AN EXAMINATION OF SIGNAL STATISTICS AND THEIR ANALYSIS ASSOCIATED WITH CLEAR AIR RETURNS

Abstract

VHF radars often called ST radars or wind profilers measure the small returns from clear air echoes. Many mechanisms exist to explain these returns and different experimental studies have suggested all the proposed mechanisms are possible. Several studies have examined the signal statistics of the quadrature components, obtained by coherent radar systems, in an attempt to determine whether these statistics can be used to help to determine the form of scattering observed and in particular echoes produced by scattering from turbulence. In these previous investigations, the signal statistics have usually been examined by determining the Nagamaki m-coefficient or the Rice parameter associated with the data. This study uses estimates of the modified Rice parameter, the corrected spectral width and the gradient Richardson number to define regions associated with intense turbulence. Data obtained at Aberystwyth (54.3N, 1.5W) by the NERC MST radar facility is used in an attempt to define regions associated with clear air turbulence during May and June 2000. Two case studies are presented which suggest the presence of turbulent regions. Possible sources of the likely turbulence seem to be associated with convective and dynamic instabilities and a critical layer associated with a Mountain wave.

Introduction

VHF atmospheric radars depend on scatter or reflection from perturbations in the radio refractive index in order for them to be able to function as tools for atmospheric studies. The most often discussed mechanisms are Isotropic turbulence, Anisotropic turbulence, Fresnel reflection and Fresnel scattering. However, there is still an ongoing debate with regard to the relative contributions of turbulent scatter and specular reflection in VHF radar studies. Generally studies of this problem have relied upon measurements obtained from the moments of the Doppler spectra. The corrected spectral width is the most often used parameter, large corrected spectral widths being associated with turbulent regions. However, it is also possible to use the statistics of the raw data (in-phase and quadrature data) to obtain information about the scattering mechanisms. The amplitude distribution of the radar raw data is examined using the modified Rice parameter in this study. Two case studies are described, the first case study suggests turbulence produced at a critical layer associated with a Mountain wave can be observed using the modified Rice parameter. The second case study shows that the modified Rice parameter can be used to identify turbulent regions associated with convective and dynamic instabilities.

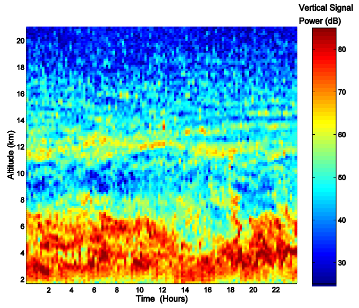

Figure 1 Time-altitude contour plot of the radar signal power returned from the vertical beam.

Case Study 1: 11th May 2000

Figure 1 displays a time-altitude contour plot of the vertical signal power observed on the 11th May 2000. This contour plot indicates that an enhancement in the vertical signal power is observed between 11 and 12km throughout the day, these enhancements being associated with the tropopause level. The vertical signal strength also suggests a frontal passage is observed between 10:00 to 16:00 UT. A plot of the corrected spectral width over the same period is shown in Figure 2. It should be noted that the corrected spectral width displays many regions where the correction factor for beam broadening is larger than the observed spectral width, these regions being white in Figure 2. Examination of these regions suggests that they are either due to regions of low signal to noise ratio, mainly associated with high altitudes, or regions where the background wind velocity is particularly strong. The error in the determination of the spectral width is thus suggested to be associated with regions where the observed scatterers do not fill the entire radar volume and statistical errors associated with determining the values of the different moments of the Doppler spectra. In Figure 2 several distinct regions of enhanced corrected spectral width can be observed, these occur between 05:00 to 06:00 UT at 7.5 to 9km, 11:00 to 12:00UT at 5 to 6km, 15:30 to 16:30UT at 11.5 to 12.5km, and 20:00 to 22:00UT at 11 to 14km and these regions can be associated with turbulence.

We will focus on the high altitude region of enhanced corrected spectral width between 15:30 to 16:30UT at 11.5 to 12.5km altitude. The vertical profile of the average of the modified Rice parameter is displayed in Figure 3. The average of the modified Rice parameter is derived from 30 separate calculations of the modified Rice parameter between 15:30 and 16:30UT. The minimum in the average of the modified Rice parameter is observed at 11 to 12km, two thin regions of small modified Rice parameter also being observed at 2 and 4km. The minimum in the modified Rice parameter is observed at the same altitude as an enhancement in the corrected spectral width. This result implies that the observed region is associated with clear air turbulence.

Examination of the background wind speed observed in this case (not displayed) shows a large shear in this region which could be the cause of the turbulence observed. However, further investigation suggests that the turbulent region may be produced by another mechanism. This suggestion is principally based on the vertical velocity data displayed in Figure 4. The most obvious feature of the vertical velocity data is regions of large vertical velocity which seem to mainly be confined to the troposphere, a large decrease in the magnitude of the fluctuation being observed above 12km . These fluctuations are associated with Mountain waves and examination of the wind speeds suggests that the turbulence is produced by a critical layer in this case.

It should also be noted that an examination of the data between 11:00 to 12:00UT at 5 to 6km displays similar behaviour with minima in the modified Rice parameter observed in the same region as the enhancement in the corrected spectral width.

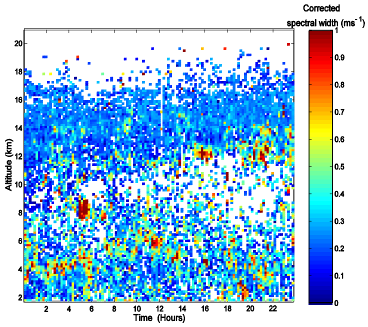

Figure 2 Time-altitude contour plot of the corrected spectral width observed on the 11th May 2000.

Case Study 2: 6th June 2000

Figure 5 displays a contour plot of the vertical signal power observed on the 6th June 2000. The signal power plot contains a great deal of small-scale structure related to a jet stream passage which is observed in the zonal and meridional velocities between approximately 5 and 10km, velocities being displayed in Figure 6. Figure 6 also displays a vertical profile of the temperature made by an ozonesonde launched at 12:00UT. Examination of the temperature profile indicates that the altitude of the tropopause is at approximately 10km, but a secondary indistinct tropopause-like level is also observed at 15km. The lower level matches up well with the tropopause level observed by the radar at the same time, however, the second feature does not match up with a second enhancement observed in the radar vertical signal power observed at approximately 12km. This suggests that the ozonesonde measurements of temperature is probably a good estimate of the conditions observed at the radar site below 10km.

Unfortunately, the accurate determination of the corrected spectral width proves impossible in regions associated with the jet stream in this case. However, examination of the gradient Richardson number determined from a combination of radar and ozonesonde data indicates a number of regions where the Richardson number falls below ¼, these being associated with regions of turbulence creation. Thin regions of low gradient Richardson number are observed at 5, 7 and 10km and a thicker layer is observed close to 6km. Examination of the average modified Rice parameter for an average taken between 12:00 and 13:00UT is shown in Figure 7, a low pass filtered version of this profile also being included for clarity. It can be observed that minima in the average modified Rice parameter are observed at approximately 6-7km and 10km, these altitudes corresponding to regions of low Richardson number displayed in Figure 6. Examination of the vertical velocity during this data also shows evidence of Mountain waves, but there is no evidence of a reduction in the wave amplitude. Therefore, these turbulent regions seem to be associated with regions of convective and dynamic instability. This case study therefore suggests again that the average modified Rice parameter may be used to determine re

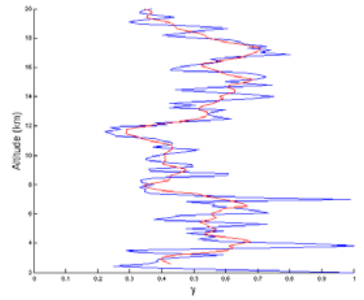

Figure 3 Vertical profile of the average of the modified Rice parameter (blue line) taken between 15:30 and 16:30UT on the 11th May 2000, a low pass filtered version of the profile (red line) also being shown for clarity.

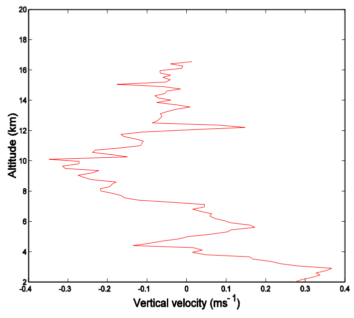

Figure 4 Vertical profile of the vertical velocity observed on the 11th May 2000 between 15:30 and 16:30UT.

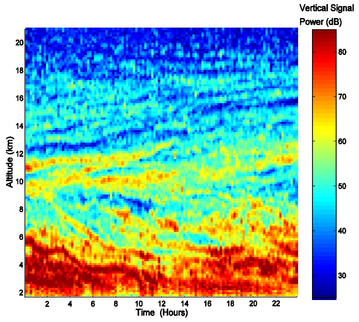

Figure 5 Time-altitude contour plot of the radar signal power returned from the vertical beam on the 6th June 2000.

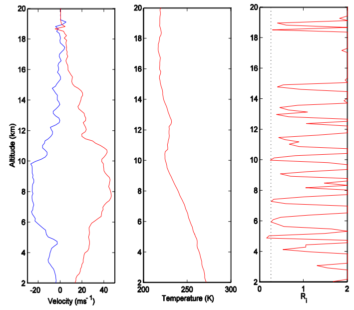

Figure 6 Vertical profiles of the zonal (red line) and meridional (blue line) velocity, the temperature and the gradient Richardson number for an ozonesonde launched at 12:00UT on the 6th June 2000.

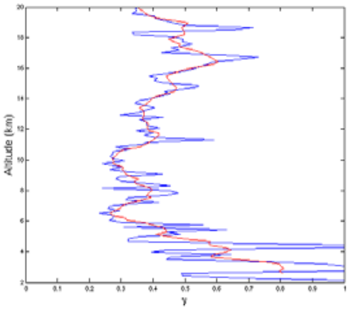

Figure 7 Vertical profile of the average of the modified Rice parameter (blue line) taken between 12:00 and 13:00UT on the 6th June 2000, a low pass filtered version of the profile (red line) also being shown for clarity.

Conclusions

A turbulent region associated with Mountain wave breaking identified by an examination of the corrected spectral width can also be observed by the modified Rice parameter. A second case study shows that regions of turbulence identified by measurements of the gradient Richardson number (derived from radar and simultaneous ozonesonde measurements) can also be identified by the modified Rice parameter. It should be noted that in the second case study these regions could not be identified by examination of the corrected spectral width because of statistical errors associated with determining the values of the different moments of the Doppler spectra.

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