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OBSERVATION OF STRONG WIND SHEAR USING PULSE COMPRESSION RADAR

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ABSTRACT

A sensitive pulse compression Doppler radar, providing a spatial resolution of 30 m, has been developed for probing the fine scale dynamical structure of the atmosphere. Using this radar, shearing instabilities have been observed in the upper troposphere which concentrated a layer of already strong shear by a factor of up to 8.

INTRODUCTION

This article illustrates a ground-based method capable of measuring wind shear at high levels in the atmosphere. The occurrence of layers of strong wind shear is of interest because of their relationship to turbulence and because of their effect on aircraft, rockets and missiles traversing them. The most extensive source of data on wind shear is from ascending balloon-borne targets but these provide individual profiles of uncertain representativeness and often lack vertical resolution. Measurements from aircraft provide a source of more detailed data. Other sources of high resolution data being used increasingly are remote probing techniques capable of measuring the Doppler shift from windborne natural targets such as cloud or dust particles and inhomogeneities of temperature and humidity. Although most of these techniques have been developed for use at short range in the atmospheric boundary layer, microwave pulsed Doppler radar is one technique whereby it is sometimes possible from a ground-based installation to obtain wind measurements to quite high altitudes.⁽¹⁾ Normally the spatial resolution of such radars is on the order of hundreds of metres. In this article we report some observations of very strong shear made using a pulsed Doppler radar specially designed to achieve high spatial resolution.

THE RADAR AND DISPLAY SYSTEM

The 25 m diameter aerial at Defford⁽²⁾ has been coupled to a 10.7 cm wavelength radar (an FPS-18 on loan from the National Center for Atmospheric Research, Boulder,

Colorado) redesigned to give a fine range resolution together with full Doppler measuring facilities. At present the peak power is limited to 320 kW. It has been modified to transmit frequency-modulated pulses of length 600 m. After reflection from targets these pulses are received, compressed and range-gated to give a resolution in range of 30 m. This is comparable with the beam-width resolution at a range of about 5 km.

The high gain of the aerial (53.2 dB), the low receiver noise temperature (170 K) and compression ratio (15 dB) produce a high sensitivity. The minimum detectable reflectivity for an extended target is $1.2 \times 10^{-15} \text{ m}^2 \text{ per m}^3$ at a range of 5 km. Two phase sensitive detector outputs from the receiver give the in phase and quadrature components of the Doppler frequency. They enable velocities to be measured unambiguously over the range $\pm 25 \text{ ms}^{-1}$. Since large returns from the ground, received in the aerial side-lobes, tend to mask the wanted targets, a range gated MTI (moving target indicator) has been built to filter out the stationary targets. This device has 256 gates, each 30 m wide, covering a total range of 7.5 km which can be set anywhere between 0 and 100 km.

The various methods of recording the data are shown in Fig 1. The output of the MTI is displayed on a rapidly processed photographic strip chart to provide an intensity modulated time-range record of target reflectivity in real time. Doppler information from 30 selected range gates covering a total range of 900 m are also recorded on audio tape. This can be replayed rapidly and frequency spectrum analysed to give an RV (range-velocity) display on a colour television. Different colours represent different levels of echo intensity in each element of the RV matrix. If other batches of 30 range gates need to be processed similarly they are extracted from a video recording of the raw radar data.

THE OBSERVATIONS

Radar observations described here were obtained between 1446 and 1454 GMT on 30 March 1977. A balloon-borne radio-sonde released during this period from the

radar site showed a strongly sheared layer of strong static stability in the middle troposphere between 6.0 and 7.7 km. The Richardson number over much of this layer, evaluated over 430 m height intervals (Fig 2), was close to $\frac{1}{4}$. This is regarded as the critical value for the onset of Kelvin Helmholtz (KH) shearing instability.⁽³⁾

The radar beam was fixed throughout the period of the observations, looking at an elevation angle of 60° into the direction (330°) of both the wind and the wind shear vector over the strongly sheared layer. The 60° elevation angle was a compromise which enabled the radar to detect a major component of the horizontal wind at the same time as obtaining a nearly vertical profile of this component. Fig 3(a) is a print of the rapid processor time-range display. The ordinate is labelled in terms of true height allowing for the 60° elevation of the radar beam. This figure shows the pattern of echo received mainly from small ice particles at the top of a cirrus cloud deck. Before 1440 the cloud top consisted of gently and uniformly inclined streamers of ice particles falling at less than 1 ms^{-1} . Fig 3(a) shows that, for a time after 1440, these streamers were distorted in a wave-like manner in the strongly sheared layer between 6.0 and 7.7 km. The crests of the waves were displaced to the right in the upper half of the layer and the troughs were displaced to the left in the lower half of the layer so as to be situated almost directly beneath the crests in the upper part of the layer. This is consistent with the pattern of air motion associated with large-amplitude KH billows.⁽⁴⁾ The purpose of this paper is to illustrate the capability of the radar to reveal the regions of strong wind shear which were associated with these billows.

Two examples of the format of the basic high-resolution range-velocity data are illustrated in Fig 4. Velocity-height matrices such as these were obtained at 3s intervals. Each element in the matrix is 26 m in height (30 m in slant range) by 0.625 ms^{-1} in radial velocity. Since the likely fall speed of the ice particle tracers and the maximum vertical air velocity inferred from the slope of the streamlines of Fig 3(a) was small ($<1 \text{ ms}^{-1}$) compared with the horizontal wind ($>20 \text{ ms}^{-1}$), the horizontal wind velocity can to a first approximation be taken as twice the

indicated radial Doppler velocity component. Using such data, we have derived a time-height diagram of the inferred horizontal wind speed for the top half of the disturbance (Fig 3(b)). We have also derived the pattern of vertical wind shear over 52 m height intervals (Fig 3(c)). Although neglect of vertical air motions does create errors in wind shear of up to $\pm 30\%$ in places, a corrected pattern of wind shear which has been derived, whilst different from Fig 3(c) in detail, does not dramatically alter the overall pattern of shear.

At 1436, before the billows developed, the Doppler measurements had shown that the shear over the 400 m height interval between 6.75 km to 7.15 km was uniform at $2.5 \times 10^{-2} \text{ s}^{-1}$. However, at times during the period depicted in Fig 3 the shear within this height interval increased locally by as much as a factor of eight, when evaluated over 52 m height intervals. The resulting shear, $20 \times 10^{-2} \text{ s}^{-1}$, can be regarded as very strong for the free atmosphere. The small vertical extent and the transient nature of the regions of strong shear would make them difficult to observe by more conventional in-situ sensing techniques.

CONCLUSIONS

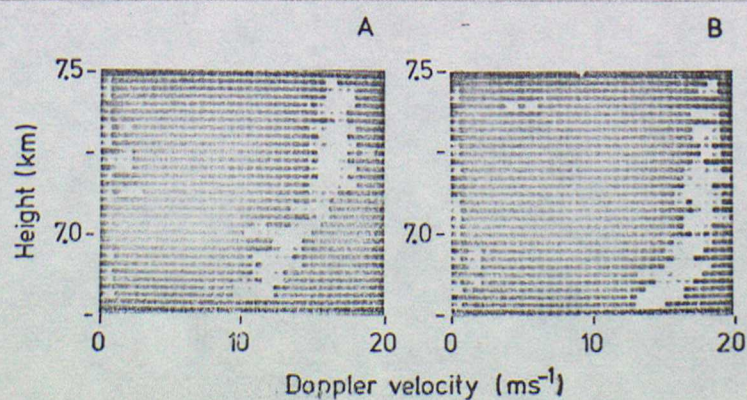
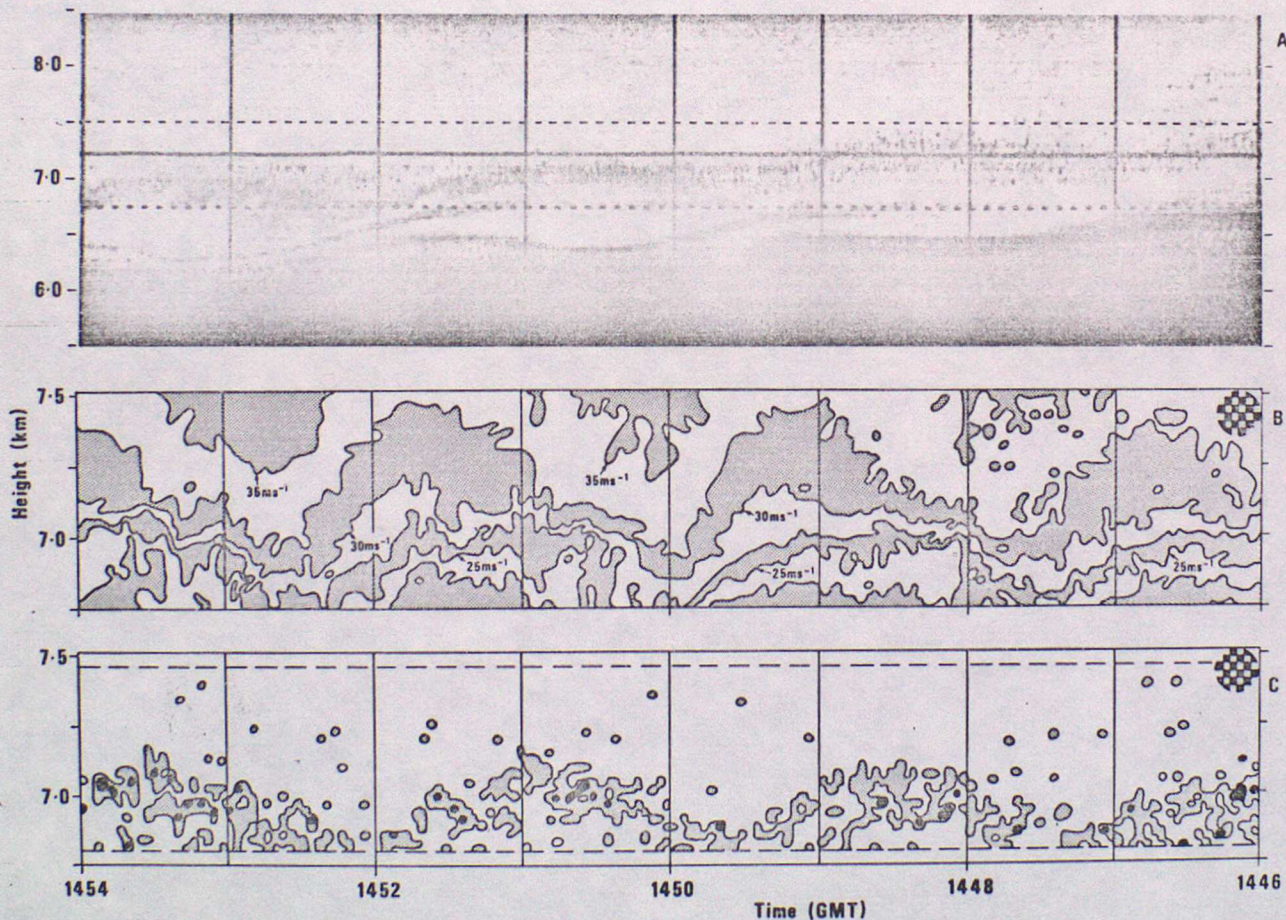
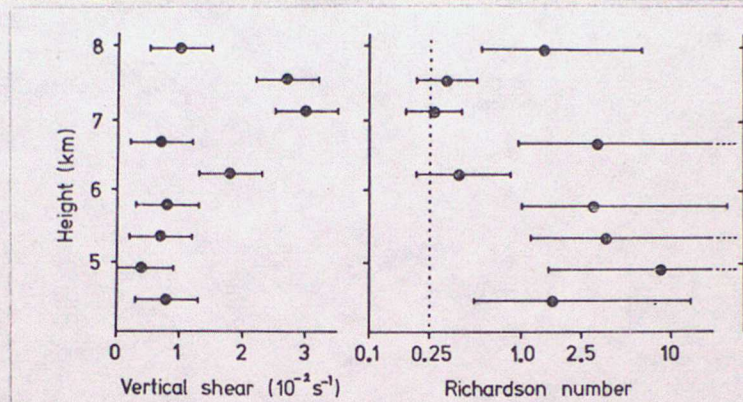
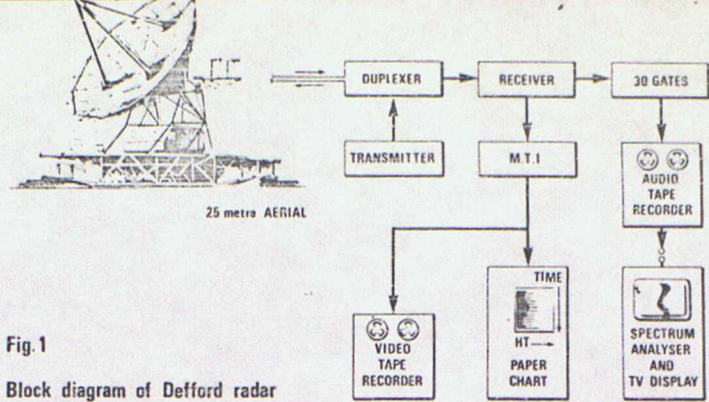
A pulsed microwave radar technique for obtaining high resolution measurements of wind shear has been described. The technique has been illustrated by means of a case study in which a vertical wind shear as strong as 0.20 s^{-1} was measured at an altitude of 7 km. The case described utilised small ice particles as tracers of the air motion. It would also work using signals back-scattered from refractive index inhomogeneities associated with humidity and/or temperature fluctuations which, with the present radar, are detectable most of the time in the boundary layer and for some of the time in the upper atmosphere, especially where there is strong shear and turbulence. Since the radar operates at a wavelength virtually unattenuated by rain and water vapour it can be regarded as having an all-weather capability. High spatial resolution and an all-weather capability can also be achieved using frequency modulated continuous wave (FMCW) Doppler radar techniques⁽⁵⁾ but so far such techniques have been restricted mainly to measuring winds in the atmospheric boundary layer.

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FIGURE LEGENDS

- Fig 1 Block diagram depicting forms of data output from the Defford radar.
- Fig 2 Vertical profiles of wind shear and Richardson number derived over layers 430 m deep from the radio-sonde release at 1450 GMT.
- Fig 3 Time-height record of a) intensity of radar echo between 1446 and 1454 GMT on 30 March 1977 showing wave-like perturbations at the top of a layer of cirrus cloud. Assuming that the pattern was advecting at the speed of the wind at the middle of the perturbed layer, the wavelength would have been 3.4 km. Time-height records are also shown of b) inferred horizontal wind velocity and c) inferred vertical wind shear computed over layers 52 m deep. The data in b) and c) are for the height interval shown between dotted lines in a): note the change in vertical scale. Isopleths of velocity in b) are at 2.5 ms^{-1} intervals. In c) regions of vertical wind shear exceeding $5 \times 10^{-2} \text{ s}^{-1}$ and $10 \times 10^{-2} \text{ s}^{-1}$ are dotted and black, respectively.
- Fig 4 Monochrome photographs of the Doppler velocity - versus height colour TV display at a) 1449.00 and b) 1449.57 GMT showing the region of wind shear and its change in height between the crest and trough of a billow (colours in the original display represented the intensity of the radar echo).



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