Simultaneous and co-located MST and Cloud-radar observations

Adrian McDonald[1], David Hooper[2], Steve George[1], Peter Huggard[2], Brian Ellison[2] and Matthew Oldfield[2]
[1] Department of Physics and Astronomy, University of Canterbury, New Zealand.
[2] Rutherford Appleton Laboratory, UK.

UNIVERSITY OF CANTERBURY
Te Whare Wananga o Waitaha
CHRISTCHURCH NEW ZEALAND

millimetre-wave technology MMT

CCLRC Rutherford Appleton Laboratory

Abstract

This study discusses a set of simultaneous observations made with the NERC MST radar at Aberystwyth, UK, and the RAL Millimetre Wave Technology groups co-located Cloud radar. The case study shown shows a clear anti-correlation between Cloud radar signal return power and NERC MST radar signal return power. Ancillary weather radar suggests this relationship is not associated with precipitation. Examination of satellite imagery and the lack of attenuation in the cloud radar observations suggests that this relationship may be partly associated with changes in the balance of liquid to ice water content in the clouds observed. These conclusions are also supported by ancillary evidence from radiosonde soundings. The variations in the returned signal power observed by the NERC MST radar are then examined using Principal Component Analysis and a simple model to determine whether these changes can be explained exclusively by changes in the fraction of ice to liquid water content in the atmosphere. It is suggested that changes in the fraction of ice water to liquid water can only explain a small amount of the reduction observed.

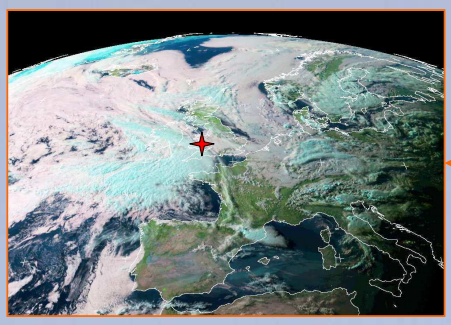


Figure 2: RGB colour composite imagery at 18:00 UT on 22nd July 2005 from the MSG SevIRI instrument. The approximate location of Abeystwyth is denoted by the red cross.

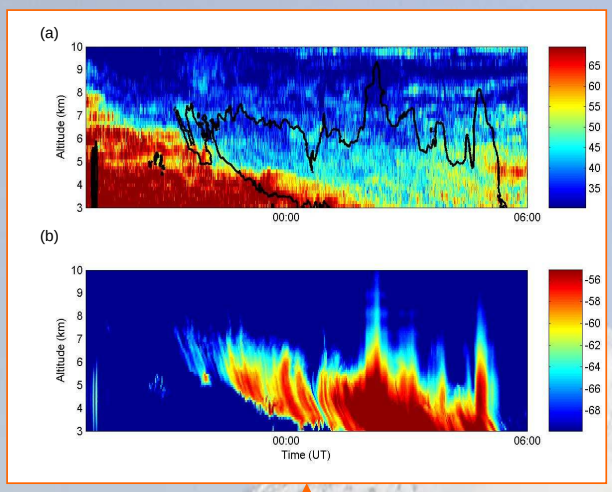


Figure 1: Signal power observed by the NERC MST radar (a) and the RAL Cloud radar (b) between 19:00 UT on 22nd January to 06:00 UT on 23rd January 2005. The top diagram also displays an outline associated with the -67 dB contour observed by the co-located RAL Cloud radar.

Results

Figure 1 displays time-altitude contour plots of the vertical signal power from VHF radar (46.5 MHz) observations made between 19:00 UT 22nd July 2005 and 06:00 UT on 23rd July 2005. Figure 1 (top) also shows an outline associated with the -67 dB contour observed by the co-located RAL cloud radar (78 GHz). Examination suggests a clear anti-correlation between the region of the cloud identified by the Cloud radar and the magnitude of the vertical signal power observed by the VHF radar. The lack of attenuation of the signal observed by the cloud radar and the appearance of fall streaks in the cloud (curved trajectories), especially around 00:00 UT on 23rd July 2005, suggests that these observations are associated with a cloud with a high ice-water content. This is confirmed by satellite imagery, shown in Figure 2, from the SEVIRI instrument on the MSG satellite which also suggests that the frontal cloud band identified by the Cloud radar is associated with cloud with a high ice-water content (light blue colour of cloud). Given that the returns observed by the VHF radar is proportional to the square of the mean vertical gradient of generalized radio refractive index which in turn includes terms associated with the saturated vapour pressure (which differs over water and ice). It is worth noting that Aberystwyth is approximately in the middle of the image (red cross in image), It seems possible that the VHF signal suppression in this case may be associated with changes in the fraction of ice to water content in the clouds. It is also interesting to note that precipitation is not observed at the surface or by weather radar in this case (not shown). The position of the zero degree isotherm at an altitude of ??? km also suggests that the cloud has a high ice water content.

To better examine the magnitude and form of the variation in the VHF radar signal power we have used Principal Component Analysis. A comprehensive description of the application of Principal Component Analysis technique to wind profiler data is made in Williams (1997). Figure 3 (a) displays the first eight principal components (PCs) of the vertical signal power once it has been corrected for the inverse range squared dependency. Figure 3 (b) displays the reconstructed vertical signal power corrected for the inverse range squared dependency , this reconstruction being determined from the first eight PCs. Figure 3 (c) shows the first eight empirical orthogonal functions. Calculations show that the first PC associated with this data explains 48% of the variance in the dataset.

Figure 4 (a) shows that the first PC displays a relatively constant structure with large values at low altitudes and values close to zero at higher altitudes. The empirical orthogonal function associated with the first PC, shown in Figure 4 (b), displays an increasing trend over the period examined. The reconstructed signal associated with the first PC forms a chequerboard pattern with low values which correspond roughly with areas of the signal power suppression observed in Figure 1 (a). Similarly, Figure 5 displays patterns associated with the second PC. The reconstructions in Figure 4 and 5 allow us to identify the magnitude of the variations in the VHF vertical signal power and to derive the fact that at least two mathematically independent independent processes contribute to the observed VHF signal suppression. The suppression is of the order of ±10 dB for the first PC and ± 7 dB for the second PC.

Using observations of temperature and humidity made at Camborne (approximately 270 km to the south of Aberystwyth but still clearly beneath the same frontal cloud shield – see Figure2) at 23:00 UT on 22nd July 2005 it is possible to derive the mean vertical gradient of generalised potential refractive index for a number of scenarios. Figure 6 displays the square of the Brunt Vaisala frequency (a) , the relative humidity (b) and the mean signal power over the period of observations compared to that defined using different models (c). Comparison suggests that the signal power between 4 and 7 km does not correspond closely to that associated with a dry atmosphere (black line in Figure 6c). Comparison also suggests that the difference between the modelled signal power when using a saturated vapour pressure over ice and water (red and green lines n Figure 6c, respectively) varies very little suggesting that any change in the signal in the range of interest can only be partially explained by changes in the fraction of liquid to ice water cloud. This conclusion concurs with previous work described in McDonald et al. (2006).

Introduction

Wind profiler radars operating in the VHF are sensitive to both clear air returns, from radio refractive index irregularities, and to a lesser extent Rayleigh scattering from hydrometeors. Recent examinations of VHF radar returns have suggested that processes associated with precipitation can directly impact the magnitude of the clear-air return acting to supress the observed VHF signal (Chu and Lin, 1994; Vaughan and Worthington, 2000; McDonald et al., 2006). In McDonald et al. (2006) it was suggested that evaporation, which occurs more often in stratiform precipitation, is important in reducing small-scale irregularities in humidity and thereby the radio refractive index. It was also hypothesised that for a particular case study signal suppression could be particularly clear because the cloud examined could be associated with a high ice water content. Changes in the fraction of liquid to ice water content would change the saturation vapour pressure because this quantity has a different value on the surface of liquid water from that on the surface of solid ice particles. This in turn would act to change the value of the mean vertical gradient of generalised potential refractive index, M, which can be written as:

$$M = M_D[1 + \frac{15500q}{T} + \frac{\frac{7800}{T}\frac{\partial q}{\partial z}}{\frac{\partial \ln\theta}{\partial z}}]$$

where z, is the altitude (m), p (hPa) is pressure, T (K) is absolute temperature, θ (K) is potential temperature and q is the specific humidity, q (kg kg^{-1}). M_D is the dry term and is represented by:

$$M_D = -77.6 \times 10^{-6}\frac{p}{T}\frac{\partial \ln\theta}{\partial z}$$

To examine whether changes in the fraction of liquid to ice water content are important we examine a case study during which co-located and simultaneous VHF radar and Cloud radar observations were made at Aberystwyth. The Cloud radar is a pre-prototype low-power, solid state, FM-CW 78 GHz instrument which is under development by the Milimetre Wave Technology Group at RAL. Cloud radar are sensitive to very small drop sizes and are also sensitive to the liquid and ice water content mainly due to the strong attenuation at the wavelengths of operation associated with liquid water (Lhermitte, 1992).

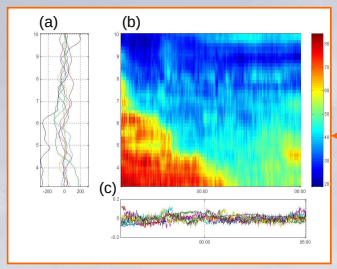


Figure 3: Principal components (a), reconstructed signal (b) and empirical orthogonal functions (c) associated with the eight largest modes of variability in the VHF vertical signal power shown in Figure 1.

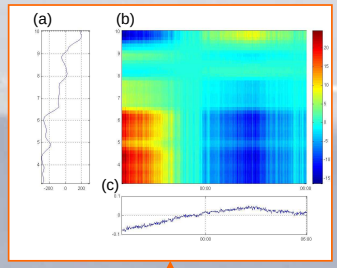


Figure 4: The first principal component (a), reconstructed signal (b) and empirical orthogonal function (c) associated with only the largest mode of variability.

Figure 6: The square of the Brunt-Vaisala frequency (a) and relative humidity (b) relating to the radiosonde launched at 2300 UT from Camborne. The final panel (c) shows the VHF radar return signal power predicted from the radiosonde measurements assuming the saturated vapour pressure over ice and water (red line) and for dry air (thin blue line). Also shown is the mean power profiles for the period of interest.

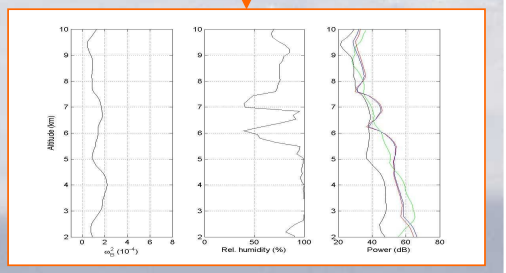
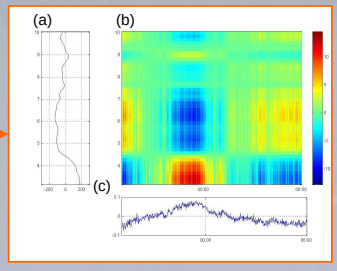


Figure 5: The second principal component (a), reconstructed signal (b) and empirical orthogonal function (c) associated with only the second largest mode of variability.



Conclusions and Further work

Simultaneous observations made by the NERC MST radar and the RAL Millimeter Wave Technology groups pre-prototype Cloud radar show a clear anti-correlation between the cloud radar signal return power and the VHF radar signal return power. Ancillary information from geostationary satellite, weather radar and radiosonde observations suggests that the frontal cloud observed has an ice-water content, this being confirmed by the fall streak structures in the cloud radar data. Principal component analysis of the VHF radar signal return power suggests that the first two PC's, which accounts for more than half of the variance in the data, are associated with the cloud structure. A simple model of the VHF radar return signal power based on radiosonde observations suggest humidity and the fraction of ice to liquid water content in the cloud may help account for these observations. The small difference between the modelled signal power when using a saturated vapour pressure over ice and water suggests that any change in the signal can only be partially explained by changes in the fraction of liquid to ice water cloud.

Acknowledgements:

We are also grateful to the British Atmospheric Data Centre which provided us with access to the UK Met Office assimilated data and the Dundee Satellite Receiving Station which provided MSG data.

References

Chu, Y.-H., and C.-H. Lin, The severe depletion of turbulent echo power in precipitation observed using the Chung-Li VHF Doppler radar, *Radio Science*, *29*, 1311–1320, 1994.
McDonald, A. J., K. P. Monahan, D. A. Hooper, and C. Gaffard, VHF signal power suppression in stratiform and convective precipitation, *Annales Geophysicae*, *24*(1), 23–35, 2006.
Vaughan, G., and R. M. Worthington, Effects of humidity and precipitation on VHF radar vertical beam echoes, *Radio Science*, 35(6), 1389–1398, 2000.
Williams, C. R., Principal component analysis of wind profiler observations, *Journal of Atmospheric and Oceanic Technology*, 14(3): 386-395, 1997.

Email
adrian.mcdonald@canterbury.ac.nz