Laboratory Production of Tornado-Like Vortices

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ABSTRACT

Tornado formation by turbulent mixing of two horizontal air currents and a vertical downdraft, as in the Wokingham model, has been simulated in the laboratory. Without the presence of the downdraft, vortices with lifetimes up to 20 sec have been produced only when the horizontal air currents have an angular separation of 65°. Maximum stability occurs when one current is inclined 6° above the horizontal. Results suggest that tornado formation probability is independent of downdraft and critically dependent on local wind directions and geometries at intermediate altitudes in severe local storms.

1. Introduction

The simulation of tornado funnels has been achieved by Davies-Jones (1973) Ying and Chang (1970), Smith (1962) and Ward (1972) for the purpose of investigating various dynamical aspects of the vortex. To date, however, no attempt has been made to produce a vortex by shear mixing of air currents, as suggested by Ludlam (1963) in the Wokingham model of a severe local storm with tornado producing potential. We wish to report here a partial simulation of this model in our laboratory.

The Wokingham model suggests that tornados are formed within the turbulent mixing region of three distinct air streams: a cold air downdraft originating at the top of the anvil of the thunderhead and two warm, horizontal air currents at altitudes low compared to the maximum altitude of the storm. One warm air current shears across the other at an unspecified angle within the turbulent mixing region. The fact that this angle may be critical in tornado formation is supported by the observation that tornados are reported in less than 10% of all severe local storms and thus must depend strongly on local wind velocities and directions.

2. Experimental

To simulate the Wokingham model, a three-sided lucite topless chamber with dimensions 90 cm×90 cm×125 cm was used in order to minimize wall effects. The downdraft in the Wokingham model was simulated by using a 3000 BTU air conditioner in series with a variable speed blower and a vertically oriented rectangular duct 60 cm above the masonite floor of the chamber. The horizontal air currents were produced by a 26-cm diameter squirrel-cage blower channeled into 7.5-cm diameter hoses leading to 2 cm×20 cm rectangular nozzles located at heights of 14 and 20 cm above the chamber floor. The flow velocity of each nozzle was regulated with a valve and had a maximum value of 9 m sec^{-1}. The experimental surface was a 90 cm×90 cm masonite slab with a 10-cm diameter hole in the center, into which was inserted a 250-ml beaker filled with ammonium hydroxide. Air bubbled through hydrochloric acid was fed into the beaker with resultant formation of an ammonium chloride suspension layer 3 cm thick on the experimental surface. This allowed direct observation of vortices which came in contact with the surface.

3. Results and discussion

An investigation of the ideal geometry for vortex formation in the Wokingham model was conducted by trial and error. It was found quite early that vortices formed in the presence of the downdraft had lifetimes of less than 1 sec, so mixing of the two horizontal air currents only was investigated. Some organized air motion was observed over a wide range of geometries, but localized vortices were observed only to occur for an angular separation of exactly 65° between the two nozzles. Maximum vortex stability had little dependence on velocities of the mixing air streams and occurred when one nozzle was inclined 6° to the horizontal. Under these conditions vortices with diameters of 3–5 cm and heights of 15 cm were observed for time durations up to 20 sec. Many exhibited shapes observed for classical tornados and, when becoming unstable, would rise from the experimental surface. Two examples are shown in Fig. 1. Multiple-vortex formation was also commonly observed, but in this case any single vortex had a lifetime of only 5–8 sec. Of the vortices observed, 80% rotated counterclockwise and only 20% clockwise.

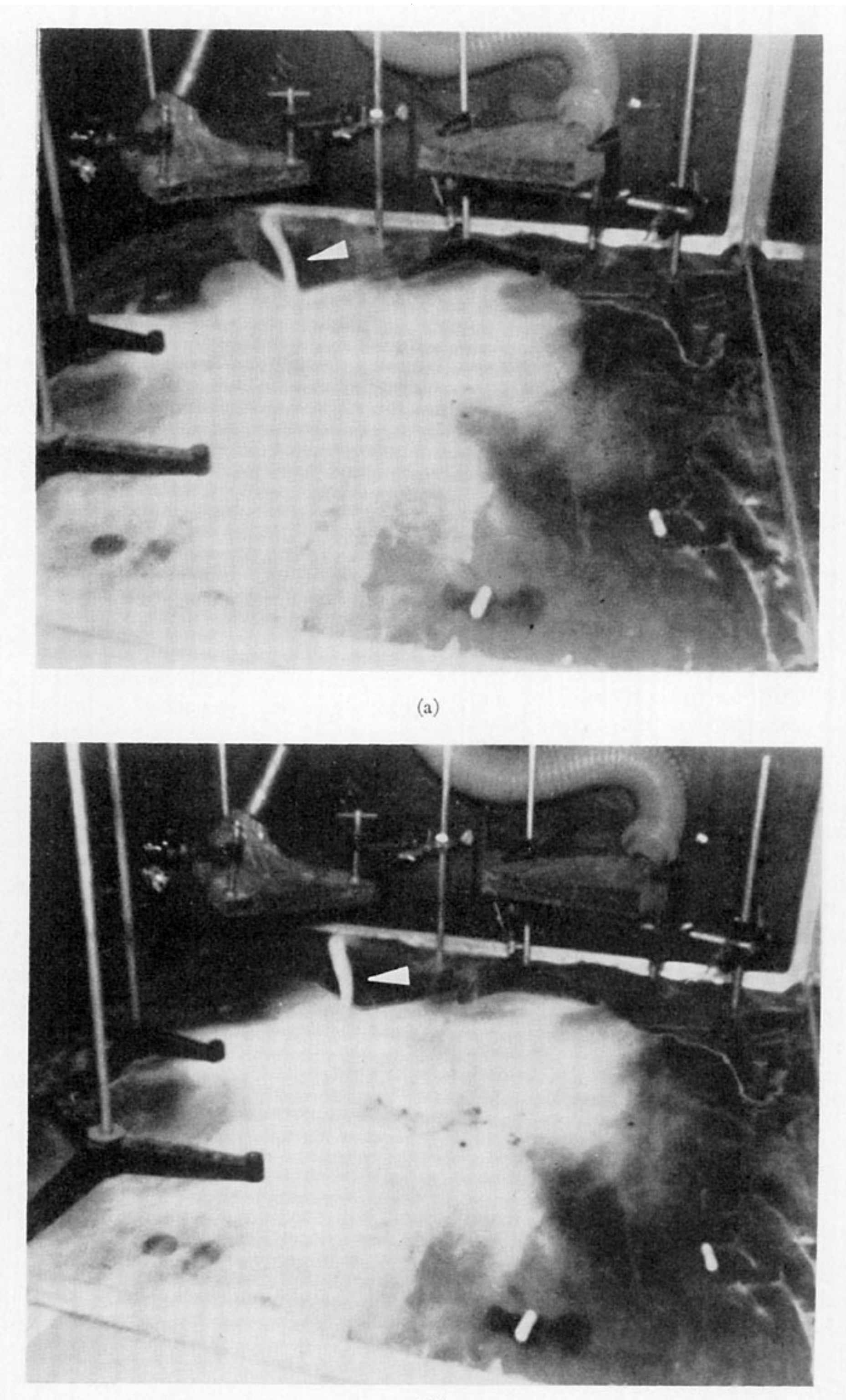

FIG. 1. Examples of cylindrical (a) and conical (b) vortices observed in laboratory simulation. Cylindrically-shaped vortices were generally somewhat more stable than those having conical shapes.

Our results indicate that vortices are easily produced by shear mixing of two air streams, but under very particular geometrical conditions. It is thus quite possible that tornados may be initiated by shear mixing of two distinct horizontal air streams, with a particular geometry, at intermediate altitudes in severe local storms.

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