# Comments on "A Simple Model for Simulating Tornado Damage in Forests"

NIKOLAI DOTZEK

*DLR-Institut für Physik der Atmosphäre, and European Severe Storms Laboratory, Wessling, Germany*

RICHARD E. PETERSON

*Atmospheric Science Group, Texas Tech University, Lubbock, Texas*

BERNOLD FEUERSTEIN

*Max-Planck-Institut für Kernphysik, Heidelberg, and European Severe Storms Laboratory, Wessling, Germany*

MARTIN HUBRIG

*Skywarn Deutschland, Lotte-Wersen, Germany*

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## 1. Introduction

Holland et al. (2006) present a very interesting study on development and evaluation of a simple analytical model of tornado vortex flow and its impact on specified forest configurations. The authors also make reference to earlier work by Johannes Peter Letzmann (1885–1971) on near-surface tornado wind fields, dating back to 1923 and reviewed, for example, by Peterson (1992a).

The authors are correct to say that Letzmann did not include information on the physics of tree response (which was unavailable in his time), even though he considered the question of whether and how twisted tree snapping occurred or how the observed tree damage should be interpreted. However, some other statements by Holland et al. (2006) about Letzmann's work can be misleading. The review by Peterson (1992a) alone is certainly not sufficient to assess fully the analytical model developed by Letzmann (1923) in his Ph.D. thesis and later summarized in a journal article (Letzmann 1925).

It appears as if Holland et al. (2006), based on the limited information they had available on Letzmann's model, reinvented parts of it. Thus it comes as no surprise that some of Holland et al.'s results "are somewhat analogous to the hand-drawn diagrams of Letzmann" (p. 1598)—the underlying model is the same. The fuzzy wording by Holland et al. (2006) may have been influenced by their references: Letzmann (1925) was cited by Hall and Brewer (1959), yet they only referred to "somewhat similar" work by Letzmann, and Peterson (1992a) mentions Letzmann's "hand calculations."

When Holland et al. (2006) refer to Letzmann's work as "experimenting" with various model parameters and emphasize several times his "hand drawn" diagrams and "hand calculations," the reader may get the false impression that Letzmann had received his results merely by chance, instead of by the rigorous analytical calculations he performed in his Ph.D. thesis and that also extend the wind-field description by Holland et al. (2006). Furthermore, hand calculations and hand-drawn diagrams were state of the art in the 1920s and 1930s, just as publishing scientific work in the German language was. Nevertheless, the authors must be highly credited for their tying in with Letzmann's research and augmenting it by the modeling of tree response.

The purpose of our comment is to draw attention to

*Corresponding author address:* Dr. Nikolai Dotzek, DLR-Institut für Physik der Atmosphäre, Oberpfaffenhofen, 82234 Wessling, Germany.
E-mail: nikolai.dotzek@dlr.de

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the full set of references to Letzmann's work relevant here and thereby to facilitate ongoing and future research on tornado damage in forests and near-surface tornado wind fields. In section 2, we sketch the historical context under which Letzmann pursued his studies, briefly review his analytical tornado wind-field model, and call attention to his guidelines for tornado research and damage surveys, which were approved by the International Meteorological Organisation (IMO) in 1937. Section 3 presents our conclusions.

## 2. Letzmann's tornado research related to forest damage

Forest damage has traditionally been taken into account when tornadoes or other severe-wind events were investigated in Europe [see, e.g., Martins 1850; Reye 1872; Wegener 1917; or very recently, the *International Conference on Wind Effects on Trees in 2003* (www.ifh.uni-karlsruhe.de/science/aerodyn/windconf.htm) and Hubrig 2004]. Thus, it was natural that parts of Letzmann's work on tornadoes were devoted to this field.

### *a. Inspiration by Alfred Wegener*

Letzmann's tornado research was significantly triggered and enhanced by the inspiration he received from Alfred Wegener, nowadays mostly remembered for his work on continental drift. However, Wegener was a dedicated and thoughtful scientist whose research interests covered an immensely broad range in geophysics and meteorology, including thunderstorms and tornadoes.

In his service during World War I, Wegener was injured. After recuperating, he started to work on a comprehensive monograph on tornadoes and waterspouts in Europe (Wegener 1917), a classic of tornado research literature. Only recently was Dotzek (2003) able to update Wegener's estimate of tornado occurrence in Europe.

After Wegener's recovery, he was assigned as a weather advisor on the Eastern Front. With the collapse of the Russian Empire, the Prussian government seized the opportunity to reestablish a presence in the Baltic states—in particular, at universities. So Wegener was dispatched to the University at Dorpat (Tartu), Estonia, in 1918. Here, Letzmann was especially interested in storms and had synthesized a synoptic climatology of thunder observations across the area (cf. Peterson 1995). He soon came under the mentorship of Wegener (Lüdecke et al. 2000). With the end of the war, however, Wegener shortly returned to Germany while Letzmann continued his studies of severe storms and tornadoes.

From 1919 to 1924 Wegener headed the Meteorological Department of Deutsche Seewarte in Hamburg, Germany. Frequent correspondence reveals that Wegener was extremely insistent that Letzmann join him in Hamburg with a suitable research position. However, Letzmann obtained a teaching position at Dorpat University and remained there until the dawn of World War II. His Ph.D. thesis (Letzmann 1923), summarized by Letzmann (1925), contained groundbreaking analytical work on near-surface tornado wind fields and damage. Both scientists maintained a friendship and a close collaboration on tornadoes until Wegener's death in Greenland in 1930.

During the 1930s, Letzmann had become a major tornado researcher, including work on the theory of vortex dynamics, details of earlier tornadoes, damage-swath investigations, case histories, photographic sequence analysis, and laboratory simulations. Along with Harald Koschmieder and on behalf of the International Meteorological Organisation, he prepared guidelines for the study of tornadoes that were officially resolved in 1937 but only appeared in print two years afterward (Koschmieder and Letzmann 1939; Letzmann 1939).

In 1940, Letzmann came to the University of Graz by invitation of Kurt Wegener. Here, he could establish a research facility for atmospheric vortices (*Forschungsstelle für atmosphärische Wirbel*) and received the title of adjunct professor. However, in late 1945 he lost his position at the university and his professorship was withdrawn. With an increasingly difficult private situation over his long-lasting struggle to reestablish his lectureship, he moved to the German island of Langeoog in 1962, where he stayed in a facility for elderly Baltic Germans. He continued studies on tornadoes until his death in 1971, but at this time his work was nearly forgotten both in Germany and the United States.

Alfred Wegener was able to provide fruitful inspiration to the younger Letzmann by his own visionary work on tornadoes. This led to a remarkable list of papers (cf. Peterson 1992a) that gain their full value only today with the availability of mobile Doppler radars (e.g., Lee and Wurman 2005), computer models (e.g., Lewellen et al. 1997), and detailed damage assessments (e.g., Wurman and Alexander 2005; Wurman et al. 2007) as envisioned by Letzmann decades ago.

### *b. Analytical near-surface tornado wind-field model*

Letzmann had presented the full analytical derivation of his near-surface tornado wind-field model only in his Ph.D. thesis[1] (Letzmann 1923). The summary that appeared two years later in the *Meteorologische Zeitschrift* was detailed but less technical (Letzmann 1925). Letzmann started from the assumption that the velocity field in a tornado vortex could be described by a Rankine vortex with a solid-body rotation in the core up to the radius of maximum winds, followed by a hyperbolic decay of both the tangential and radial wind speeds for larger radii, called the "mantle" by Letzmann. The ratio between the two vortex wind components determined the angle of deflection (*Ablenkungswinkel*) $\alpha$. A further key parameter describing the flow field was $G$, the ratio between rotational and translational motion of the tornado, and, last, $\psi$ denoted the angle between the local instantaneous wind speed in a given point versus the direction of translation of the tornado.

This nomenclature was introduced by Peterson (1992a) in his review of Letzmann's work, and Holland et al. (2006) apply it in their paper. It is clear that their wind-field model description is a reiteration of the main parts of Letzmann's analytical model. Although other authors such as Wurman and Alexander (2005) also assume Rankine-type vortices, only Holland et al. (2006) directly follow the analytical formalism as set out by Letzmann (1923).

Holland et al. (2006) used velocity ratios $G_{max}$ that vary between 2.1 and 20, whereas Letzmann (1923, 1925) started his range of parameters $G$ already below the critical value $G_{max} = 1$ and found that for $G_{max} < 1$ the flow field loses some of its vortex characteristics and corresponds more to a wave pattern. Of interest is that Letzmann focused on the case $G_{max} \approx 6$, which he assumed to be representative of tornadoes in the United States. Furthermore, we note that Holland et al. (2006) only treat the case of $\alpha$ = constant whereas Letzmann allowed for values of $\alpha$ that vary with radius.

In creating the resulting streamline diagrams, Letzmann could rely on earlier work by Sandström (1909), which he developed further to his "method of individual circles" (*Methode der Individualkreise*). This technique allowed him to identify singular lines (*singuläre Linien*) of convergence and divergence lines within the vortex, as well as the locations of calms. In those vortices that contained a closed singular line, a "genuine core" (*echter Kern*) was present if the singular line showed convergence on both sides (outflow in the center of the vortex) and a "false core" (*unechter Kern*) was present if the singular line showed a convergence–divergence couplet (inflow at the vortex's center). In modern terminology, this corresponds to the distinction between a two-cell and a one-cell tornado, respectively.

For $G_{max} \geq 1$, two other types of singular lines become discernible in the vortex: First, a "separation line" (*Grenzlinie*) dividing two regions of the vortex in which the streamlines enter the vortex from the rear side and either leave the vortex at the front side or converge into the separation line. Second, a "blocking line" (*Sperrlinie*) that surrounds an area of the vortex in which streamlines entering from the rear flank cannot reach the vortex front side but converge either toward the central calm or to the separation line. By identifying these different lines and their locations in a reconstructed streamline diagram, Letzmann (1923, 1925) was able to study a wide range of specified vortex setups. Note further that his analysis was derived in principle for any kind of vortex, and he consequently treated tropical and extratropical cyclones as well to reinforce the general applicability of his analytical approach.

Before turning toward Letzmann's application of his method to forest-damage patterns, we finally address the issue of the "hand calculations" and "hand-drawn diagrams" mentioned by Peterson (1992a) and Holland et al. (2006) to shed light on the soundness of this method of streamline reconstruction. The technique was developed by Sandström (1909), and the Letzmann legacy contains a later-published textbook on graphical streamline reconstruction.

Thus, Letzmann (1925) refers to the "Sandström technique," which was likely motivated by its relevance to produce streamline maps in synoptic meteorology: after computing the isogone fields for a given flow field, the streamlines obeying the equation

$$dy/dx = f(x, y) \tag{1}$$

could be obtained graphically or, for a larger number of fields or a parameter study, also mechanically. Sandström (1909) describes a mechanical device (Fig. 1a) that was developed by his student V. Söderberg and that was able to solve graphically about 100 differential equations like Eq. (1) per day. Sandström (1909) presents a large number of worked-out examples of idealized and synoptic isogone and streamline fields, of which we show one very complex specimen in Fig. 1b.

### *c. Guidelines for tornado research and forest-damage surveys*

Letzmann's guidelines for the study of tornadoes were resolved by the IMO in September 1937 (Salzburg,

[1] Because the Ph.D. thesis is not easy to obtain today, it has been made available online in digitized form on the European Severe Storms Laboratory (ESSL) Internet site, and paper copies of the specimen from Letzmann's legacy are available from the first author upon request.

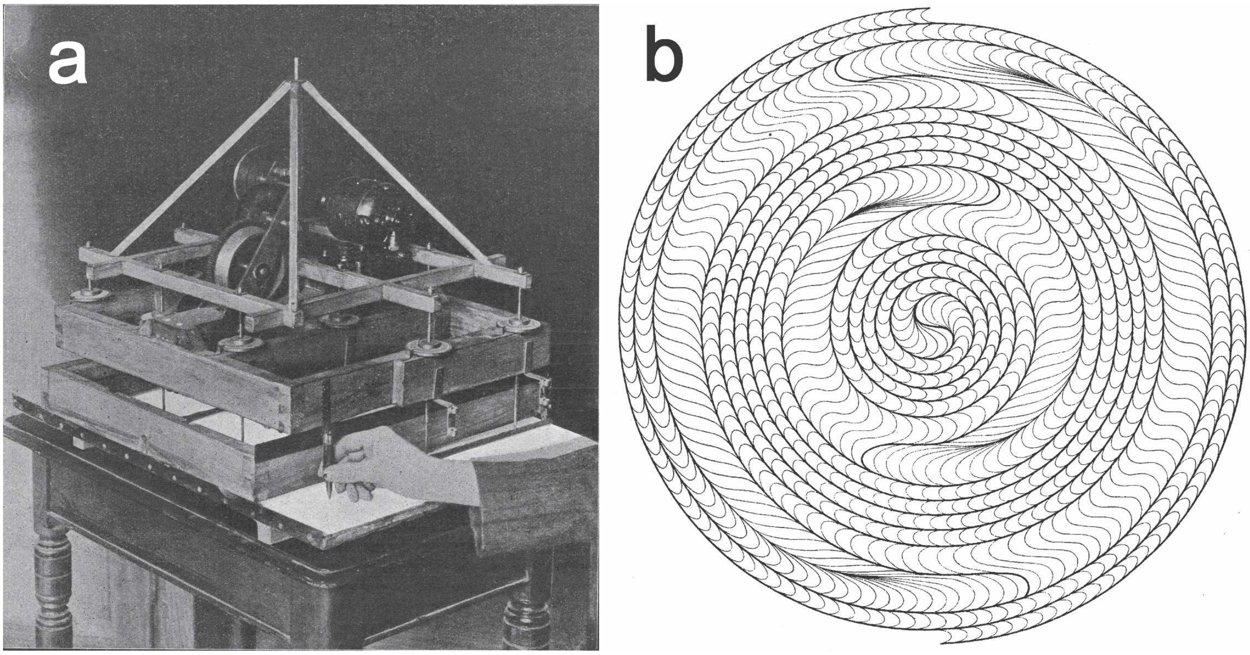


FIG. 1. (a) Söderberg's apparatus for graphical solution of differential equations, as used by Sandström (1909, his Fig. 3) for construction of isogones and streamlines, and (b) example of graphical solution of the streamline equation $dy/dx = \tan[3\pi \sin(x^2 + y^2)^{1/2}]$ from Sandström (1909, plate 32).

Austria, 14 September 1937, resolution IV) following earlier recommendations by the Climatological Commission of the IMO to the member states to pay more attention to tornadoes (at the meeting in Danzig in 1935; see IMO Publ. Nr. 25, p. 21). The authors are presently unaware of whether IMO resolutions from that time still bear validity in the context of present-day WMO regulations.

The IMO guidelines from 1937 appeared in print two years afterward[2] (Koschmieder and Letzmann 1939; Letzmann 1939) and were only slightly revised later on by Letzmann (1944). After falling into oblivion for decades, they have been reviewed by Peterson (1992a) and translated to English (Peterson 1992b), as well as summarized and augmented by a Fujita-scale wind-damage description adapted to central Europe by Dotzek et al. (2000). Both Peterson (1992a,b) and Dotzek et al. (2000) demonstrate their being well ahead of their time.

However, not only did the advent of World War II prevent their widespread international application, but so too—in particular for the United States—did the skeptical commenting letters by J. B. Kincer, then Chief of Division of Climate and Crop Weather at the U.S. Weather Bureau, in which he expressed little confidence that ambitious tornado research programs as proposed in Letzmann's guidelines could ever be accomplished. These letters were attached to Koschmieder and Letzmann (1939), and one of them was reproduced and discussed by Peterson (1992b).

Based on his streamline analysis, Letzmann (1923, 1925, 1928) had produced images of tree-fall pattern along cross sections of a tornado damage swath for various combinations of the parameters $\alpha$ and $G_{max}$ (cf. Fig. 11 of Peterson 1992a). To do so, he had assumed that tree fall always occurred in the direction of the instantaneous wind at the location of the tree in the moment of its failure. The same assumption was also made by Holland et al. (2006). Letzmann then categorized the resulting swath patterns into four main types and showed these for six discrete values of the angle of deflection $\alpha$. This diagram also appeared in the IMO guidelines (Letzmann 1939) and has been reproduced by Peterson (1992a, his Fig. 8), Peterson (1992b, his Figs. 1 and 2), and Dotzek et al. (2000, their Figs. 1 and 2) and hence is not included here again.

When compared with individual swath cross sections (horizontal rows) of Holland et al. (2006, their Figs. 9–15), their resemblance to Letzmann's characteristic swath types is striking. The only significant step forward by Holland et al. (2006) is the inclusion of the detailed tree-response model, which was unavailable in Letzmann's times. What Letzmann (1923) did investi-

[2] Both Koschmieder and Letzmann (1939) and Letzmann (1939) are available online on the ESSL Internet site.

gate, however, was the effect of wind-induced torsion on trees, following the descriptions by Martins (1850) and Wegener (1917). He identified regions inside the vortex that might support twisting-off of trees by the vortex itself (cf. Fig. 12 of Peterson 1992a), instead of the more common case in which an asymmetric tree crown exposed to a more straight-line wind can also lead to a twisted fracture of the trunk.

For completeness, we mention that Letzmann's IMO guidelines also gave an extensive treatment on how to conduct ground and aerial damage surveys to provide the best possible data of the forest-damage swath to enable proper reconstruction of the tornado characteristics. Given that the technique of aerial damage surveys was only later taken up and developed to full maturity by Ted Fujita (e.g., Fujita 1981), we can only speculate what fruitful cooperation could have resulted if Letzmann and Fujita had the chance to work together on tornado-damage analysis.

## 3. Conclusions

We welcome the paper by Holland et al. (2006) very much for their addressing a line of research directly linked to Letzmann's investigations in the 1920s and 1930s. However, the following three points are important to put Letzmann's work in a proper perspective:

1) Based on the limited information they had on Letzmann's work, Holland et al. (2006) have apparently reinvented parts of Letzmann's analytical tornado vortex model.
2) The full versatility of the analysis by Letzmann (1923, 1925) remains yet to be exploited by Holland et al. (2006) and other groups addressing tornado damage assessments.
3) We have provided here the necessary background and references to Letzmann's work and thus hope to stimulate further use of Letzmann's results for development or refinement of forest-damage models such as that of Holland et al. (2006).

We are confident that Letzmann's achievements still can foster contemporary tornado research. The well-documented forest damage swath of the 2 October 2006 F3 (on the Fujita scale) Quirla tornado in Germany might serve as a test case to apply the Holland et al. (2006) model over hilly terrain.

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