an organized way. Figure 1 shows images of some SLD found during one of the flights carried out at temperatures of –3ºC.

Table 1 shows the values of some of the variables

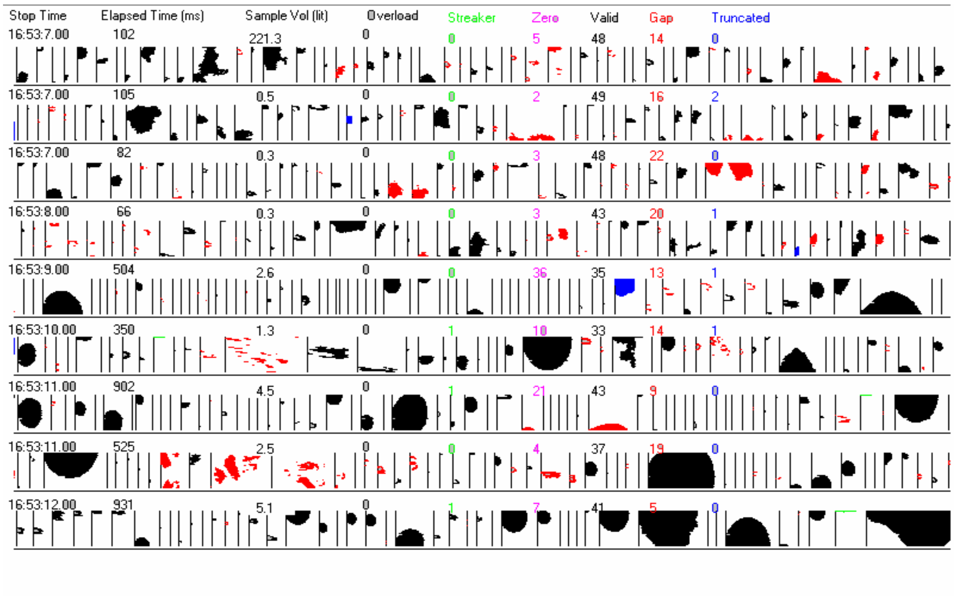

Figure 1: 2D-C images are shown. Vertical lines separating each image are 1.12 mm long. Images appear to be small ice particles, graupel (in top) and the beginning of the SLD accumulation zone (bottom)

The 17 cases present a number of common results, which could be summarized as follows

1. SLD have been detected during all the flights carried out under the following conditions:
   - More than 3ºC of buoyancy at 500 hPa.,
   - Storms with a cloud base temperature above 6ºC, thus the collision-coalescence processes were very active,
   - In regions situated at an altitude where the temperature is a little below 0ºC,
   - In peripheral zones of thunderstorms, and always in the most active convective cells (also called feeder cells).

2. The data provided by the meteorological radar made it possible to state that this type of drops are found more frequently during the formation and development of the storm cells, rather than towards the end or dissipation of the cells.

Case no.	Flight temp (ºC)	Flight altitude (m)	Cloud base altitude (m)	Cloud base temp (ºC)	SLD Sample time (s)	Updraft Type	2D LWC (g/m^3)	SLD region
1	-7	4900	2700	12	24	a	4,9	Isolated
2	-1	4000	2600	12	42	c	----	Isolated
3	-1	4000	3400	6	35	b	0,7	Isolated
4	-5	4400	2700	12	10	b	0,25	Isolated
5	-5	4200	2400	12	23	b	0,58	Isolated
6	-5	4400	2400	12	10	b	0,75	Isolated
7	-3	3800	2400	12	204	b	5,7	Isolated
8	-4	4000	1800	16	216	b	50,5	Isolated
9	-2	3500	1800	16	29	b	1,7	Mixed
10	-4	3900	1800	16	25	b	0,36	Isolated
11	-5	4000	2200	13	55	b	4,5	Isolated
12	-3	3700	2200	13	15	b	14,8	Isolated
13	-3	3800	2200	13	135	b	0,1	Isolated
14	-5	4000	2200	13	40	b	5,2	Isolated
15	-3	3800	2200	13	7	b	0,0002	Isolated
16	-2	3600	2200	13	28	b	1,7	Isolated
17	-5	4000	2200	13	5	b	8,4	Mixed

Table 1: Values found, from left to right: (*case no*) the case analyzed, (*flight temp*) the temperature during the flight, (*flight altitude*) the altitude during the flight, (*cloud base altitude*) the altitude of the storm base, (*cloud base temp*) the temperature of the cloud base, (*SLD sample time*) the duration in seconds during which the SLD were found, (*updraft Type*) the updraft speed estimated following the classification indicated in the text, *(2D LWC*) the Liquid Water Content calculated by analyzing the 2D images, (*SLD region*) when the SLD were found isolated (without any ice crystals or graupel) it is expressed as

"isolated", when the SLD were found together with ice crystals and graupel is expressed as "mixed".

3. The bigger the upward currents within the convective cells:
   - The bigger the concentration of large and giant drops
   - The bigger are the maximum sizes of the SLD spectrum

4. The regions where SLD have been found show the following characteristics:
   - In the case of storms that are being formed or growing, the SLD are grouped in certain zones without any contact with ice particles or graupel, constituting zones of large drops accumulation. Around these areas are others where important amounts of graupel is found together with small size ice particles.
   - The flights carried out have shown that these accumulation zones may have a size of several kilometres.
   - In all cases the aircraft icing load was intense.
   - The accumulation zones do not always present high amounts of LWC (measured by the OAP-2D-C), even though growing or newly formed thunderstorms usually present high amounts. This may be due to the fact that the existence of these large drops is related to liquid-water processes (FP) and liquid-water depletion (DP). The FP is primarily, due to adiabatic ascent. The DP are due to vapor deposition, growth of ice particles (crystals and graupel) coalescence among cloud drops and removal as precipitation and by entrainment of dry air. The depletion rates are a function of ice and graupel concentration, temperature of habits of ice crystals, the cloud supersaturation and liquid-water content, concentrations of cloud condensation nuclei, and the characteristics of cloud-mixing processes.
   - When the convective cells (or feeder cells) surrounding a thunderstorm are less strong, which happens when the storm is near its end or dissipating, large drops are less frequent and are found together with graupel and ice particles.

4. DISCUSSION

It seems obvious that in the Mediterranean storms are more frequent during the summer seasons, precisely at the time when the air traffic is more intense. The presence of accumulation zones of the SLD types described in this paper (big and giant drops) is an important factor in the formation of ice on the airframe elements of the aircraft. The flights carried out by most propeller aircraft frequently travel at an altitude where these SLD have appeared. The results have shown that on some occasions the SLW in the SLD accumulation zones is high (sometimes over 10g/kg). Taking into account that these accumulation zones normally spread along several kilometres, these data should be considered when building de-icing systems.

The occasional appearance of giant raindrops is not easy to explain, and the quantities found in Mediterranean storms will increase the controversy. The fact that, no drops bigger than 5 mm in diameter could be found in updrafts of approximately 10m/s, seems to be a confirmation of Langmuir (1948), who suggested that a drop diameter of the order of 6 mm is something of a critical size, as hydrodynamic instability tends to break up larger drops. It might be possible that the fragments return to acting as new embryos of precipitation, and grow in size until they break again, and so on successively in a "chain reaction". The deformation of the drops detected in the images evidences that these particles were indeed supercooled water (Willis and Hallet, 1991). Farley and Chen (1975) indicate that for Langmuir "chain reaction" to be broken, ascending air currents of at least 10 m/s would be required. The results found in the Ebro Valley seem to be consistent with these statements.

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