Unusual Cloud Formation – 10October2016- 0900z. Wokingham.

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An unusual cloud formation was seen at the 0900z routine synoptic observation at Wokingham, Berkshire, UK, 51.4N 0.8W on 10th October 2016.

Observation.

The cloud consisted of 2 okta of a thin sheet of what looked at first sight to be high altocumulus stratiformis undulatus translucidus, but had a rather odd dull appearance, with a complete absence of the brightness normally associated with a water cloud. The colour was an almost uniform grey, with an absence of any shadowing. This cloud sheet had an edge to the SW, and seemed to be extensive beyond this edge.

Beneath this sheet and elsewhere there were sacttered about, patches of white cirrus uncinus. Of the cirrus patches that were clear of the cloud sheet, some were passing overhead, moving quickly towards the SSE. When one of these patches was in the vicinity of the sun, it produced a brilliant parhelion. At least one thick condensation trail was also seen at the cirrus altitude in the area clear of the stratiform sheet.

Data.

Having a satellite receiving station, I displayed the metopB overpass of the UK, which was timed at 0921z. Using the built in thermal measuring facility (software by David Taylor; http://www.satsignal.eu/)

the temperature of the stratiform cloud sheet was shown as between -25C and -30C. When measuring the temperature of cloud from space, allowance has to be made for the fact that the satellite IR sensor may be able to sense the radiation from below the cloud through thin parts of the cloud sheet, and will thus indicate a higher temperature than the actual for the cloud. This was the case here, and explains why the cloud temperature seemed to vary over a 5 C range. In such instances, the lowest indicated temperature is likely to be closest to the true cloud top temperature, which in this instance is -30C.

Fig 1 (p6) is a copy of the IR image over southern UK and the English Channel. Although this polar orbitting satellite has a resolution of 1 km at the sub-satellite point, the resolution falls away towards the edges of the image, due to the curvature of the earth, and unfortunately the area of interest from this metopB image lay near the edge of the orbital swathe, so the resolution is a good deal less than ideal. Nevertheless, it does reveal a number of interesting features. In this image, the stratiform sheet can be seen extending from Mid Wales to the Isle of Wight. Some scattered cirrus patches can be seen between roughly the Isle of Wight and Bristol. It should be noted that many of these patches have a similar orientation and shape, aligned roughly W-E.

Interestingly, what can also be seen are a number of cloud holes, most evident over the English Channel SE of the Isle of Wight. These have the appearance of fall-streak holes that can form when there is a thin layer of super-cooled water cloud, indicating an atmospheric layer saturated with respect to water, and super-saturated with respect to ice. Any disturbance in this cloud can lead to nucliation of the water droplets, the resulting ice crystals finding themselves in a supersaturated environment will grow rapidly, reducing the relative humidity towards saturation with respect to (wrt) ice, but in so doing, reduce it to well below saturation wrt water, leading to the evaporation of the existing water cloud in the vicinity. In this environment a hole will form in the water cloud and will usually contain near its center the fall-streak ice cloud. Some of the cloud holes SE of the Isle of Wight do contain a patch of cloud in their centre.

Having ascertained that the cloud temperature for the stratiform sheet was near -30C, I then turned to the Larkhill ascent made at 0900z, Fig3 (p8) (available from the University of Wyoming), and this shows a shallow high humidity layer between -27C and -31C, approximately 7260 m to 7740 m altitude. This approximately 500m layer was characterised by a near saturated adiabatic temperature profile, theta e constant, capped by a stable layer. From this profile I would expect the cirrus uncinus to be located in this layer, with the stratiform cloud in the capping layer.

It was evident from my own observation, that the cirrus patches visible to me did not appear to be penetrating the startiform sheet, though they appeared to be very close to it. Also, although I expected and looked for fall-streak holes, I witnessed none. Here the cirrus patches orientated W-E mentioned earlier may hold a clue. I think these patches may be spreading aircraft contrails which formed in the moist layer as individual aircraft climbed through this layer. One dense contrail was observed here, though it formed in the clearer air just north of the stratiform sheet, and seemed to be at approximately the same height as the stratiform cloud. It was persistant but relatively short. The altitude of the cloud and moist layer, about 25000 ft, is well below the cruising level of modern passenger aircraft, and any aircraft at that level would probably be ascending or descending. The cloud sheet is in the flight path of frequent departures from Heathrow heading westwards, and these pass Wokingham at an altitude of approximately 7000 ft. Extrapolating the rate of climb, they would pass the 25000 ft level roughly along the line of the white cirrus patches. It is also possible that some of the cirrus uncinus patches observed to the north of the cloud sheet edge may have originated from earlier condensation trails.

The Chilbolton cloud radar, Fig2, (p7) picked up the cirrus cloud, although the thin stratiform cloud is not identifiable as a seperate feature. The altitude of the cloud detected by the radar is base 6790 m, top 7830 m. The cloud top is surrated, indicating that it contained turbulent elements. The radar cloud tops are at the base of the inversion, temperature -31.5C, and the radar cloud base is near -26C, at the top of a very dry layer, RH 8% at 6520 m. It is possible that isolated convection in this moist layer could also produce the cirrus uncinus, but I would have expected some indication of a dry adiabatic lapse rate (theta constant), probably starting near the base of the moist layer near 6800 m if this were the case, but this was absent on the Larkhill ascent.

The stratiform cloud sheet.

But what of the stratiform cloud sheet. Visual observation suggested that it was above the cirrus, and the Larkhill sounding suggests it was near 7837 m, -31.5C. It is evident from photos of the cloud sheet with its fall-streak holes which were taken in the Bournemouth area, Fig6, (p11), and from the satellite image, that, at least there, the stratiform sheet consisted largely of super-cooled water drops. But there is a question as to why, in the Wokingham area at 0900 GMT, fall-streak holes were not observed, despite the expectation that there might be some, yet cirrus uncinus, some below the stratiform sheet, and some in the clear area to the north of the sheet, were very apparent.

So let us hypothesise as to possible reasons: a) The holes may have formed earlier and subsequently closed up, leaving the longer-lasting cirrus uncinus. b) The cirrus uncinus that passed overhead, well clear of the stratiform cloud, may have formed in fall-streak holes, the holes subsequently widening to devour all the stratiform cloud up to the edge I could see to the SW. c) The stratiform cloud in my vicinity may not have been entirely or even partially a water cloud. d) The cirrus uncinus observed at Wokingham at 0900z may have been produced by another mechanism. Suggestion c is borne out by the satellite evidence of fall-streak holes in some parts of the cloud sheet and not in others, indicating that cloud sheet was inhomogenous, composed of mainly water in some places and ice in others. If this were the case, then where it was mainly ice already, the mechanism for generating fall-streak holes would have been absent. The presence here of cirrus uncinus below the stratiform sheet but apparently having no associated holes hints at a different origin for this cirrus, (d above) with one likely explanation being that they evolved from short contrails formed as aircraft ascended/descended through this layer.

The Chilbolton radar shows a fairly continuous return within the period 0800 to 1100 GMT. There is no indication of holes, or of isolated cirrus uncinus. This suggests that the stratiform sheet consisted of a generating layer near or at the top of the echo, and a 1 km deep layer of falling ice crystals or virga. In this case the cloud top temperature of -31.5 C may be important. Cloud forming at this temperature will initially be composed mainly of water droplets and will thus require an initial humidity of 100 % or more with respect to water. However, after a period of time the composition of the cloud could change and become composed mainly of ice crystals. For water drops near -41 C at normal surface pressure, the time taken for nucliation is very short, in the order of 1 second, but at lower pressure spontaneous nucleation occurs at higher temperatures. The temperature at which rapid nucliation takes place is also dependant on droplet size, and approaches -30 C for droplets over 1 cm diameter, unlikely to be found outside vigorous deep convection at this altitude and temperature and not an option in the present case. However, a study done by C.D.Westbrook and AJ Illingworth at Reading University found that the fraction of super-cooled water drops in ice-phase cloud layers ranged from over 90 % for temperatures warmer than -20 C and fell to 0 % for temperature of -37 C, while the value was 30 % for -31 C . This study is pertinent to this present case as it shows that layer cloud initially composed of super-cooled water drops at the temperature of the cloud top on the Larkhill ascent is likely to evolve into a cloud containing at least 70% ice crystals. In the humidity structure on the Larkhill ascent, ice crystals would be expected to grow in the region super-saturated wrt ice, and precipitate out.

Freezing can also be initiated by a disturbance, such as the passage of an aircraft through a sub-zero water cloud leading to fall-streak holes, but turbulence within the cloud can also be a factor, decreasing the time taken for super-cooled cloud droplets to freeze. For a cloud sheet with little or no cloud above, the temperature structure within the cloud will be dominated by the long-wave radiation from the cloud top. The resulting rapid cooling not only lowers the temperature of the cloud top significantly, leading to destablisation of the cloud layer and initiation of convective overturning within the cloud, but also the establishment of a lapse-rate close to the saturated adiabatic through the depth of the cloud. This is the type of temperature structure on the Larkhill ascent between 7260 m and 7779 m. The visual structure of the stratiform cloud, which resembled Altocumulus undulatus, indicates that weak convective over-turning was or had taking place. The grey apperance of the sheet was probably due to extensive virga.

The humidity structure through the cloud layer on the Larkhill ascent does not show water saturation, the maximum reported humidity with respect to (wrt) water being 84 %, that is 114 % wrt ice for the reported temperature of -31 C. For the stratiform cloud to form, the RH in the layer where condensation was taking place must have been at least 100 % wrt water. The fact that the maximum RH reported on the Larkhill ascent was only 84 % wrt water as the sonde traversed the cloud could be a result of the change of state of the cloud from water to largely ice, which would have reduced the RH to an intermediate value between the saturation wrt ice and that wrt water. It could also be an artifact of the instrument. Not being familiar with the type of radio-sonde currently in use I am not sure if there is any appreciable lag on the RH element, which I believe to be of a capacitive sensor type. It is conceivable that if the saturated layer was, say, less than 50 m thick, and if the sonde was ascending at a standard rate of 6 m/s, it would only have experienced a saturated environment for about 8 seconds or less, perhaps not giving the sensor time to fully react. But it could also be the case that the cloud sampled by the Larkhill ascent was already nucliated throughout its depth, and the humidity sensor was giving a true indication of the actual humidity, with the fact that the humidity wrt ice was well above 100 % indicating that the rate of production of ice crystals was limited by the dearth of ice nuclii, the production being just sufficient to replace the virga fallout. If the there was an abundance of ice nuclii, leading to a much greater uptake of water vapour, I would have expected the maximum humidity wrt ice to have been much closer to 100 %.

In order to examine the likelyhood of turbulence in the cloud layer, the Richardson number (Ri) between each reported level on the Larkhill ascent was calculated. Turbulence is not thought to be possible for Ri >1, but is likely if Ri is <0.5. In the layer of the radar returns at Chilbolton, 6790 to 7830 m, Ri was 0.9 at 7722 m, 0.3 at 7779 m and 0.5 at 7827 m. This low Ri region lies exactly at the top of the radar echoes, indicating that the stratiform cloud layer most probably did contain turbulent patches which may well have assisted with the nucleation process.

Conclusion.

In conclusion, it seems that the interesting cloud observed in Wokingham on the morning of the 10th October 2016, existed in a moist environment at a temperature near -30 C. The two types of cloud identified consisted of a stratiform cloud sheet, and cirrus uncinus that resembled fall-streak cirrus. Using available satellite imagery, it could be determined that in some parts of the stratiform cloud sheet, fall-streak holes were occuring, whilst in other parts of the sheet they were absent, and in places there were elongated patches of cirrus visible without any holes in the stratiform sheet.

Photographic evidence was found on the internet, from the Bournemouth area, for fall-streak holes in the same stratiform sheet on the morning of the 10th October. These could also be observed on available satellite imagery. The observation at Wokingham that fall-streak holes were not present at 0900z (and between 0830z and 0930z) yet patches of cirrus uncinus were present both beneath the stratiform sheet, and in the clear sky beyond the northeastern edge of the sheet poses interesting questions concerning the physical process taking place on that morning.

Satellite imagery indicates that the stratiform sheet was quite extensive, and was in a strong northwesterly airflow. This raises the possibility that the cloud may have been formed or enhanced orographically over the Welsh mountains. The physical mechanism for the formation of fall-streak holes is well known, and I have observed them on many occasions in the past. Data from the Larkhill ascent, which almost certainly sampled the cloud, and from the Chilbolton radar, also from the IR satellite image, indicated that the cloud top temperature was near -31C. However, in my experience it is rare to find fall-streak holes generated in such a cold cloud. The more likely range of temperatures where I have observed them lie between -15C and -25C. I think that the cold cloud temperature in this case may offer an explanation for the absence of cloud holes in some parts of the cloud sheet.

The cloud top temperature of -31C is not far from the spontaneous nucliation temperature for super-cooled water at this pressure, (ca -35C) so it is perhaps not unexpected to find that, while parts of the cloud sheet were composed of super-cooled water, other parts were almost entirely of ice crystals. The cloud structure had the appearance of an altocumulus sheet composed of cellular cloud elements, indicating weak convective overturning, typical of cloud sheets below clear sky, where radiation from the cloud top leads to a lpse rate within the cloud that is close to the saturated adiabatic.

The Chilbolton radar return indicated a fairly uniform echo top and base, though with small perturbations, and is consistent with possibly weakly convecting and turbulent generating layer with a continuous fall of virga beneath which dissipated when descending into an extremely dry layer. The grey appearance of the sheet when viewed from Wokingham supports this scenario. The presence of a low Ri near the top of the radar echoes supports the liklihood of turbulence.

The explanation for the cirrus uncinus beneath the stratiform sheet in the absence of fall-streak holes, and also for its appearance away from the stratiform cloud sheet, is consistent with the agency responsible being the passage of aircraft through the high humidity layer. The altitide of the cloud was below the cruising level for commercial jets, but short sections of trails would result from aircraft climbing or descening through the layer. The white patches in the stratiform layer seen on the IR satellite image, and mostly having a similar orientation to each other, could also be the result of aircraft traversing the altitude band of high humidity. The likely reason why these did not produce obvious fall-streak holes, despite having left an enhanced patch of cloud, was that the stratiform sheet there was already mainly nucliated. The cirrus uncinus patches observed beneath the stratiform sheet over Wokingham, and which also had no fall-streak hole, were probably also the result of aircraft passage, as were those observed in the clear area to the NW of the stratiform sheet.

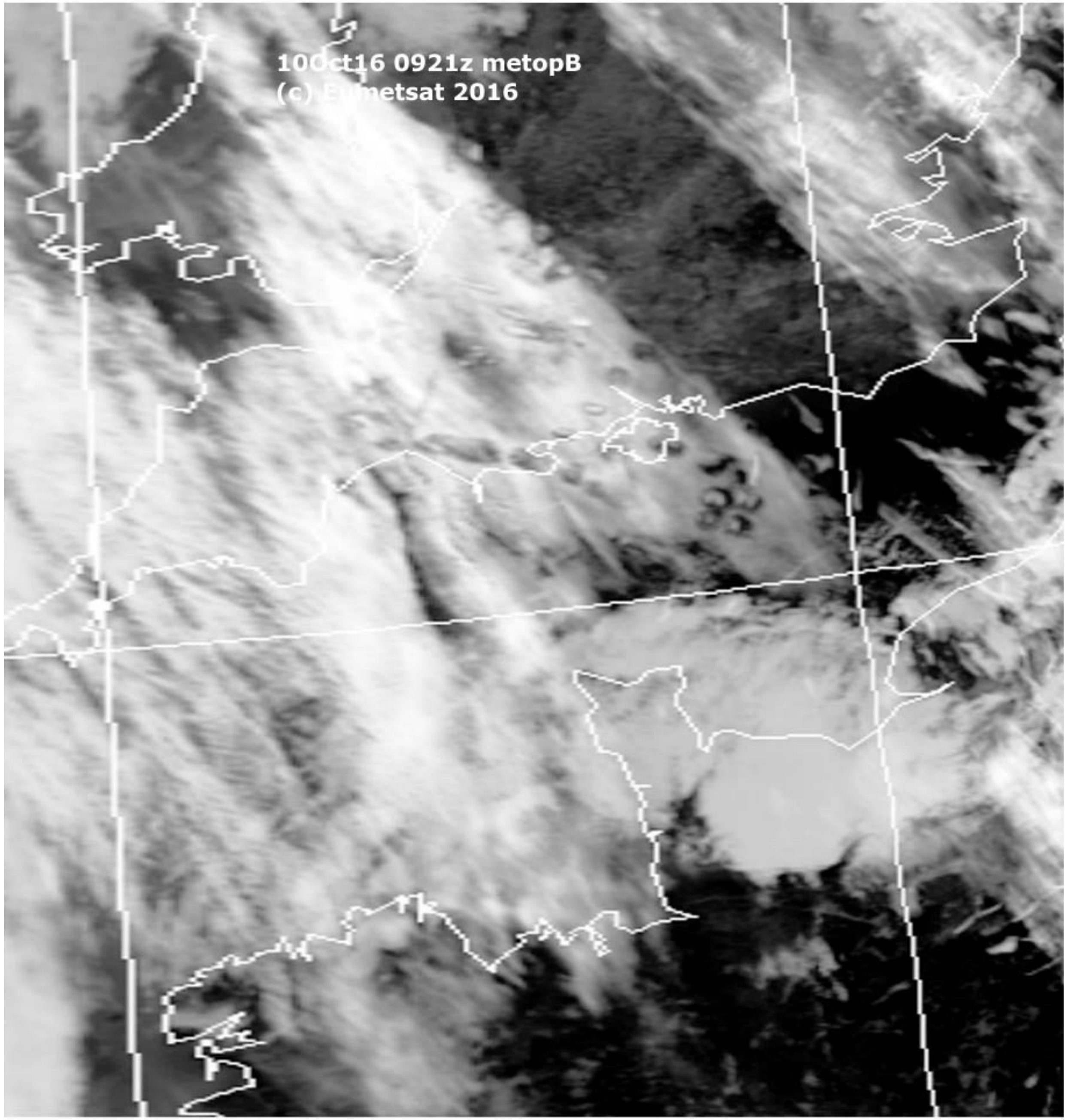
The reason for the existance in the same cloud sheet of both super-cooled water phenomenon, (fall-streak holes), and of nucleated areas where all or most of the super-cooled water changed phase, could be associated with either the age and/or thickness of the cloud layer. There could also have been more subtle effects, such as variations in the amount of turbulence in the stratiform cloud. Small changes in the lapse rate and or vertical wind shear in the cloud layer would have had a bearing on the Ri and could have rendered some areas of the sheet more stable than others.

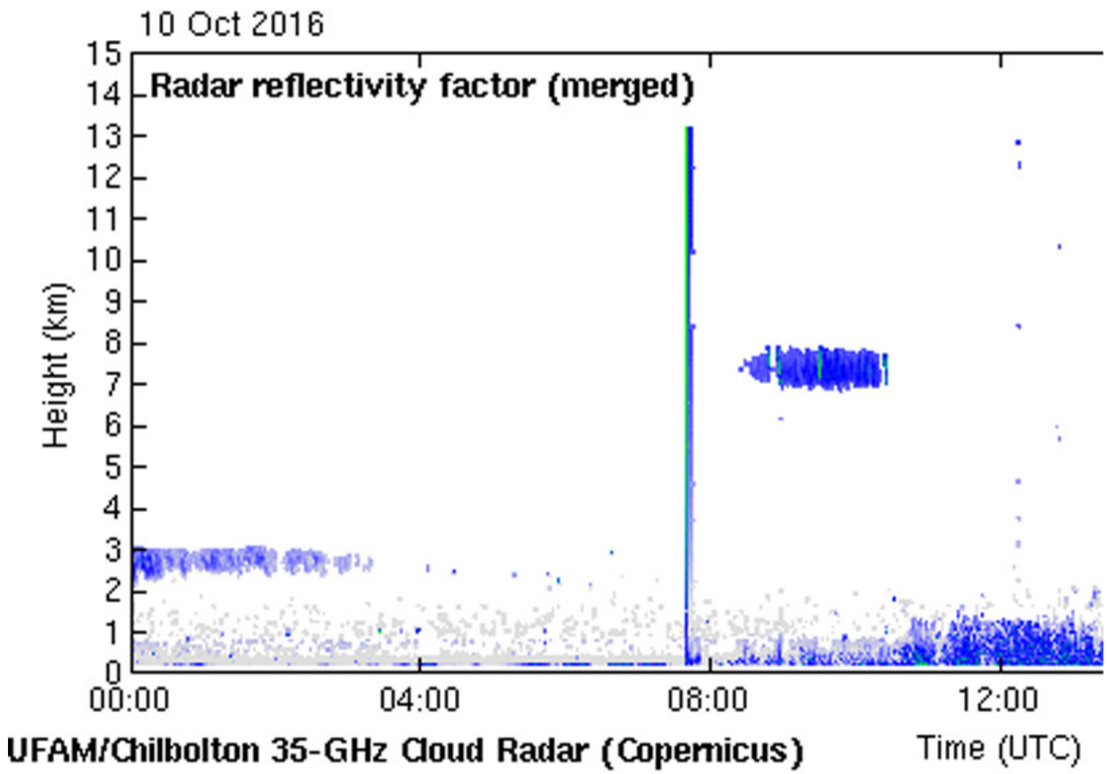
This analysis of the interesting cloud event of the 10th October 2016 over southern England has been fortunate to have had several fortuitous sources of data enabling an unique insight into atmospheric physical processes. One final observation, the stratiform cloud in the photograph over Bournemouth could easily be mistaken for altocumulus, yet as this study has shown, it was at an altitude of around 25000 ft, and at a temperature of near -31 C.

Reference

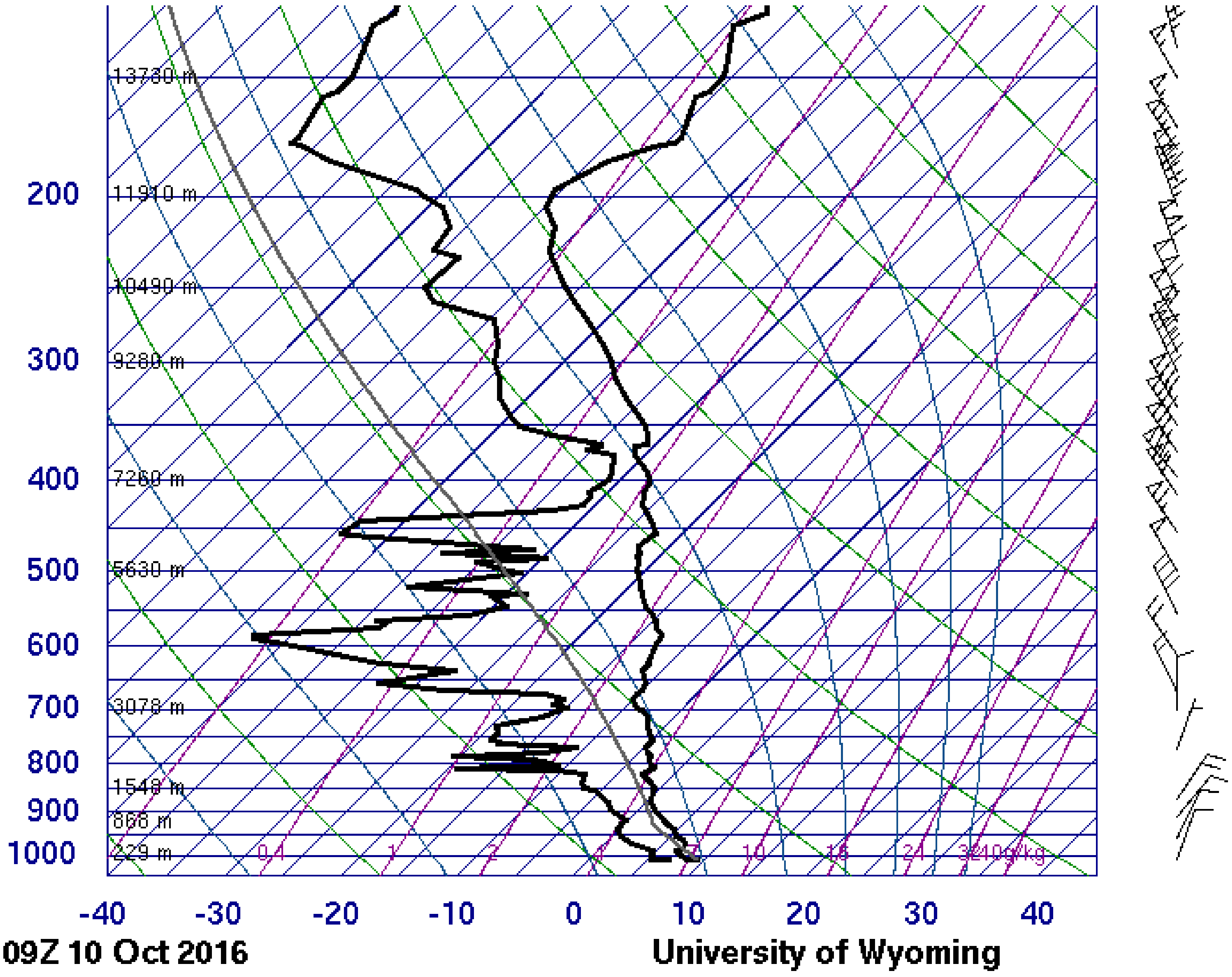
C.D.Westbrook and AJ Illingworth
Evidence that ice forms primarily in supercooled liquid clouds at temperatures > -27°C
http://www.met.reading.ac.uk/~sws04cdw/New_IN_03.pdf

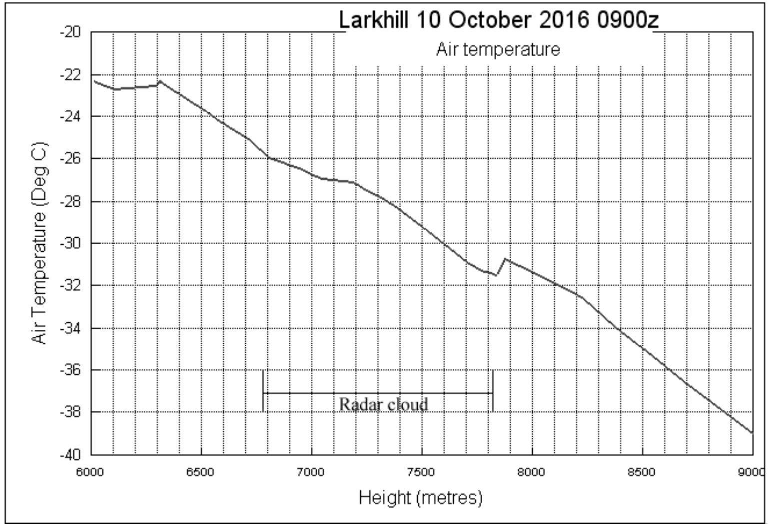
Figures

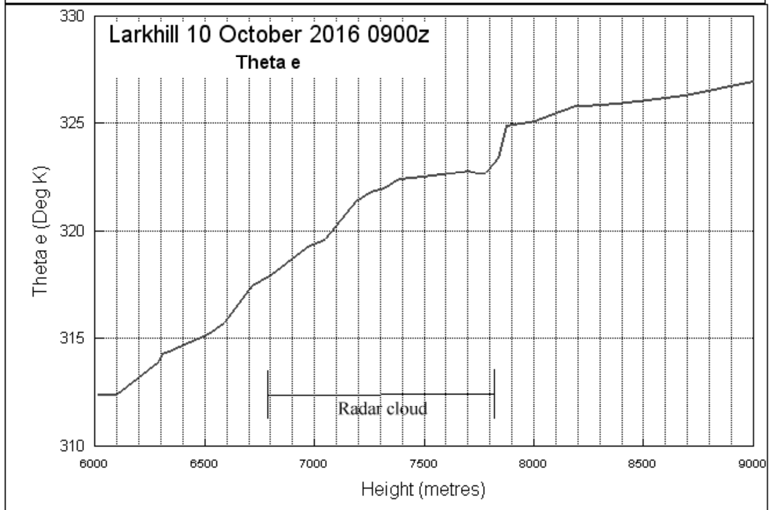

10Oct16 0921z metopB
(c) Eumetsat 2016

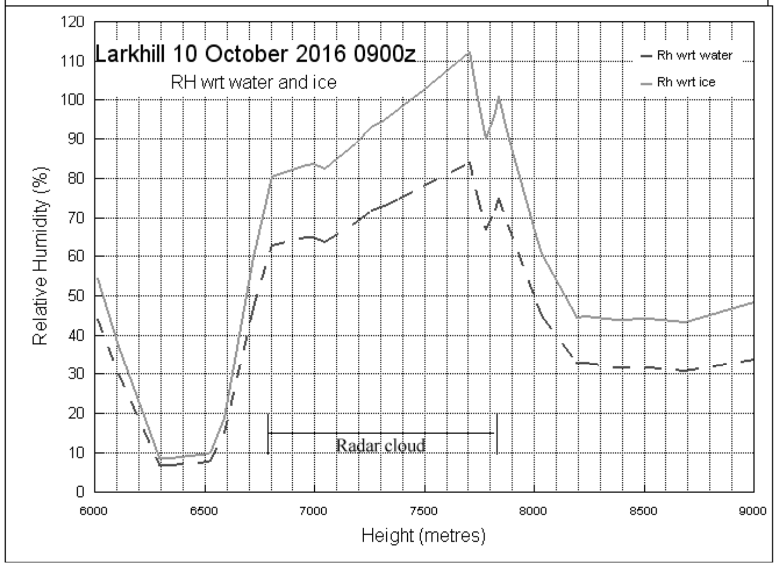


10 Oct 2016
Radar reflectivity factor (merged)
Height (km)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
00:00
04:00
08:00
12:00
UFAM/Chilbolton 35-GHz Cloud Radar (Copernicus)
Time (UTC)


13730 m
11910 m
10490 m
9280 m
7260 m
5630 m
3078 m
1548 m
868 m
229 m
200
300
400
500
600
700
800
900
1000
0.4
1
2
4
7
10
16
24
32
40g/kg
-40
-30
-20
-10
0
10
20
30
40
09Z 10 Oct 2016
University of Wyoming


Larkhill 10 October 2016 0900z
Air temperature
Air Temperature (Deg C)
Radar cloud
Height (metres)


Larkhill 10 October 2016 0900z
Theta e
Theta e (Deg K)
Radar cloud
Height (metres)


Larkhill 10 October 2016 0900z
RH wrt water and ice
Rh wrt water
Rh wrt ice
Relative Humidity (%)
Radar cloud
Height (metres)

Larkhill-03743-10Oct16 0900z

P	Ht(Gpm)	TT	TD	RH	r	dd	ff(kt)	Theta	ThetaE	ThetaV
614.0	4085	-12.2	-38.7	9	0.22	325	21	300.0	300.8	300.0
604.0	4210	-12.5	-42.2	6	0.16	325	28	301.0	301.6	301.1
597.0	4299	-12.7	-44.7	5	0.12	328	31	301.8	302.3	301.8
593.0	4350	-12.8	-46.3	4	0.10	330	33	302.3	302.7	302.3
589.0	4402	-12.9	-47.9	4	0.09	331	33	302.7	303.1	302.8
584.0	4466	-13.1	-48.1	4	0.08	332	34	303.2	303.6	303.3
573.0	4611	-14.1	-38.1	11	0.25	334	35	303.7	304.6	303.8
565.0	4717	-14.7	-37.7	12	0.27	335	36	304.2	305.2	304.3
563.0	4744	-14.9	-38.9	11	0.24	335	37	304.3	305.2	304.4
556.0	4838	-15.5	-31.5	24	0.50	335	39	304.7	306.4	304.8
554.0	4866	-15.7	-31.1	26	0.52	335	40	304.7	306.6	304.8
544.0	5002	-16.9	-28.9	35	0.65	335	42	304.9	307.2	305.1
531.0	5183	-18.1	-31.1	31	0.54	335	44	305.6	307.5	305.7
528.0	5226	-18.3	-28.3	41	0.71	335	44	305.9	308.3	306.0
520.0	5339	-18.9	-38.9	15	0.25	334	46	306.5	307.4	306.5
501.0	5615	-20.5	-30.5	40	0.61	330	51	307.8	309.9	307.9
500.0	5630	-20.7	-31.7	37	0.54	330	51	307.7	309.7	307.8
496.0	5689	-20.9	-32.9	33	0.49	330	50	308.2	309.9	308.3
488.0	5810	-21.3	-35.3	27	0.39	329	53	309.1	310.6	309.2
484.0	5870	-21.7	-29.7	48	0.68	329	54	309.4	311.8	309.5
482.0	5901	-21.9	-30.9	44	0.61	328	55	309.5	311.7	309.6
479.0	5947	-21.9	-38.9	20	0.28	328	56	310.1	311.1	310.1
475.0	6008	-22.3	-31.3	44	0.59	328	57	310.3	312.4	310.4
469.0	6102	-22.7	-35.7	30	0.39	327	59	310.9	312.4	311.0
457.0	6292	-22.5	-48.5	7	0.10	325	63	313.5	313.9	313.5
456.0	6308	-22.3	-49.3	7	0.09	325	63	313.9	314.3	314.0
454.0	6340	-22.5	-49.2	7	0.10	325	64	314.1	314.4	314.1
443.0	6520	-23.7	-48.7	8	0.10	325	64	314.8	315.2	314.8
439.0	6586	-24.2	-43.5	15	0.19	325	64	315.0	315.7	315.1
431.0	6720	-25.1	-33.1	47	0.55	325	65	315.5	317.5	315.6
426.0	6805	-25.9	-30.9	63	0.69	325	66	315.5	318.0	315.6
417.0	6960	-26.5	-31.1	65	0.69	325	67	316.7	319.2	316.8
415.0	6994	-26.7	-31.3	65	0.68	325	67	316.9	319.4	317.0
412.0	7047	-26.9	-31.7	64	0.66	324	69	317.2	319.6	317.4
404.0	7188	-27.1	-31.1	69	0.71	321	73	318.8	321.4	318.9
400.0	7260	-27.5	-31.0	72	0.72	320	75	319.2	321.8	319.3
397.0	7314	-27.8	-31.1	73	0.72	320	77	319.4	322.0	319.6
393.0	7387	-28.3	-31.3	75	0.72	322	78	319.7	322.4	319.9
387.0	7497	-29.2	-31.8	78	0.69	325	79	320.0	322.5	320.1
376.0	7703	-30.9	-32.7	84	0.65	325	76	320.4	322.8	320.5
374.0	7741	-31.1	-34.0	75	0.58	325	75	320.6	322.7	320.7
372.0	7779	-31.3	-35.4	67	0.51	325	76	320.8	322.7	320.9
370.0	7817	-31.4	-34.8	72	0.54	325	78	321.1	323.1	321.2
369.0	7837	-31.5	-34.5	75	0.56	325	79	321.3	323.4	321.4
367.0	7875	-30.7	-34.7	68	0.55	324	80	322.9	324.9	323.0
360.0	8012	-31.4	-38.9	48	0.37	320	83	323.7	325.1	323.8
359.0	8032	-31.5	-39.5	45	0.35	320	83	323.8	325.2	323.9
351.0	8191	-32.3	-43.3	33	0.24	324	81	324.8	325.8	324.9
349.0	8232	-32.6	-43.6	33	0.23	325	81	324.9	325.8	324.9
342.0	8374	-33.9	-44.9	32	0.21	327	81	325.1	325.9	325.1
335.0	8519	-35.1	-46.1	32	0.18	330	82	325.4	326.1	325.4
327.0	8687	-36.5	-47.5	31	0.16	331	86	325.7	326.3	325.7
312.0	9012	-39.1	-49.1	34	0.14	334	93	326.5	327.0	326.5
308.0	9100	-39.7	-49.7	34	0.13	335	95	326.8	327.4	326.9
307.0	9122	-39.9	-49.9	34	0.13	335	96	326.9	327.5	326.9
300.0	9280	-40.9	-50.9	33	0.12	335	101	327.6	328.1	327.6
293.0	9439	-42.2	-51.6	35	0.11	335	105	328.0	328.5	328.0
288.0	9556	-43.1	-52.1	36	0.11	335	107	328.3	328.8	328.3
285.0	9626	-43.7	-52.5	37	0.10	335	109	328.4	328.9	328.5
272.0	9937	-46.3	-54.4	39	0.09	330	110	329.1	329.4	329.1
271.0	9962	-46.5	-54.5	40	0.09	330	110	329.1	329.5	329.1