Observing Fog And Low Cloud With A Combination Of 78GHz Cloud Radar And Laser Ceilometer

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ABSTRACT

Results from two demonstration tests of a FMCW (Frequency Modulated Continuous Wave) 78GHz cloud radar are used to examine the radar's ability to measure low cloud and fog. The first test took place at Payerne, Switzerland (from Nov 2003 to Feb 2004), as part of the COST 720[2] TUC (Temperature, Humidity & Cloud Profiling) Project; and the second test took place at the Chilbolton Facility for Atmospheric and Radio Research (CFARR), UK (Aug 2004). The FMCW radar was of similar sensitivity to the pulsed cloud radars at Chilbolton and the good vertical resolution of the system allowed accurate detection of fog top and cloud top in layered clouds.

INTRODUCTION

In partnership with the Met Office a vertically pointing 78.2GHz FMCW cloud radar has been developed by the Space Science and Technology Department of the Rutherford Appleton Laboratory (RAL), to demonstrate the potential capability of the system in cloud detection and the benefits it can offer in comparison to existing observing systems (i.e. Laser Cloud Base Recorders – LCBR). Figure 1 shows a picture of the antenna of the system along with the specification details[2].

Frequency: 78.2 GHz
Transmitted Power:250mW
Operated at 16km Range (30m spatial resolution) at Chilbolton
Operated at 8km Range (15m spatial resolution at Payerne)
Temporal Resolution: 1s
Radiometer Sky Temperature Accuracy: +/- 1K
Pulse duration: 800 µs
Pulse separation: 1.5 - 2.0 ms
Polarisation: linear
Total chirp excursion: 10 MHz
Dynamic range of receiver:50dB
Viewing Angle: Zenith
Beam width: ~0.5 degree (half power)

Figure 1 – RAL 78.2GHz Cloud Radar and system specification[3].

As part of the development and assessment of this system, it has been deployed at several UK observing sites since early 2001. Major improvements to the sensitivity and data range/resolution have been added to the system through a complete redesign of the antenna and the backend processing. As such only results from the later deployments are relevant in the assessment of the systems capabilities. This paper concentrates on the results from two deployments, firstly at Chilbolton, UK (Aug 2004) and secondly, Payerne, Switzerland (Nov 03 to Feb 04).

CHILBOLTON EXPERIMENT

The Chilbolton experiment was designed to provide absolute calibration of the reported cloud radar signals, which was necessary to satisfy requirements from participants in the COST TUC experiment. As well as comparing directly with the pulsed 35GHz Copernicus Cloud Radar, it was also possible to confirm that the calibration was consistent with historical records of the signals observed with the 94GHz Galileo Cloud Radar at Chilbolton.

The Vaisala 905nm CT-75K ceilometer, at Chilbolton, was used to check for low-level clouds with small drop size distributions (eg. Stratocumulus), which cloud radars find difficulty in detecting.

Figure 2 provides an example of the cloud radars performance on a day with several layers of cloud and with little precipitation. (Note Data from the FMCW radar has been range corrected.) The dashed purple line in both the cloud radar plots indicates the maximum in the ceilometer signal, which is associated with relatively thin cloud, at about 2km in height. The FMCW radar was more sensitive to the lower thin cloud, than the pulsed radar. Both cloud radar's were able to detect the higher cloud at around 5km, although due to its higher resolution, cloud structure is more evident in the FMCW profile. The ceilometer was unable to detect any of the higher cloud, due to obscuration of the signal by the lower thin cloud.

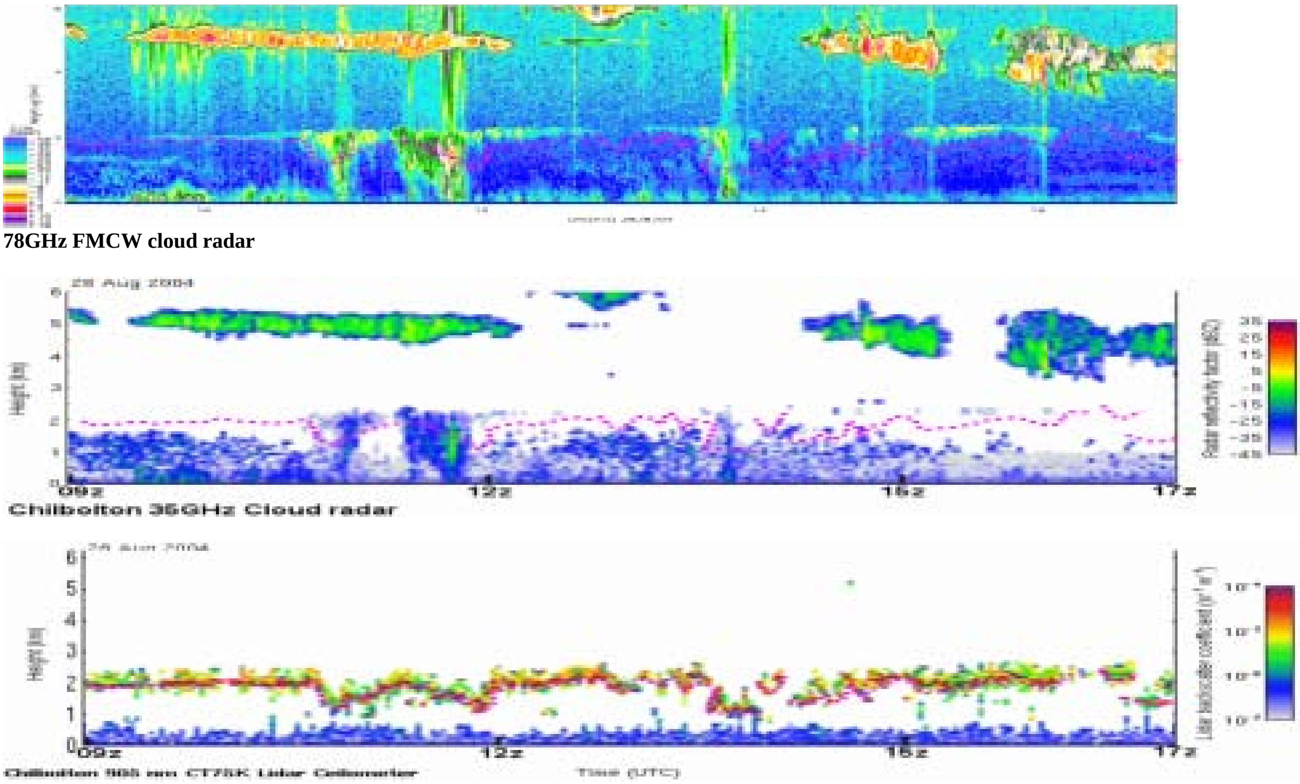

Figure 2. Time-Height cross-section plots from fmcw radar, 35GHz pulsed radar & Lidar: 28/8/04

Figure 3 illustrates the FMCW radar's ability to resolve cloud structure close to the ground, in a region where the pulsed radar is less reliable.

The dashed red line in both the cloud radar plots indicates the maximum in the ceilometer signal on this day. Note that the Chilbolton ceilometer has relatively poor resolution in the boundary layer. For these lower altitude signals the ceilometer returns are very strong, and are well matched to the cloud base from the FMCW radar. However these low level clouds were not resolved very well by the 35GHz pulsed radar.

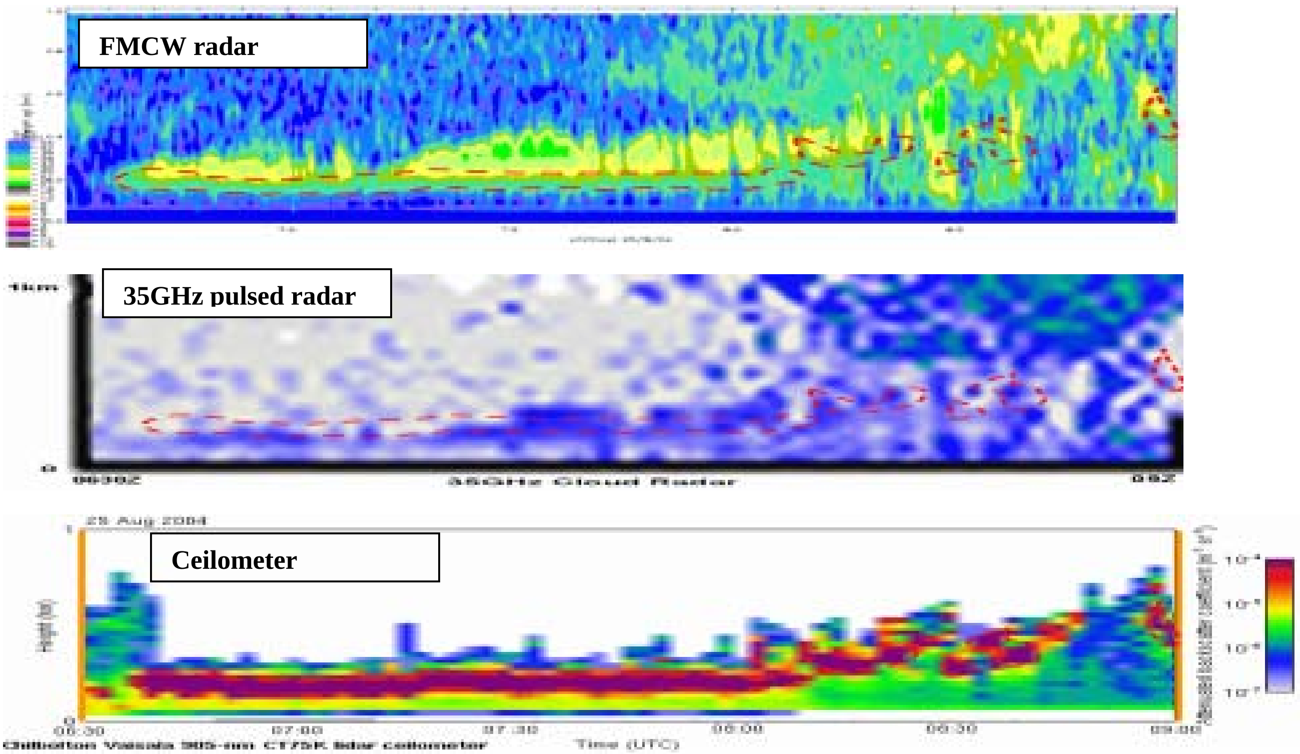

Figure 3. Time-Height cross-section plots from FMCW radar, 35GHz pulsed radar & Lidar: 25/8/04

CONCLUSIONS FROM CHILBOLTON EXPERIMENT

- The results from Chilbolton indicate that the sensitivity of the 78GHz FMCW Cloud Radar was comparable to that of a modern pulsed Cloud Radar.
- The FMCW cloud radar was able to detect multiple cloud layers.
- The FMCW radar was able to detect clouds up to ~12km in height.

The testing at Chilbolton stopped after the cloud radar failed, due to the ingress of water during summer usage, which caused a short circuit. Some system degradation may have occurred before the complete failure, but this did not produce a significant shift in calibration.

PAYERNE EXPERIMENT

The TUC experiment was specifically targeted on the detection of fog & cloud and thus there was a comprehensive range of ground-based remote sensing and surface measurement systems at Payerne.[4] Measurements from the FMCW cloud radar could be directly compared with regular Radiosondes ascents, a 1290 MHz Wind Profiler, a Vaisala CT-25K Ceilometer and surface instruments, including an Infra-Red Radiation Pyrometer, Present Weather sensor, and a total sky camera.[5]

Figure 4 shows an example of verification of fog top using a Radiosonde temperature profile. An increase of Temperature to ~4 deg C from the IR Pyrometer after 19utc indicated the time when this fog thickened. Low surface visibility from surface sensors at this time also indicated fog at the site, and Relative Humidity at 2m was 100%, with APCADA (Automatic Partial Cloud Amount Detection Algorithm) recording an upward jump after 19utc from 96%. The Radiosonde temperature profile (23utc launch time shown as red line) is consistent with the top of a thick fog layer at ~205m.

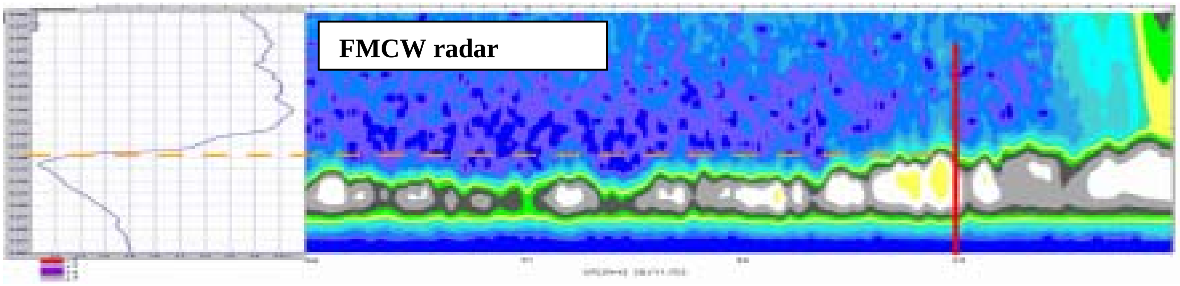

Figure 4. Time-Height cross-section plot from FMCW radar, with 23utc Radiosonde Overlay: Fog 26/11/03

The FMCW cloud radar plot in Figure 5 shows a day at Payerne on 6/12/03, where the fog is on the ground for part of the time, and then later lifts. The region with strong readings from the ceilometer is overlaid as a red dashed line on the FMCW radar profiles.

The fog top as deduced from the FMCW radar is superimposed as a yellow dashed line on the Wind Profiler S/N plots. In many types of cloud, especially when it is raining, the wind profiler signals in cloud are high, because of backscattering from the raindrops or ice crystals. However, in clouds or fog with low mean drop size, wind profiler signals become very low. This is because small cloud or fog droplets have very low scattering at 1GHz. In addition for this type of cloud there is very little backscattering from refractive index variations due to changes in relative humidity. In this example taken at night, the increase in wind profiler signal above the cloud/ fog correlates reasonably well with the top of the fog indicated by the cloud radar.

The S/N ratio from the Wind Profiler can be used to check on fog top. The ceilometer plot shows that the fog lifts to form an elevated layer after 0200utc, this can be seen as an increase in surface visibility. Surface measurements also showed decrease in Relative Humidity at 2m from 99% at the start of the period, to 95% at 0400utc. The S/N ratio values on the Wind Profiler plot are very low under the deduced fog top, and above the fog top rise to a relative maximum in signal power.

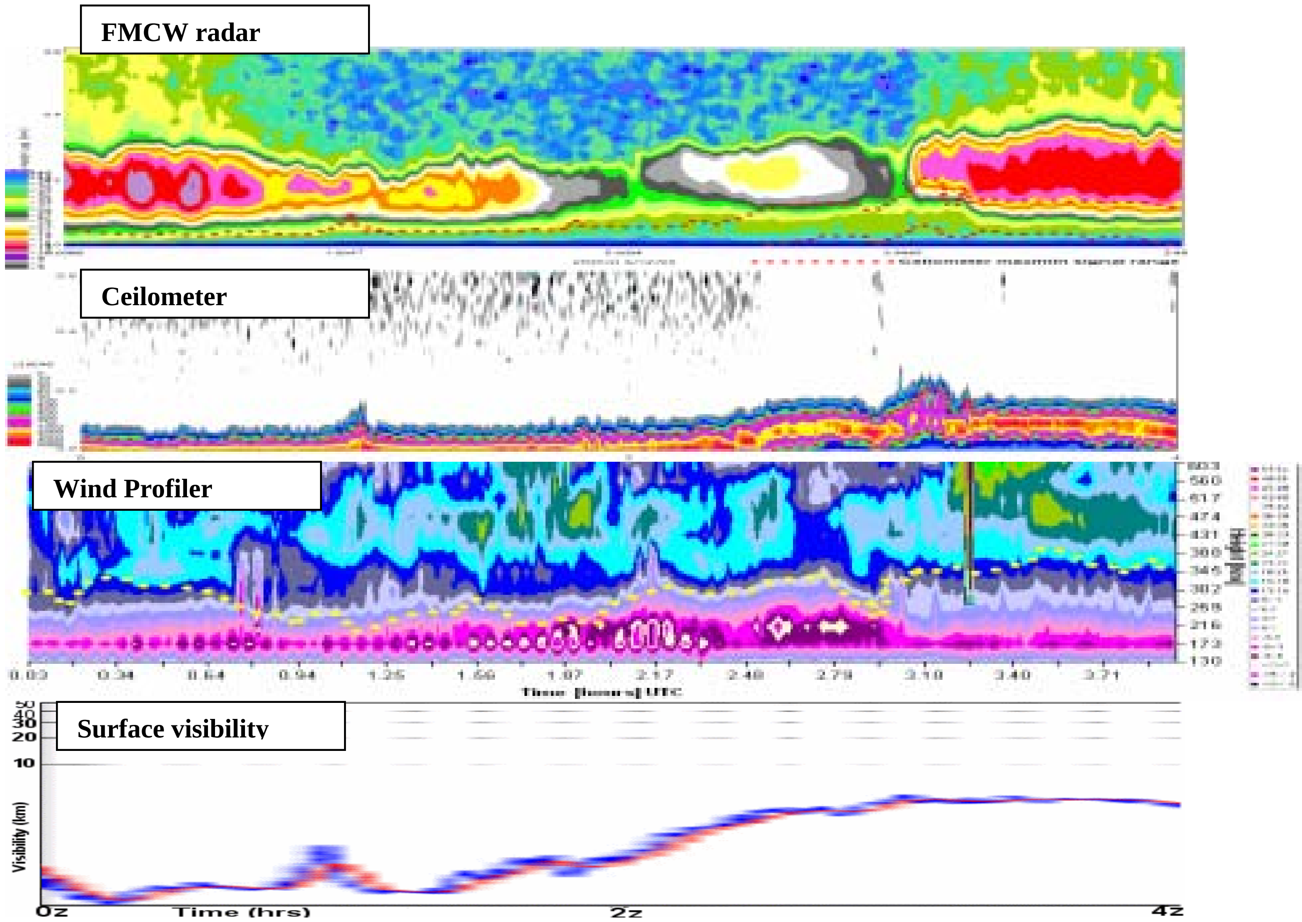

Figure 5. Time-Height cross-section plots from FMCW Radar, Lidar & Wind Profiler S/N, and Time-Distance Surface Visibility plot: 6/12/03 0000-0400utc

Later in the day, low cloud persisted at Payerne. The elevated layer evident in the latter part of Figure 5 is continuous during the period shown in Figure 6. The cloud base in the FMCW radar plots in Fig 5 & Fig 6, shows good agreement with the ceilometer signal, and tracks changes in altitude of the base. This only happens when there is negligible precipitation falling to the ground.

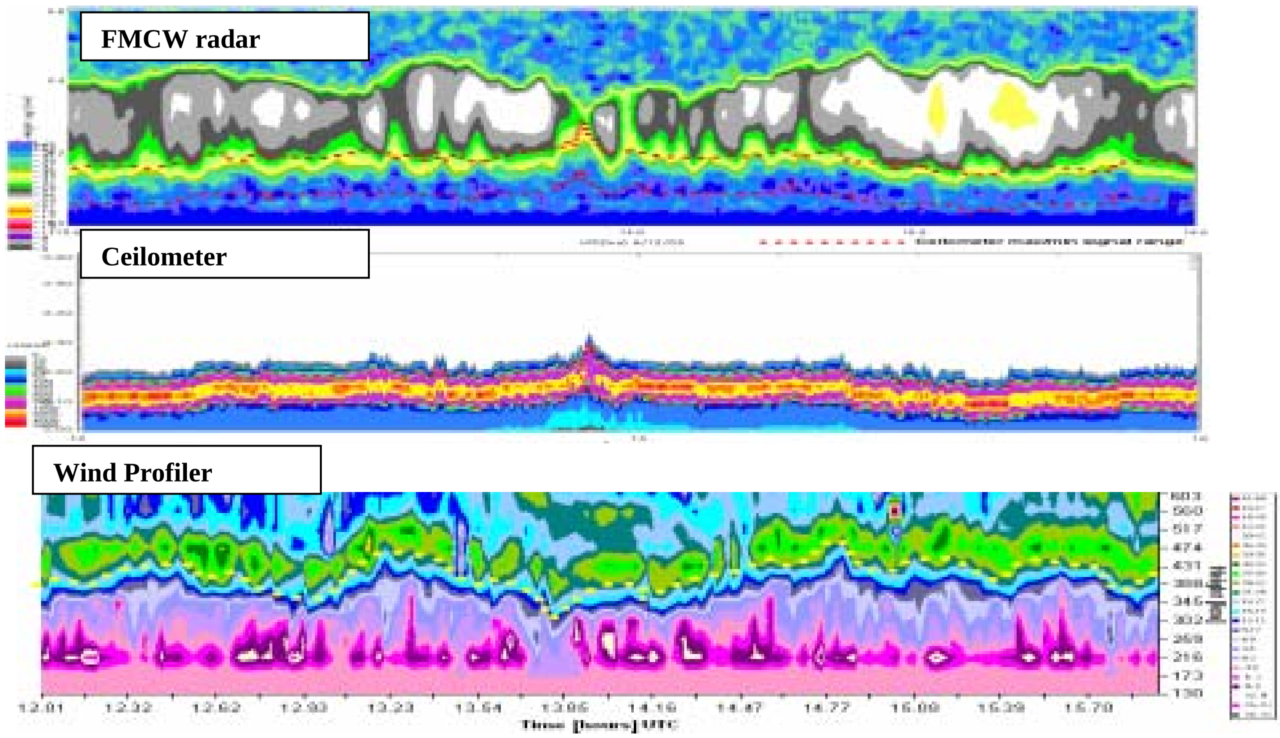

Figure 6. Time-Height cross-section FMCW Radar, Lidar & Wind Profiler S/N plots: 6/12/03 1200-1600utc

The cloud top from the FMCW Radar plots (overlain as the yellow dashed line in the Wind Profiler S/N plots) coincides, in this case, with an increase in Wind Profiler signal. The relative maximum above the cloud top, is even more pronounced in daytime (dark green area: ~30dB) than in Figure 6, a period at night when there is little mixing.

Figure 7 shows the continuing cloud radar, ceilometer and wind profiler SNR measurements for the evening of 6/12/03 (1600-2000utc). At 1800utc, when there was precipitation, the cloud radar signals extended towards the ground, but there was no major shift in cloud base recorded by the ceilometer. This can be explained by the FMCW radar being sensitive to the falling droplets from the cloud, and locking onto them. Although precipitation was reaching the surface, the radar showed a weakening of the signal at lower altitudes, giving a false indication of cloud base. This drop in signal on the FMCW cloud radar plot, is due to insensitivity in the bottom range gates, and the calibration not being optimised to compensate for this.

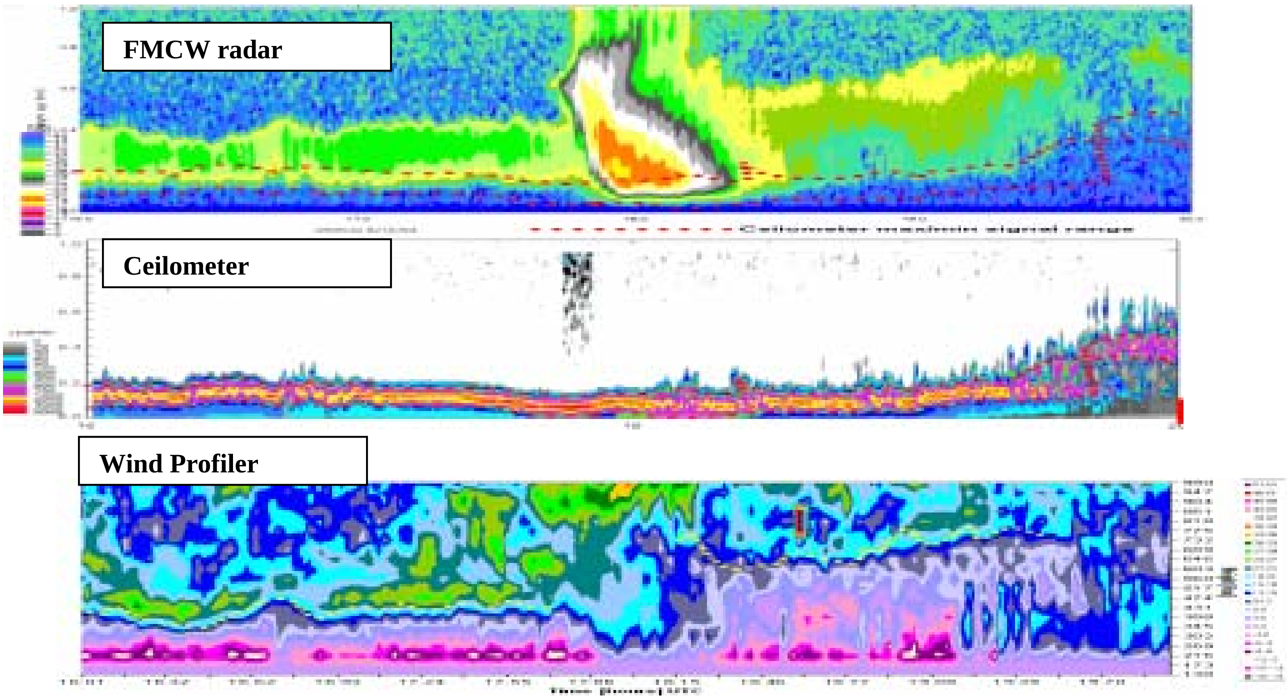

Figure 7. Time-Height cross-section FMCW Radar, Lidar & Wind Profiler S/N plots: 6/12/03 1600-2000utc

Figure 8 shows the development of hill fog at Payerne on 26/11/03. The FMCW radar and ceilometer both show a lowering of the cloud base from 1015utc, to a minimum at ~1030utc, corroborated in a lowering of surface visibility from 5km down to 500m during this period. The sky camera view also showed a deterioration in visibility (although the pole in the distance can still be seen). By 1130utc, the FMCW radar showed the cloud top had lowered to an extent where the top was too low to be reliably detected, due to insensitivity in the lowest range gates. As the cloud base also lay in this insensitive region, the cloud had appeared to dissipate on the FMCW radar plot. The sloping red line on the FMCW radar plot indicates the height of the cloud top. The ceilometer and surface visibility plots showed that the low cloud base persisted until 1140utc. Note that the ceilometer also showed insensitivity in its lowest range gates, as the strongest signal returns occur where the cloud base has lifted above a height of ~40m (as shown by the short black horizontal lines on the ceilometer plot which signify cloud base estimation. After 1140utc, the surface visibility increased, and the ceilometer showed stronger signals (yellow backscatter colour), as the cloud base lifted out of the lowest insensitive range gates. The lifting can also be seen in the sky camera view for 1153utc. At midday, the FMCW radar shows the development of another layer of hill fog, elevated at first, and undetected by surface visibility measurements. The layer gradually lowers on both the FMCW and ceilometer plots, and at ~1210utc, the fog makes ground contact, as the surface visibility suddenly lowers to a minimum, which continues for the duration of the plot. The sky camera view shows a thick ground fog, with the pole now invisible. The ceilometer records it’s lowest cloud base, and again, signal strength is subdued (orange –red backscatter colour) due to insensitivity near the ground. The FMCW radar plot displayed a well-defined fog top after this time, but fog base is shown at a higher altitude than the ceilometer, again due to insensitivity near the ground.

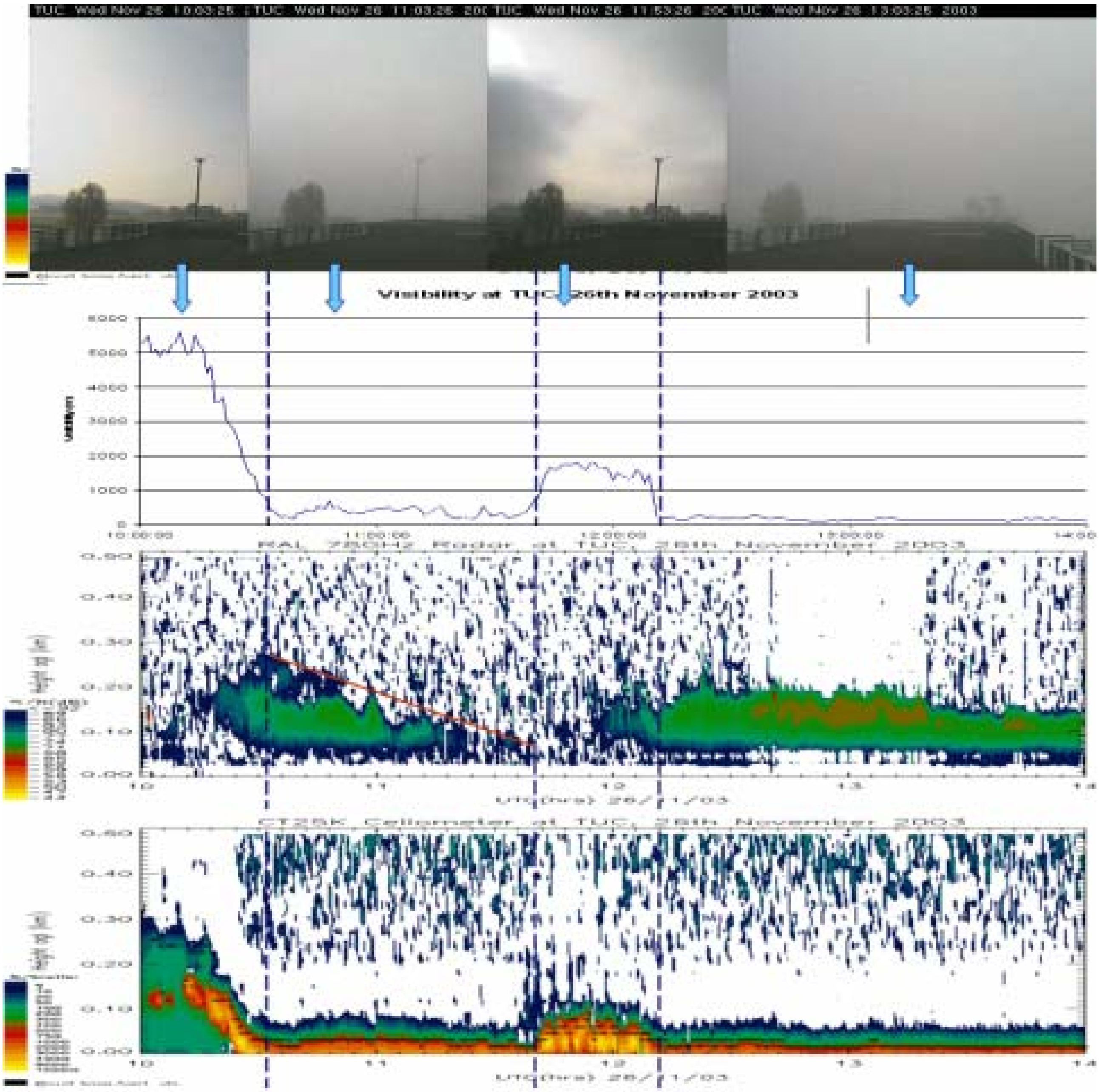

Figure 8. Sky Camera view, Time-Distance surface visibility, and Time-Height cross-section fmcw radar & lidar plots: 26/11/03 1000-1400utc

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CONCLUSIONS FROM PAYERNE EXPERIMENT

On many days, the FMCW cloud radar was able to detect clouds reliably. On some occasions the cloud base is also detected, but a ceilometer is needed in conjunction with the cloud radar to identify cloud properties. This is due to insensitivity of the radar in its lowest range gates.

Sometimes in very thin fog the cloud radar only records weak signals, due to the radar's inability to detect scattering from small water droplets. This was apparent in only a small proportion of cases.

OVERALL CONCLUSIONS

The FMCW cloud radar has shown to be a useful system for detecting; (a) the tops of low cloud, mist and fog (at a minimum height above the radar of ~25m); (b) multiple cloud layers; and (c) upper cloud (cloud measured at >12km height).

The radar is also useful in identifying the precipitation conditions beneath cloud, in combination with a ceilometer.

Fog measurements require a combination of laser ceilometer and cloud radar measurements.

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REFERENCES

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[2]COST is an intergovernmental framework for European CO-operation in the field of Scientific and Technical research, allowing the co-ordination of nationally funded research on a European level. The COST720 Action is concerned with the "Integrated Ground-based Remote-Sensing Stations For Atmospheric Profiling".

[3] Ellison, B.N., Oldfield, M. and Bradford, W.J., “Millimetre wave cloud radar”, poster presentation at 9th International Workshop on the technical and scientific aspects of MST radar – MST9, Toulouse, 13-18 March 2000.

[4] D.Ruffieux, **T.J.Hewison**, C.Gaffard, R.Nater, B.Andrade, M.Perroud, H.Berger and P.Overney, The COST720 Temperature, Humidity and Cloud Campaign: TUC, Proceedings of microRad, Rome, 24-27 Febraury 2004

[5] COST720 WG2 "Integrated Ground-based Remote-Sensing Stations For Atmospheric Profiling" TUC Experiment Database, available by ftp from Dominique Ruffieux, MeteoSwiss, Payerne, Switzerland.
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