Overview of the flights and datasets

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INTRODUCTION

The CLARE98 Campaign was successfully executed during the period 5–23 October 1998. The C-130 and ARAT aircraft were present throughout the campaign. The DLR Falcon aircraft was present from 12–23 October. Seven missions were flown which used up the total flying hours available from the three aircraft. Ground based data were taken during the flights from radars at 3, 35 and 94/95 GHz, together with radiometers, interferometers, ceilometers, and flux meters. For most of these instruments data was also logged during the whole of the campaign; this data is described in subsequent summaries. In this document we concentrate on the seven aircraft flights.

The aircraft flew legs towards and away from the Chilbolton site on the 260° azimuth. The Falcon was flying at a high level of about 10 km with a downward looking lidar generally above the cloud; the ARAT was generally at its ceiling of 5 km with its radar and lidar looking downwards to cloud below where, ideally, the C-130 was making in-situ microphysical measurements. The co-ordination of the aircraft worked very well with a pair of synchronised inbound and outbound legs over Chilbolton typically every thirty minutes.

A summary of the number of single legs per mission is as follows:

Date	Mission	C-130 legs	ARAT legs	Falcon legs
7 Oct 98	1	8	8	-
13 Oct 98	2	16	10	10
14 Oct 98	3	14	8	8
16 Oct 98	4	14	-	-
20 Oct 98	5	28	18	18
21 Oct 98	6	8	6	6
22 Oct 98	7	12	-	-

Twelve single legs were identified for intensive analysis. They include data in stratocumulus (liquid), ice and mixed-phase clouds:

Date	Mission	Time	Comments
20 Oct	5	1420	3.9 km ‘Thick cirrus’
		1450	4.5 km ‘1.2 g kg^{-1} ice snow, -10.1°C
		1520	5.4 km ‘thick ice cloud -14.5°C
13 Oct	2	1340	2.3 km ‘300 m deep stratus 5°C
21 Oct	6	1020	5.7 km -20°C Ice cloud.
			ARAT lidar up, Falcon down.
7 Oct	1	1400	1.95 km, ‘Supercooled Sc’ (No Falcon).

The comments are those of the C-130 which was making in-situ penetrations. The times (UTC) are those for the nominal inbound overflight of Chilbolton. The data gathered thus cover a variety of clouds which are typical of those that a future space-borne mission would sample.

OVERVIEW OF THE INSTRUMENTS

Ground based at Chilbolton:

RAL 3 GHz scanning and 94 GHz vertically-pointing radars. 22/28/78/94 GHz zenith pointing radiometers. UV lidar. Ceilometer. Standard Met instruments. Cloud camera.

CRA 35 GHz scanning radar. 35GHz radiometer.

GKSS 95 GHz vertically pointing radar.

KNMI IR radiometer. Video camera. Vis-IR radiative fluxes.

TU Delft/TU Eindhoven 21.3, 23.8, 31.65, 51.25, 53.85, 54.85 GHz ESTEC radiometers.

Scientists from Heidelberg operated a high resolution A-band radiometer from which it should be possible to derive the optical depth and photon path-length distribution through the clouds.

In addition, experimenters outside the main CLARE group were as follows: University of Bath, UK—GPS path integrated vapour, 95 GHz high performance radiometer; University of Portsmouth—40 GHz radiometer and satellite receiver.

During the flights the scanning radars performed slow RHIs (Range Height Indicator—that is, a scan in elevation at constant azimuth) following the aircraft as they flew along a radial to and from the site. On other occasions the radars performed more rapid RHIs to gain a greater knowledge of the total cloud environment. At other times the scanning radars joined the other instruments in recording vertical dwells during the period of the experiment.

Aircraft:

MRF Hercules aircraft: Temperature, wind, humidity, particle size spectra, bulk water measurements, radiation measurements—broad band, narrow band plus microwave.

IPSL ARAT aircraft: 94 GHz cloud radar (Kestrel from University of Wyoming) and lidar (LEANDRE) and an array of radiometers.

DLR Falcon with ‘ALEX’ lidar and FUBISS spectrometer together with short and long wave radiometers.

To avoid interference of ground based radars with those on the ARAT, the GKSS radar had its E-field vector at 45° to the

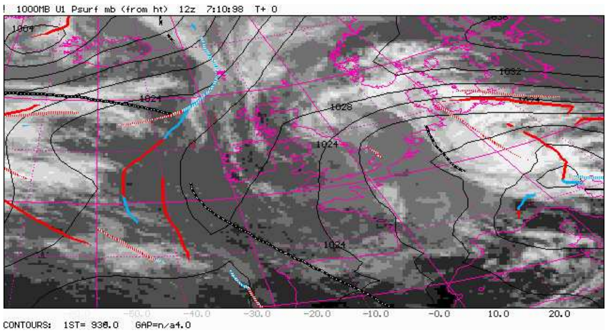

Fig. 1: Synoptic situation at noon on 7 October 1998 over the UK. Blue and red lines indicate objectively-analysed cold and warm fronts respectively.

aircraft azimuth, and the Galileo (RAL) scanning radar had its E-field in the vertical plane.

Details of the performance of these instruments both on the aircraft and ground are given in subsequent papers. We now provide an overview of the seven missions illustrated with some typical data gathered.

FLIGHT/MISSION SUMMARIES FOR THE CLARE CAMPAIGN OCTOBER 1998

Times are those of nominal co-ordinated overpasses—precise times to the second (when available) are those when the aircraft were over Chilbolton. The comments and temperatures are from the C-130 when sampling cloud—usually when overhead Chilbolton. Unless otherwise stated the first time is for the inbound leg, the second for the outbound leg, and the aircraft are on a true azimuth of 260°. Flight heights are converted into km using 1000 ft = 304.8 m The runs in bold are those identified for priority analysis.

The synoptic analyses use the objective frontal identification of Hewson (1998, Met. Apps., **5,** 37–65: 'Objective fronts') in which the isobars are overlaid with the IR satellite data, warm fronts are red and cold front cold, with upper fronts marked hashed and the broad black lines represent upper level jets. The sondes ascents are from Larkhill which is 28 km to the west of Chilbolton .

Mission 1: 7 OCT 1998

Figure 1 shows the synoptic situation at noon. A slack north-easterly airstream was bringing low level stratocumulus in from the North sea. The sonde ascent shows a saturated profile up to about 770 mb with very dry air above. Stratocumulus cloud top was at about 2.2–2.4 km. Initially, the stratocumulus cover was continuous with thicker patches containing drizzle, but after 1410 some breaks were observed. The legs from the mission are listed in Table 1.

Figure 3 is a twenty minute section of the vertical profile of reflectivity taken with the 94 GHz GKSS radar. Patches of reflectivity near −10 dBZ coincide with drizzle are clearly visible separated by thinner cloud (typically only 200 m) with reflectivities closer to −40 dBZ. The instrument only records reflectivities above 900 m.

The reflectivity viewed from the downward pointing

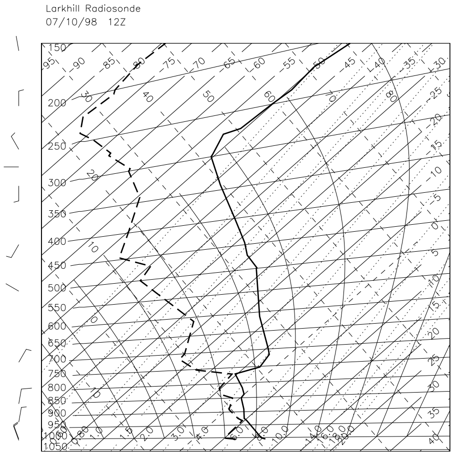

Fig. 2: Radiosonde ascent from Larkhill at 12Z on 7 October 1998.

ARAT and C-130 only. ARAT at 3 km.		
1130:02/1132:34	C-130 only	low level run
1200:16	C-130 only	2.74 km - clear air
1222:45/1226:12	C-130 only	2.74 km - clear air
1249:22/1252:35	C-130 only	2.29 km - 'in/out cloud tops'
1330:46/1333:52	C-130+ARAT	1.5 km - mostly below cloud
1356:30/1359:49	C-130+ARAT	1.95 km - 'mainly water droplets −3.7°C'
1426:17/1429:57	C-130+ARAT	1.8 km - −2.4°C 'over Chilb very little cloud'
1456:26/1459:44	C-130+ARAT	2.1 km 'no cloud over Chilbolton'

Table 1: Summary of legs in Mission 1.

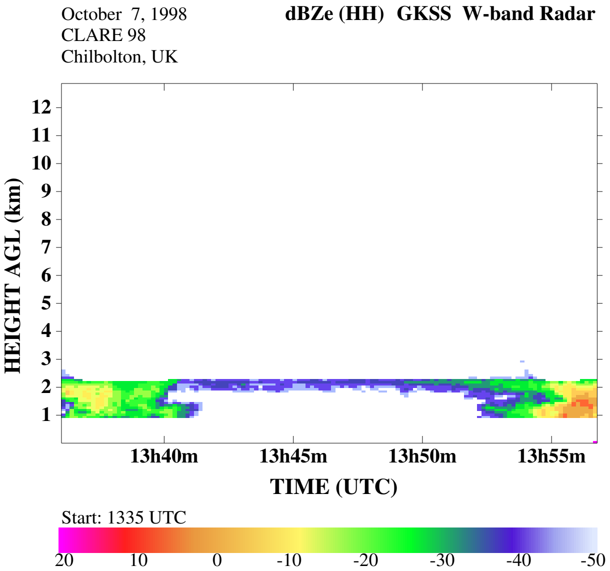

Fig. 3: Time-height section of radar reflectivity from the GKSS 95 GHz radar on 7 October 1998.

KESTREL radar on the ARAT is displayed in Fig. 4. The regions of drizzle extending down to the ground with reflectivities of about 0 dBZ are clearly visible embedded in lower regions of reflectivity. Figure 5 shows that the downward point-

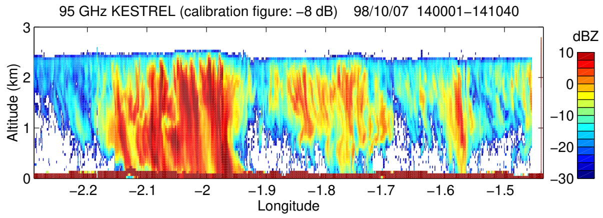

Fig. 4: Radar reflectivity from the airborne 95 GHz KESTREL radar.

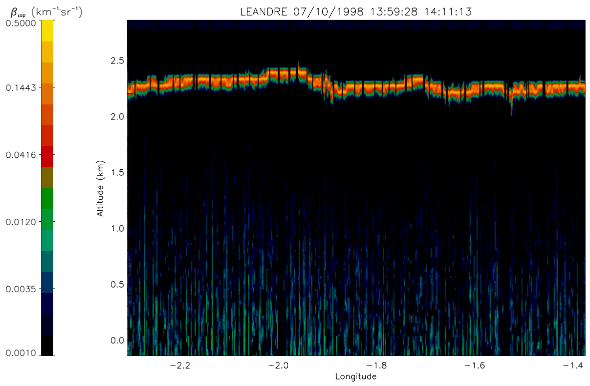

Fig. 5: Backscatter coefficient from the airborne LEANDRE lidar.

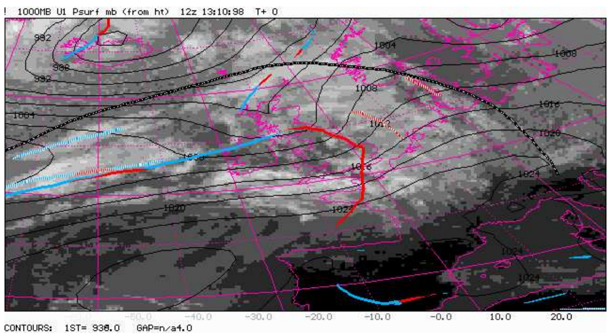
Fig. 6: Synoptic situation at noon on 13 October 1998.

ing LEANDRE lidar was severely attenuated by the water cloud and only able to penetrate a very few gates.

Mission 2: 13 OCT 1998

Figure 6 shows that the Chilbolton area was in an open warm sector, and the noon day sonde ascent (Fig. 7) shows the air moist and saturated up to 680 mb, and then another moist layer from 500 mb to the tropopause. The ground based radars showed a thick layer of ice cloud extending from 5–10 km at 100 h overlying low cloud, but by the time the aircraft took off this ice cloud had thinned and dispersed. The C-130 penetrated the ice cloud at 1204, but by the time the other two aircraft were on site the most interesting clouds were the thin (300 m) stratocumulus at a height of 2.3 km which were penetrated by the C-130 whilst the other two aircraft flew overhead. The ARAT and Falcon had to return after 1445, after which some higher cloud spread over and the C-130 made some penetration through very thin ice cloud between 5 and 7 km. Table 2 summarises the legs of the mission.

The stratocumulus cloud was thin and of low reflectivity

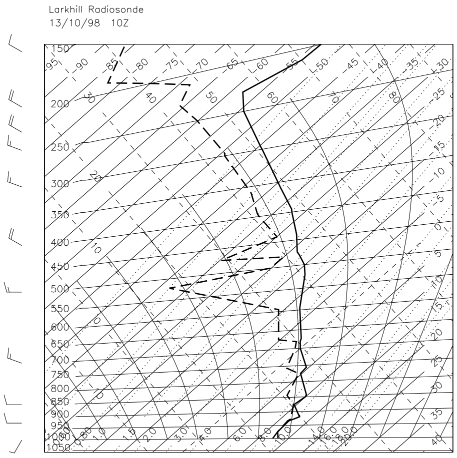

Fig. 7: Radiosonde ascent at 10Z on 13 October 1998.

ARAT at 4 km Falcon 10.5 km		
1108:32	C-130	low level run 1.0 km
1130:42	C-130	overhead climbing
1204:33/1210:06	C-130	7.29 km −28°C Crystals on 2D-C
(Now co-ordinated with ARAT and Falcon)		
1240/1244	C-130	3 km Ci 25k Ac/As 3 km St 1 km
1310:39/1314:42	C-130	3.2 km -1°C 'in thin cloud'
(1316:33 Falcon ohd)		
1340:35/1345:36	C-130	2.3 km '300 m deep Sc no drizzle +5°C'
1410:06/1414:25	C-130	2.1 km 'cloud breaks some blue sky, no cirrus above'
(1409:55 Falcon)		
1440:19/1445:05	C-130	1.2 km 'Entire run in Sc' (GKSS cloud up to 1.5 km)
(ARAT/FALCON return)		
1510:00/1514:34	C-130	4 km Apparently no cloud. GKSS no cloud at 4 km
1543:05/1547:38	C-130	6 km -20°C 'brushing cloud top'
1600	C-130	6 km

Table 2: Summary of legs in Mission 2.

during the 1345 penetration as confirmed by the ground based radar reflectivity displayed in Figure 8. The reflectivity was below the threshold for the KESTREL, although the LEANDRE lidar (not shown) received a strong signal from cloud top that again was attenuated after a very few gates by the liquid water cloud.

Mission 3: 14 OCT 1998

A weak cold front accompanied by some very light drizzle cleared through the Chilbolton area (Fig. 9) by 1200. The sonde ascent at 1200 (Fig. 10) shows that the air was saturated and stable up to 825 mb and then moist again above 400 mb. Behind the front until 1300 there was some low level stratocumulus and cumulus through which the C-130 flew. After 1340 the ARAT and Falcon had to return, just as a layer of cirrus between 7 and 8 km was spreading across; this layer was subsequently penetrated by the C-130. Table 3 summarises the legs in this mission.

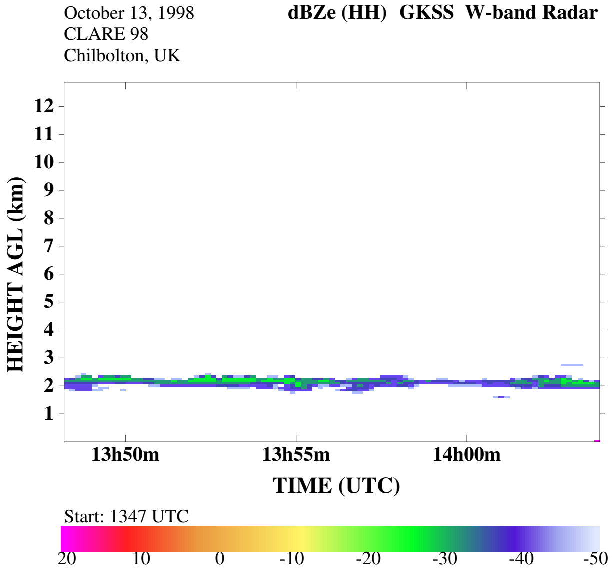

Fig. 8: Radar reflectivity from the GKSS 95 GHz radar.

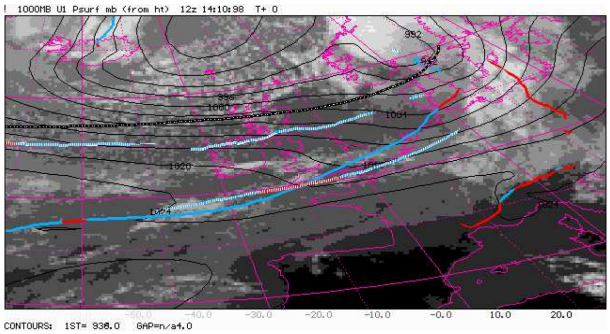

Fig. 9: Synoptic situation at noon on 14 October 1998.

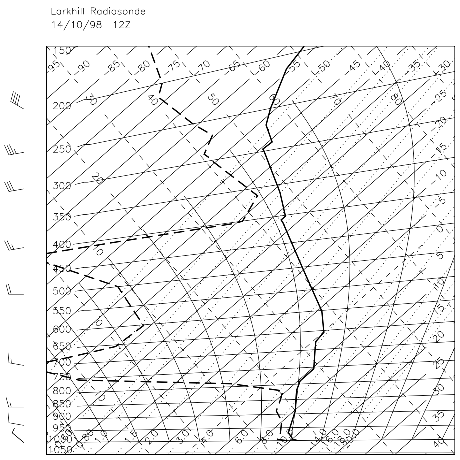

Fig. 10: Radiosonde ascent at 12Z on 14 October 1998.

A typical twenty minute vertical dwell through the cirrus from the ground based GKSS radar is displayed in Fig. 11. A well defined and persistent layer of cirrus between 7 and 9 km is evident with reflectivities generally in the range −30 to −10 dBZ. The final ARAT leg with the LEANDRE lidar looking up into the cirrus layer is shown in Fig. 12; in this case the lidar is able to penetrate the depth of the ice cloud. The track of the C-130 as it penetrates the cirrus deck just below 8 km is

ARAT at 3.7 km, Falcon 11.5 km		
1210:07/1215:00		1.8 km 6.2°C 'skimming Sc/Cu tops' but Z seems low
(1209:35 Falcon)		
1240:29/1245:02		1.5 km 'in stratus over Cu below', Z seems v. low
(1239:54 Falcon in: 1240:14/1240:06 ARAT)		
1310:00/1314:11		1.06 km 'only cirrus above'
(1309:30 ARAT: 1310:18/1316:03 Falcon)		
1339:30/1345:46	Falcon	(1345:37 ARAT looking up) C-130 climbing
(ARAT returns; Falcon returns - laser problem)		
1424:40/1429:45	C-130 only	7.5 km −31°C'thin cirrus' good echo 7.5 to 8 km
1458:42/1503:33	C-130 only	8.11 km 'tops of cirrus - aggregates and rosettes'

Table 3: Summary of the flight legs in Mission 3.

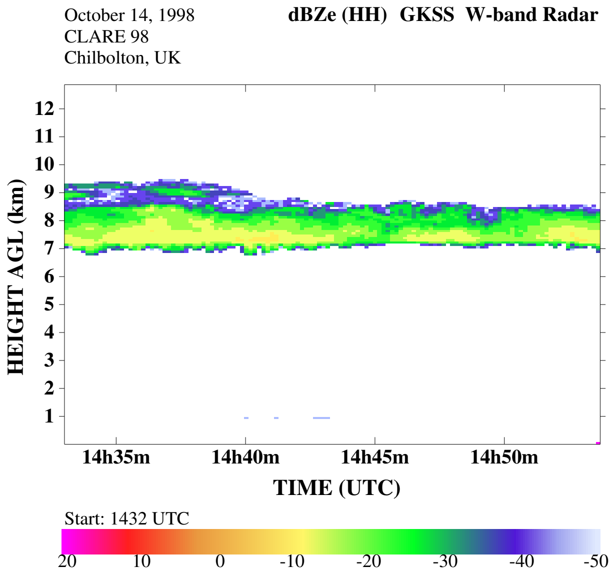

Fig. 11: Radar reflectivity from the GKSS 95 GHz radar.

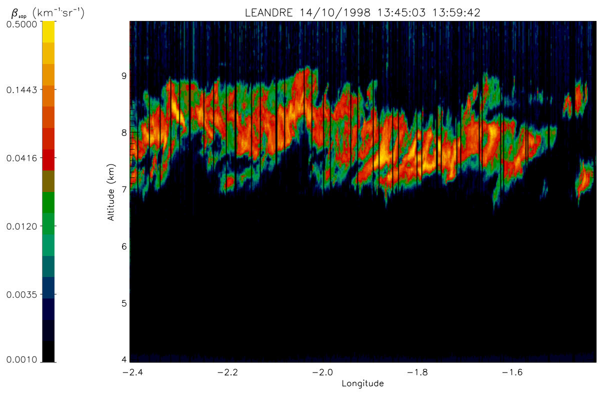

Fig. 12: Backscatter coefficient from the airborne LEANDRE lidar.

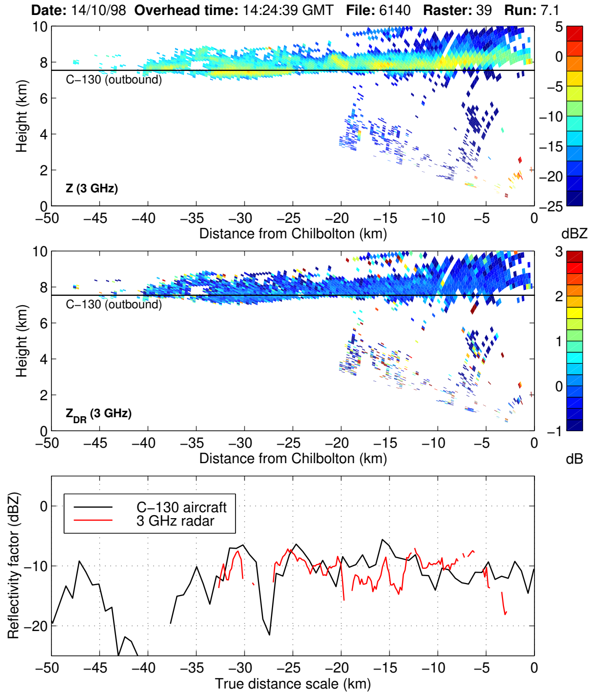

Fig. 13: Radar reflectivity and differential reflectivity measured by the CAMRa 3 GHz radar, and comparison with the C-130.

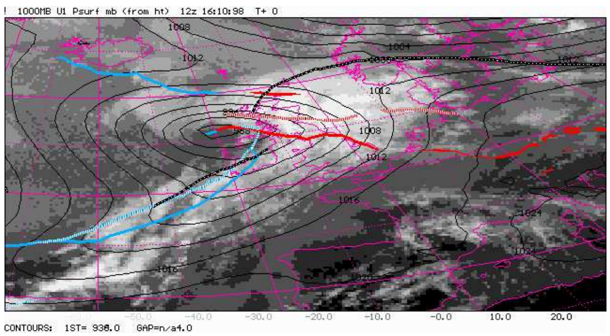

Fig. 14: Synoptic situation at noon on 16 October 1998.

shown in Fig. 13 superposed on the 3 GHz radar scan through the ice cloud. The lower panel of this figure compares the value of Z calculated from the 2-D probe on the aircraft compared with that measured by the radar.

Mission 4: 16 OCT 1998

On this day there were very strong SW winds in a warm sector ahead of an approaching cold front (Fig. 14). Because of the strength of the winds and the low visibility only the C-130 was able to take off. The midday ascent in Fig. 15 shows saturation up to 800 mb. There was persistent low cloud below 2 km, but although the C-130 remained airborne for four hours there was no cloud above this lower deck. About 30 minutes after the C-130 had landed a layer or cirrus spread across the area. The legs in this mission are summarised in Table 4.

Mission 5: 20 OCT 1998

Successful co-ordinated flights were made through ice and mixed-phase clouds ahead of advancing fronts in a strengthen-

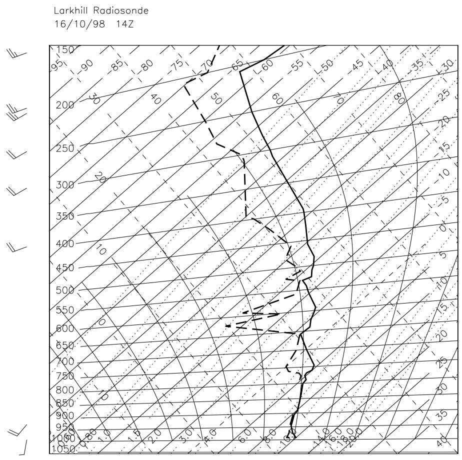

Fig. 15: Radiosonde ascent at 14Z on 16 October 1998.

Cold front approaching—but no cirrus.
Very windy so C-130 only. Warm sector.

1103:53/1108:08	900 m climbing—in slight drizzle and cloud
1141:58/1147:38	7.31 km −31.7°C ‘clear over Chilb’
1217:18/1222:38	6 km not in cloud
1250:37/1254:40	6.6 km −24°C ‘no cloud’
1329:53/1335:47	‘9 km’ −46°C clear over Chilb
1420:41/1425:52	2.43 km 4°C
1454:41/1458	1.52 km 7.8°C ‘not in cloud’

Table 4: Summary of the flight legs in Mission 4.

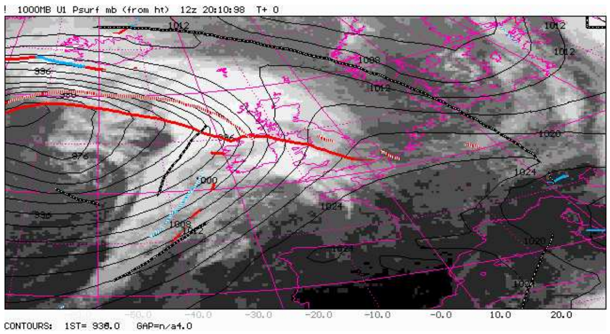

Fig. 16: Synoptic situation at noon on 20 October 1998.

ing SW windflow (Fig. 16). The ascent (Fig. 17) shows a saturated layer at 650–500 mb. The C-130 remained airborne for 8 hours but the other two aircraft had two sorties and returned at lunch time to refuel. The legs for this Mission are summarised in Table 5.

This flight has been the intensively analysed and is the subject of a number of subsequent papers. So, here we have chosen two examples of the data which are not reproduced later on. Figure 18 shows the ALEX lidar looking down from the Falcon for the 1400 leg. The upper cirrus layer between 10 and 12 km is clearly visible, and although the ice attenuates somewhat, some highly reflecting layers at a height of 4 to 6 km are evident. As these layers do not depolarise the laser signal it will be argued that they are supercooled liquid water cloud. By 1521, these layers have disappeared, and Fig. 19 shows a consistent com-

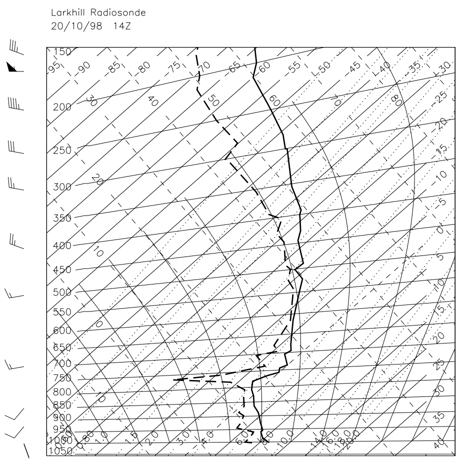

Fig. 17: Radiosonde ascent at 14Z on 20 October 1998.

0820:15	C-130	ohd climbing
0841:33/0845:10	C-130	3.04 km climbing
09:20:44/0924:50		3.64 km 'C-130 in tops for < 1 minute'
(0918:26/0925:39 Falcon)		
0950:22/0954:25		2.25 km 'skimming tops of clouds over Chilb'
(0950:25/0955:11 ARAT)		
(0949:48/0956:00 Falcon)		
1020:00/1024:10	C-130	'no cloud'
(1019:30 ARAT in)		
(1020:21/1026:07 Falcon)		
1050:06/1054:14	C-130	3.9 km just above thick cirrus over Chilb.
(1049:50/50 ARAT in)		
(1050:00/1056:01 Falcon) ARAT & Falcon return to refuel		
1120:12/1124:15	C-130 only	3.7 km in cloud thruout 'mixed phase $-7.5°C$
1152:01/1156:02		3.75 km, inborne 'in-cloud', outbound 'just above'
1223:33/1227:20		3.75 km $-7°C$ 'thin cloud all around this level'
1300:18/1302:55		3.04 km 'drizzle o'head chilb'
1320:27/1327:03	ARAT	- No C-130.
(1318:02/1327:03 Falcon)		
1349:35	C-130	2.4 km 'above cloud'
(13:50 Falcon, 1353:20 ARAT outbound)		
1420:01/1423:30		3.9 km thick cirrus $-6.3°C$
(1420:27 ARAT in, 1420:40 Falcon in)		
1449:58/1454:24		4.5 km '1.2g/kg snow, ice bul rosettes $-10.1°C$'
(1450:18 /1454:48 ARAT: 1454:30 Falcon)		
1521:00/1525:45		5.4 km 'thick ice cloud graupel, snow, needles $-14.5°C$
(1519:58 ARAT - below C-130)		

Table 5: Summary of the flight legs in Mission 5.

parison of the 3 GHz ground based radar with the Z values calculated from the C-130 probe data.

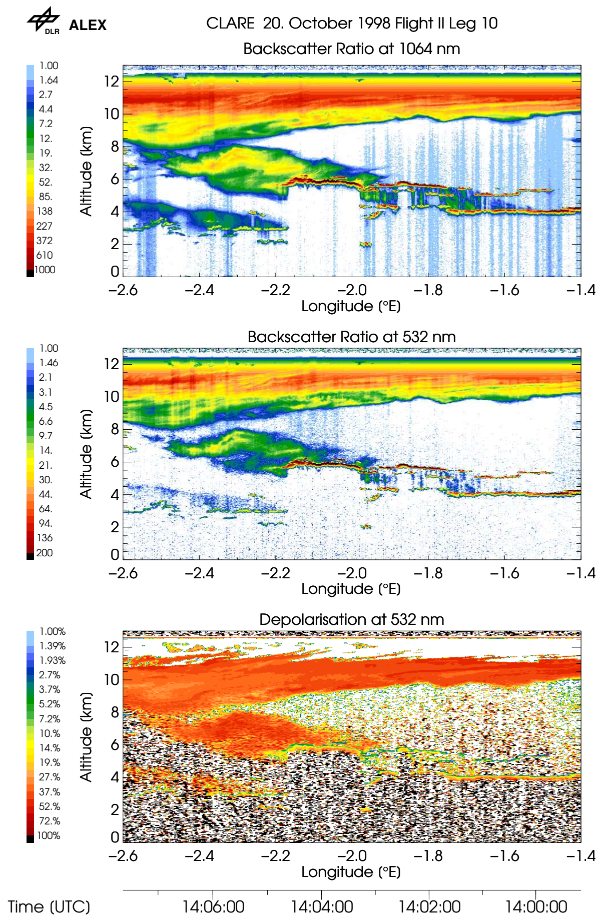

Fig. 18: Observations by the airborne ALEX lidar on 20 October 1998.

0923:53/0927:26	C130 at 0.380 km, 13°C, just clipping cloud base.
0948:22 (in)	3.04 km, -1°C ('go in cloud at 0957')
(0950:23 Falcon inbound)	
1019:51/1025:15	C-130 5.7 km $-17°C$ 'in cloud base of cirrus- crystals'
(1019:42 ARAT in looking up / 1019:03 Falcon in)	
1050:15/1055:47	5.7 km $-20°C$ 'not in cloud'
(1049:33/1055:35 ARAT: 1049:51/1055:53 Falcon)	

Table 6: Summary of the legs flown in Mission 6.

Mission 6: 21 OCT 1998

Figure 20 shows that a cold front which had cleared through Chilbolton by 0900 and was followed by a strong SW airflow with a moist layer from 500–350 mb (Fig. 21). It was followed by low cloud which then broke somewhat, and subsequently a patch of cirrus above 5 km in height moved over the region at about 1100 followed by clear skies. The legs in this mission are summarised in Table 6.

The layer of ice cloud between 4.5 and 6.5 km is clearly visible in the ground-based radar return in Fig. 22. The lidar return from the LEANDRE lidar looking up is displayed in Figure 23 with the backscatter from the ice cloud clearly visible, and also a highly reflecting layer at cloud top which did not show up in the radar return. The highly reflecting layer at cloud top is

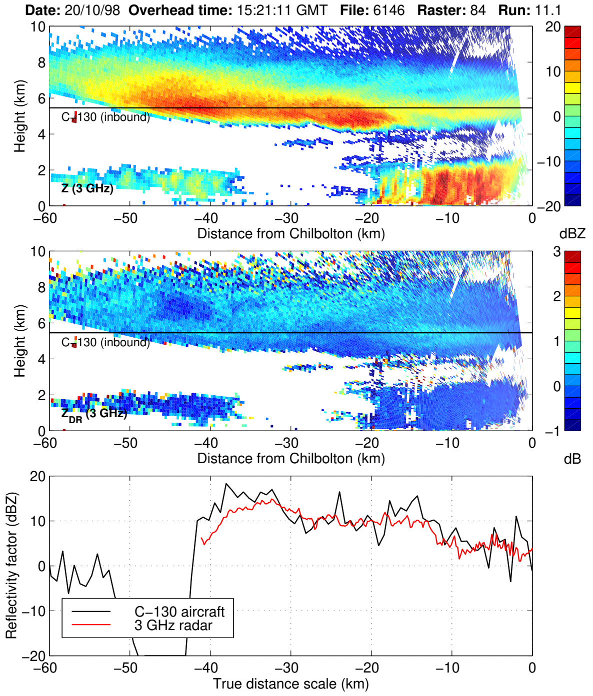

Fig. 19: Comparison of 3 GHz CAMRa reflectivity with values calculated from the concurrent C-130 in situ measurements.

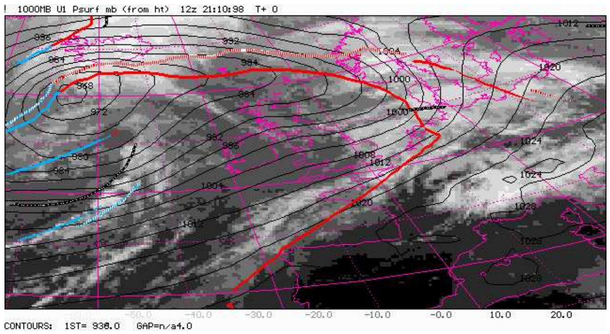

Fig. 20: Synoptic situation at noon on 21 October 1998.

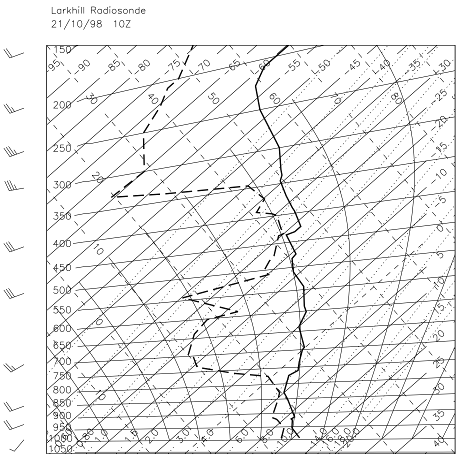

Fig. 21: Radiosonde ascent at 10Z on 21 October 1998.

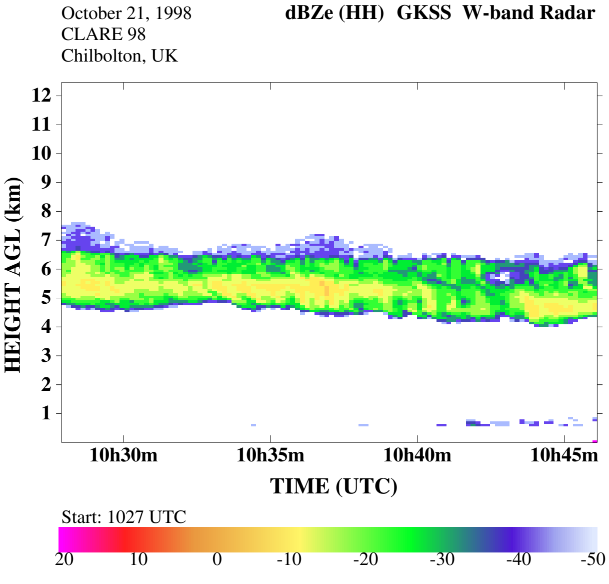

Fig. 22: Radar reflectivity from the GKSS 95 GHz radar.

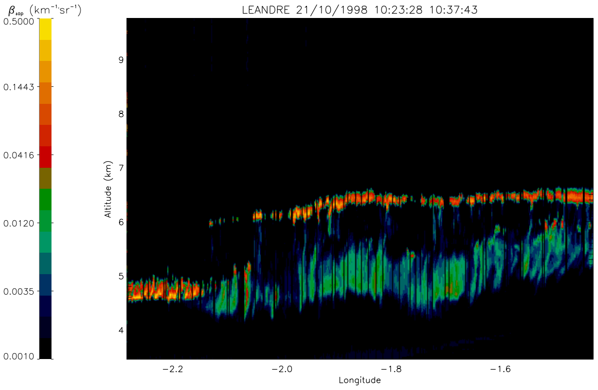

Fig. 23: Backscatter coefficient from the airborne LEANDRE lidar.

also clearly visible in the downward looking ALEX lidar data in Fig. 24; the depolarisation data suggesting this is in fact ice crystals and not supercooled water.

Mission 7: 22 Oct 1998

The C-130 flew alone because of the strong SW cross winds. In the strong SW in the tropical maritime air (Figs. 25 and 26) there was persistent low cloud which was penetrated at the beginning and end of the flight. There was some cirrus to the north but none over Chilbolton. An approaching deep low with cirrus—arrived much later. This data has not yet been analysed in any depth. Table 7 summarises the legs flown in this mission.

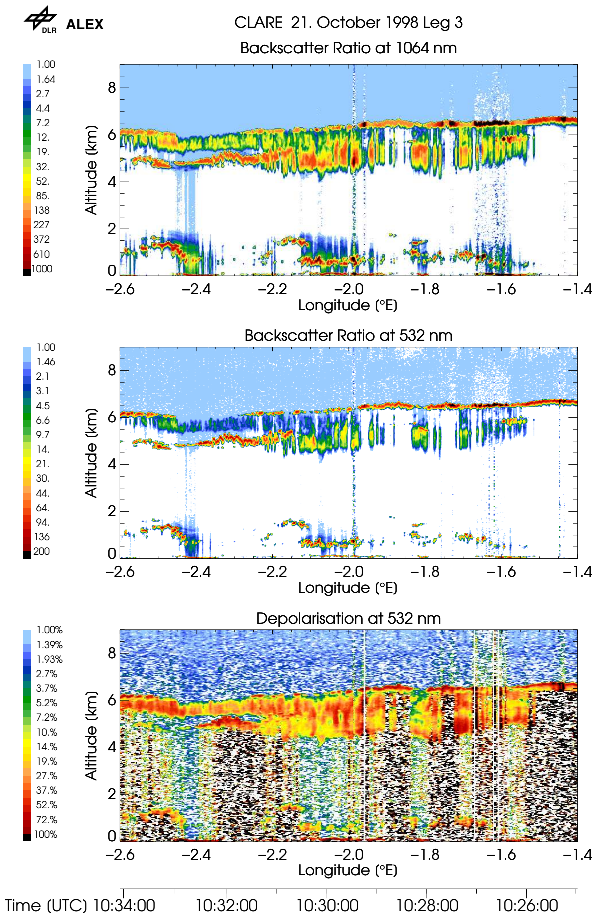

Fig. 24: Observations by the ALEX lidar on 21 October.

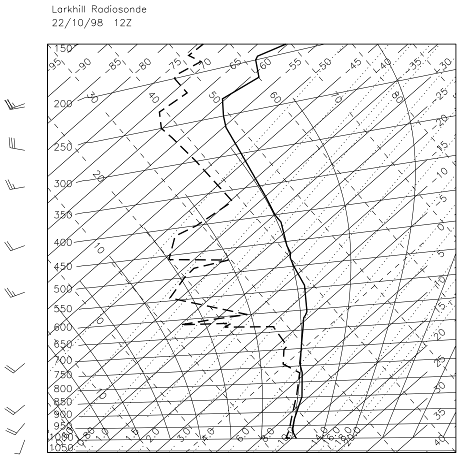

Fig. 26: Radiosonde ascent at 12Z on 22 October 1998.

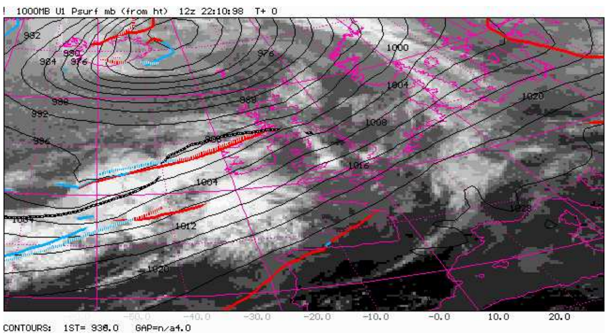

Fig. 25: Synoptic situation at noon on 22 October 1998.

1121:47/1125:50	900m +9°C ‘thick cloud and drizzle’
1202:25/1207:30	7.5 km ‘cirrus to the west’
1236:06/1240:57	7.5 km −35°C ‘thickish cirrus’ (7-10 km from radar)
(from satellite - we are southern edge of band of cirrus)	
1305:10	8.1 km - not in cloud
(Various clear air runs as cirrus moved away to the NW Then descend to run through low level stratus)	
1443	Expect overhead - 900m - break off - air traffic control
1507:20	Inbound 9.6°C ’in thick cloud’ - THEN RETURN.

Table 7: Summary of the flight legs in Mission 7.