Atmospheric Research 178–179 (2016) 320–328

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Dynamics and thermodynamics of a tornado: Rotation effects

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ARTICLE INFO

Article history:
Received 7 January 2016
Received in revised form 15 March 2016
Accepted 28 March 2016
Available online 6 April 2016

Keywords:
Tornado dynamics
Tornado energy source
Tornado rotation
Tornado heat transfer
Latent heat
Water vapor condensation

ABSTRACT

This paper investigates the relevant processes in the tornado including the dynamics of rotation and thermodynamics as well as condensation. The main novelty of this paper is the explanation of the phenomena occurring in the central downflow. The reduced pressure in the tornado's funnel sucks air and water vapor from the cloud above the tornado. The latent heat of condensation is released in the funnel. The centrifugal force drives the generated water drops out of the funnel. The latent heat of condensation released is also transferred out of the funnel, and supplies the helically ascending air flow surrounding the tornado with additional buoyancy energy. This process gives the tornado increased strength compared to the dust devil type of flow, thus explaining why tornadoes occur always under a cloud, and why the tornado pipe can reach a height of a kilometer and more. To sustain a tornado, the temperature of water vapor at the cloud's base should be higher than the surroundings by a certain minimal value. Remote infrared temperature measurements of clouds' bases may provide indications of the probability that a cloud can spawn a tornado, which may increase the lead time.

1. Introduction

1.1. General

Tornadoes are abundant and cause destruction mainly in the Tornado Alley in the U.S.A. but they exist in many other countries as well. Knowledge of the tornado mechanism may increase the lead time and save lives.

A tornado in its simplest form is a wind system consisting of an exceedingly fast rotating pipe or funnel (that is mainly a vortex wind; see Section 2.1 below), around which a fast torus of winds rotates in the same direction. The pipe stems from an upper cloud (see Fig. 1).

Section 2 describes the dynamics typical to a tornado. Section 3 presents approximate quantitative thermodynamical calculations of the funnel. Section 4 discusses supporting evidence. Section 5 explains some "paradoxes" in tornado behavior. Section 6 discusses and suggests some remote infrared measurements, which may increase the lead time.

The fast rotation of a tornado implies that the conservation of energy and angular momentum prevents the ambient humidity around the funnel from reaching inside the central funnel in spite of the low pressure inside it. This paper discusses the dynamics of a tornado and raises the hypothesis that tornadoes depend on a continuous supply of water vapor from a cloud. Hopefully cutting the supply of water vapor from the cloud to the tornado may eventually (when appropriate experience and control will be achieved) weaken or even stop a tornado.

1.2. (Not) Understanding tornadoes

Bluestein (1999) wrote that modifying tornadoes is impossible without understanding how they are created, and trying to alter tornadoes without a theory that can be put to the test is like shooting in the dark. Bluestein (2005) wrote that "Tornado formation… is not well understood."

Rotating supercell storms may be predecessors of tornadoes. Splitting cumulonimbus clouds into cyclonic and anticyclonic supercell storms may also lead to the formation of tornadoes. A hook image in Doppler radar is a much better definitive precursor of a tornado, but it is identified too late, leaving a lead time of only 13 min.

In 2013 Bluestein affirmed that it is still not known what is the difference between supercells that spawn tornadoes and those that do not.

Apparently the existing models are still insufficient to suggest how we can weaken tornadoes or even how to increase the lead time. This motivates us to describe further modified models like the present model.

1.3. Some phenomena similar to tornadoes

Few phenomena remind some features of tornadoes. Examples are:

- The shape of vortex around a draining hole (Feynman et al., 1965. See Section 2.5 below, and Fig. 2).
- Shear in flow causes hurricanes to spawn tornadoes.
- Shear in flow causes vortices between layers of winds moving with different velocities (see Fig. 3). This is the accepted belief of how

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http://dx.doi.org/10.1016/j.atmosres.2016.03.025
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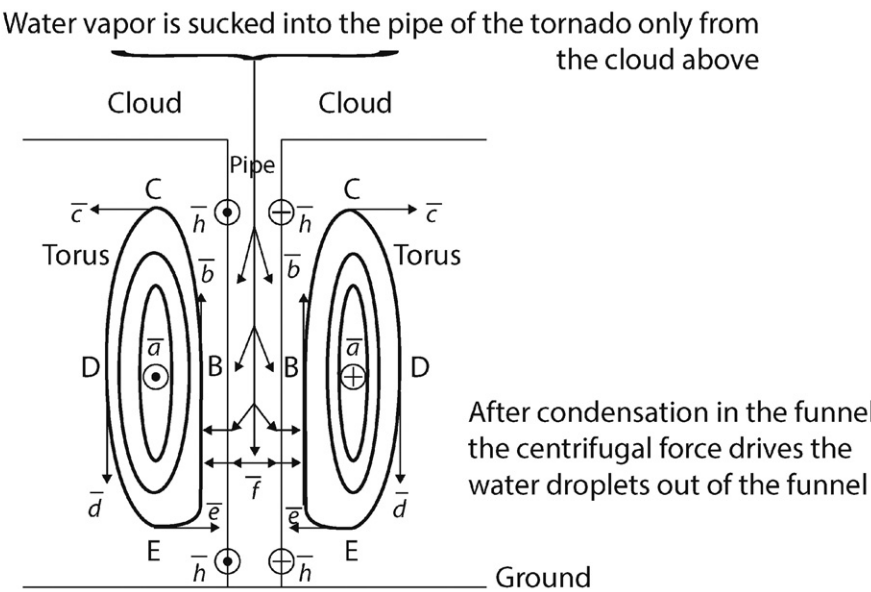

Fig. 1. Schematic section of the simplest configuration of a model tornado. Lowercase letter vectors denote the direction of wind velocities. Capital letters denote regions discussed in the text. $\overline{a}$) Main circumferential air flow direction. $\overline{a}+\overline{b}$) Helical air flow upward. $\overline{a}+\overline{c}$) Spiral air flow outward. $\overline{a}+\overline{d}$) Helical air flow downward. $\overline{a}+\overline{e}$) Spiral air flow inward. $\overline{f}$) Downward pipe flow direction. $\overline{h}$) Rotational pipe flow direction.

shear between winds on Earth high above in the level of clouds produces horizontal roll flow that later evolve to vertical tornado.
- Shear in flow may split a storm to twin rotating storms. See, i.e., Fig. 4 and C'uric' and Janc (2011, 2012).

1.4. More about tornadoes

Our additional necessary condition of a relatively warm region at the base of the cloud (which can be measured by remote infrared methods, as discussed in Section 6 below), is an additional criterion (besides the hook image in Doppler radar) for early identification of tornado spawning clouds. This can contribute to increasing certainty of diagnosis and warning time.

The main damage tornadoes cause is done by the pipe and the system around it when the pipe touches the ground. (In a few tornadoes the rotating torus around the pipe (Fig. 1) causes the damage even when the pipe does not touch down). Winds with a velocity of hundreds of km. per hour in the torus cause a huge amount of damage to practically everything in its path. The pipe has the power to destroy entire houses.

Sometimes satellite tornado funnels are seen around the main tornado funnel. In our opinion they are created because of the high rate of shear of the winds rotating closely around the main funnel, which is created first.

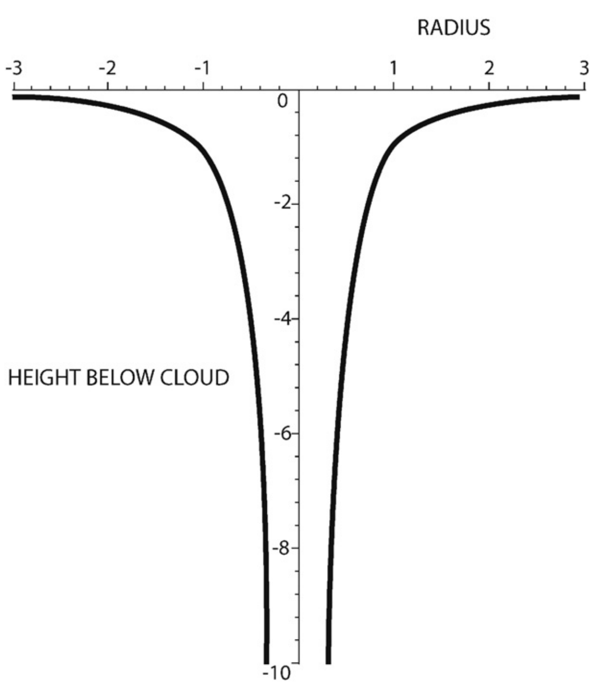

Fig. 2. Approximated surface of funnel of tornado (schematic section, Eq. (14) normalized).

2. Dynamics typical to tornado

2.1. Models of tornado

Many models were developed for tornadoes (see, e.g., Yih, 2007 and Liu et al., 2006 (two-fluid models); Bluestein and Golden, 1993; Golden, 1971, 1974; Lewellen, 1993; Whipple, 1982; Hsu and Fattahi, 1976; Idso, 1974; Davies-Jones, 1995). See also references in Idso (1974) and Davies-Jones (1995).

Many models were supported by laboratory experiments, numerical simulations and measurements of actual tornadoes. These supports are model dependent, whether they are physical models, conceptual

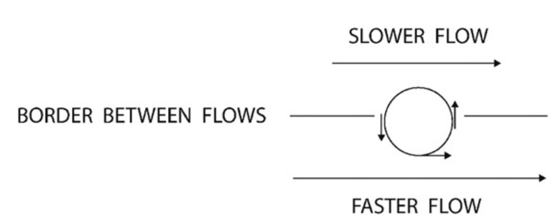

Fig. 3. A view on a vortex between slow and fast flows (schematic): View from the side on the flow of winds high above on Earth. This is the accepted belief of how shear between winds on Earth high above in the level of clouds produces horizontal roll flow that later becomes a vertical tornado.