THE STRUCTURE OF AN INVERSION ABOVE A CONVECTIVE BOUNDARY LAYER AS OBSERVED USING HIGH-POWER PULSED DOPPLER RADAR

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Abstract. The high-power Defford radar has been upgraded to provide Doppler information regarding the motion of echoes from weak refractive index inhomogeneities within the optically clear atmosphere. A case study is presented in which data from the radar are used to derive the detailed velocity structure in and above the planetary boundary layer. These data are analysed to show how convective circulations in the boundary layer can perturb the height of a shallow inversion overlying it, thereby producing local enhancements of wind shear and a decrease in dynamic stability within the inversion. The measurements were obtained as part of a Boundary-Layer Project in which simultaneous measurements were made using fast-response instruments suspended from a tethered balloon within the region scanned by the radar. The balloon-borne probes showed that the most intense turbulence and fluctuations of temperature and refractivity were encountered when radar-detected hummocks in the height of the inversion were advected through the probes. The fine-scale turbulence measurements within the perturbed inversion are consistent with the existence of Kelvin-Helmholtz billows.

1. Introduction

One of the challenging problems in meteorology today concerns the vertical transfer of properties from the surface of the earth to the overlying atmosphere. The vertical transport of heat, water vapour, and momentum is important to the long-term general circulation of the atmosphere and it cannot always be ignored even in short-term numerical forecasting models. At the same time, the transport and dispersion of pollutants is causing increasing concern as an environmental problem. All this calls for more knowledge than we have at present of the fine-scale structure of the lower atmosphere. The acquisition of such knowledge also has significance for the radio engineer in relation to the scatter propagation of electromagnetic radiation beyond the normal horizon. As a result there is now a growing effort to study the structure of the planetary boundary layer and in particular to extend our present relatively detailed knowledge of the lowest 30 m up to heights of the order of 1 km.

Considerable impetus has been given to these studies by the recent development of remote sensing techniques capable of detecting small-scale fluctuations of refractive index associated with irregularities of humidity and temperature occurring in the visually clear atmosphere. Echoes received from these irregularities are useful in that they delineate the shapes of atmospheric structures which may be responsible for some of the vertical transfers. Two remote probing methods have proved particularly appropriate because of their ability to detect exceedingly weak gradients and also because of their high resolution, of the order of metres in the vertical. One of these
methods is sodar (acoustic echo sounding); this method depends mainly on backscatter from temperature irregularities. The other method is FM/CW radar; this depends mainly on backscatter from humidity irregularities. Both techniques provide a vivid portrayal of the lowest kilometre or so of the atmosphere, revealing layered structures, gravity waves, breaking billows and convection.

The major contribution of these new techniques has, in the broadest sense, been to show that some aspects of the turbulence in the planetary boundary layer, which hitherto had to be described in statistical terms, can now be accounted for in terms of distinct and definable physical structures—structures which are often inhomogeneous, non-isotropic, and non-stationary. The way ahead is to use fast-response instruments operating simultaneously with the remote sensing measurements.

Although the remote sensing techniques mentioned above have opened up new horizons for probing the small-scale structure of the lower atmosphere, the existing techniques suffer from the disadvantage that their beams have been essentially fixed in the vertical so that structures were observed in an Eulerian sense as they drifted across the beam. What is also needed is a remote sensing technique whereby the spatial distribution of atmospheric structures can be observed so as to enable their time history to be observed in a Lagrangian sense. The purpose of this paper is to present results which have been obtained using just such a technique. Results are presented of a case study in which a fully steerable, high-power, pulsed radar was used to make range-height (RHI) scans through a low-level inversion. The radar used was the Defford radar described by Watkins (1971). This has recently been upgraded by one of us (AJW) to give full Doppler velocity information on the clear-air echoes, thereby enabling the velocity structure of parts of the clear atmosphere to be observed in considerable detail (Browning et al., 1972).

The data in this paper were obtained as part of a Boundary-Layer Project in which the Defford radar was scanning a vertical section through fast-response instruments.