ROLL VORTICES IN THE PLANETARY BOUNDARY LAYER: A REVIEW *

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Abstract. Roll vortices may be loosely defined as quasi two-dimensional organized large eddies with their horizontal axis extending through the whole planetary boundary layer (PBL). Their indirect manifestation is most obvious in so-called cloud streets as can be seen in numerous satellite pictures. Although this phenomenon has been known for more than twenty years and has been treated in a review by one of us (R.A.Brown) in 1980, there has been a recent resurgence in interest and information. The interest in ocean/land-atmosphere interactions in the context of climate modeling has led to detailed observational and modeling efforts on this problem. The presence of rolls can have a large impact on flux modelling in the PBL. Hence, we shall review recent advances in our understanding of organized large eddies in the PBL and on their role in vertical transport of momentum, heat, moisture and chemical trace substances within the lowest part of the atmosphere.

1. Introduction

It is time for another review of instabilities, secondary flows, coherent structures, helical vortices, large eddies or rolls in the planetary boundary layer (PBL). The proliferation of terminology testifies to the common-place study of these phenomena. To save space, we shall refer to them generally as rolls or roll vortices, except to make a point.

The title of our review might suggest that we are treating any kind of organized roll vortices larger than the usual small-scale turbulence. Although research on "large eddies" or "coherent structures" is quite popular at present in turbulent boundary layers (see Liu, 1989 or Robinson, 1991 for recent reviews on the subject in engineering flows), we shall restrict our paper to horizontal roll vortices extending throughout the whole PBL). This kind of vortex can be best visualized by so-called cloud streets as in Figure 1, which have become common knowledge due to high resolution satellite pictures available on a routine basis (see Scorer 1986, 1990 for a collection).

The interpretation of this special type of cloud pattern can be easily achieved by assuming the existence of counter-rotating vortex rolls with axes approximately in the direction of the mean wind, as displayed schematically in Figure 2. Clouds

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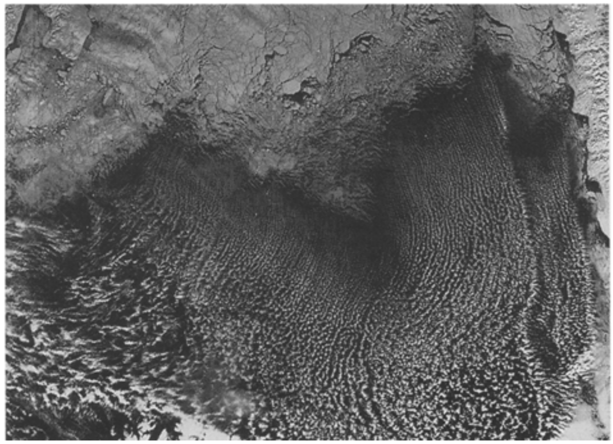

Fig. 1. Satellite picture of organized boundary-layer clouds during a cold air outbreak over the Barents Sea. NOAA 7, AVHRR, 6.4.1988.

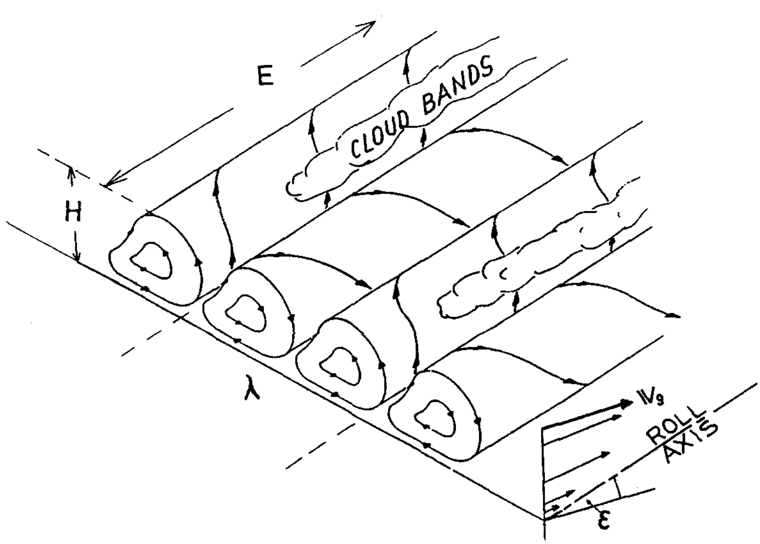

Fig. 2. Schematic of organized large eddies (horizontal roll vortices) in the PBL.

are formed above the updraft parts of the roll circulations; cloud-free areas are due to sinking motions. These facts have been known by glider pilots for a long time, as they used this special kind of upward motion organized in streets for long-distances soaring. An account of early flight reports and photographs of cloud streets taken from airplanes are given in Küttner (1959). These eddies in