

IMMERSIVE TORNADO SIMULATION



VR & Mixed Reality for Spatial Understanding of Atmospheric Phenomena

Undergraduate Research Symposium | GEOG 457

THE PROBLEM

Tornadoes are complex **three-dimensional atmospheric phenomena** — yet almost all visualizations present them on **flat 2D surfaces**.

This fundamentally limits our ability to understand true scale, rotational structure, and spatial relationships — exactly the concepts that matter most for education and preparedness.

How can **immersive technologies** improve comprehension of tornado dynamics compared to conventional 2D visualizations?



ORIGINAL ARTICLE

Mathematical modeling of tornadoes and squall storms

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KEYWORDS

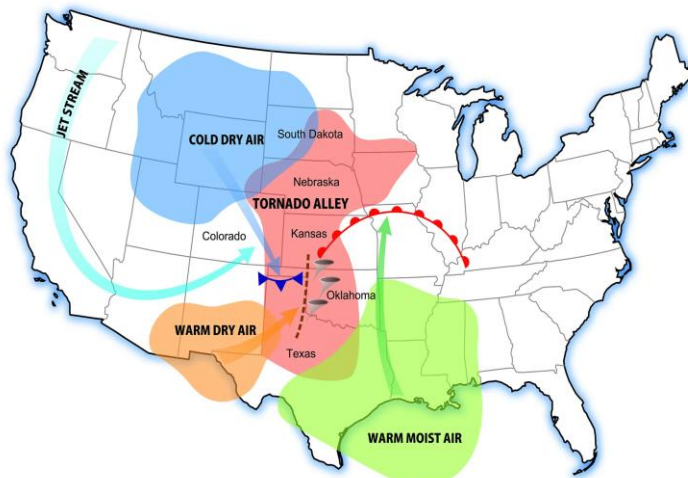
Tornadoes;
Squall storms;
Atmospheric boundary
layer;
Mathematical modeling

Abstract Recent advances in modeling of tornadoes and squalls consist of significant achievements in mathematical calculation of occurrence and evolution of a violent F5-class tornado on the Fujita scale, and four-dimensional mathematical modeling of a squall with the fourth coordinate time multiplied by its characteristic velocity. Such a result can arise in a four-dimensional approach filled with turbulent vorticity. A theory of the squall storm is presented. The squall storm is modeled by vortex generation of the turbulent vorticity on the lower boundary of cloudiness. This generation is induced by the action of strong baroclinic winds in the upper and middle troposphere, and looks like a vortexing solitary wave (cyclone) which is developed also in a field of pressure and velocity of a wind. If a solution of a squall storm goes into the four-dimensional approach then this solution is supported by a flux to additional pressure fall of air inside a storm supported and stimulated amplification of wind velocity here. As a result, a cyclonic balance inside a storm supported generates a vortexlike compression of the radial distribution of wind velocity inside a squall storm calculated by using the new formulae and equation with radial distribution of the wind velocity inside Texas Tornado Event in 1999 and inside the May 3–10th Oklahoma City Tornado down good correspondence.

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1. Introduction

Research on tornadoes is a very wide and "hot" topic in atmospheric and geophysical sciences. Arsen'yev et al. (2010) have recently reviewed results in this field. New results have been obtained by our team at the Institute of the Earth's Physics, the Russian Academy of Sciences (RAS) in Moscow (Arsen'yev et al., 2010a; Arsen'yev et al., 2010b; Galin et al., 2010). The most significant achievement in the mathematical calculation of the process of occurrence and evolution of a violent tornado of class F5 on the Fujita scale with velocity of wind from 400 up to 514 km/h. The maximum velocity of a wind reaches 500 km/h as an anomalous pressure of about 230 hPa (value in the center of a tornado) (Arsen'yev et al., 2010a,b). A similar event, for



Mathematical Modeling of Structure and Dynamics of Concentrated Tornado-like Vortices: A Review

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Abstract Mathematical modeling is the most important tool for constructing the theory of concentrated tornado-like vortices. A review and analysis of computational and theoretical work devoted to the study of the generation and dynamics of air tornado-like vortices has been conducted. Models with various levels of complexity are considered: a simple analytical model based on the Bernoulli equation, an analytical model based on the vorticity equation, a new class of analytical solutions of the Navier–Stokes equations for a wide class of vortex flows, and thermodynamic models. The approaches developed to date for the numerical simulation of tornado-like vortices are described and analyzed. Considerable attention is paid to developed approaches that take into account the barotropic nature of tornadoes. The first part is devoted to the analysis of models where about the tornado, concerning its structure and dynamics (up to the breakdown) and the conditions for its occurrence (barotropization). Mathematical modeling data are necessary for interpreting the available field measurements while also serving as the basis for planning the physical modeling of tornado-like vortices in the laboratory.

Keywords: concentrated vortices; analytical model; thermodynamic model; numerical calculation; physical modeling

MSC: 80A72; 76D03; 76N10; 82D05



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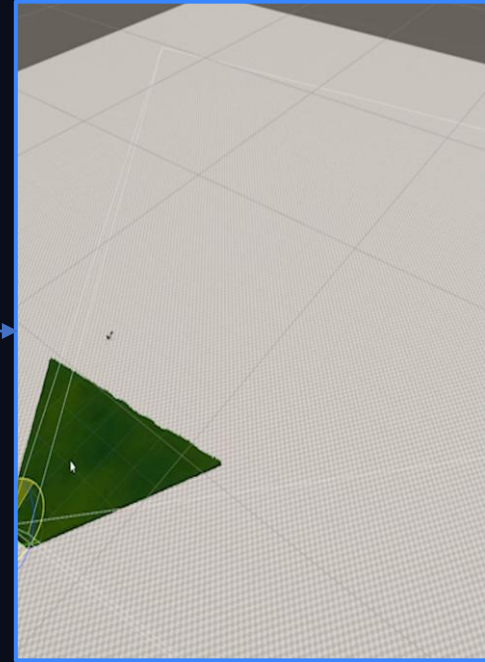
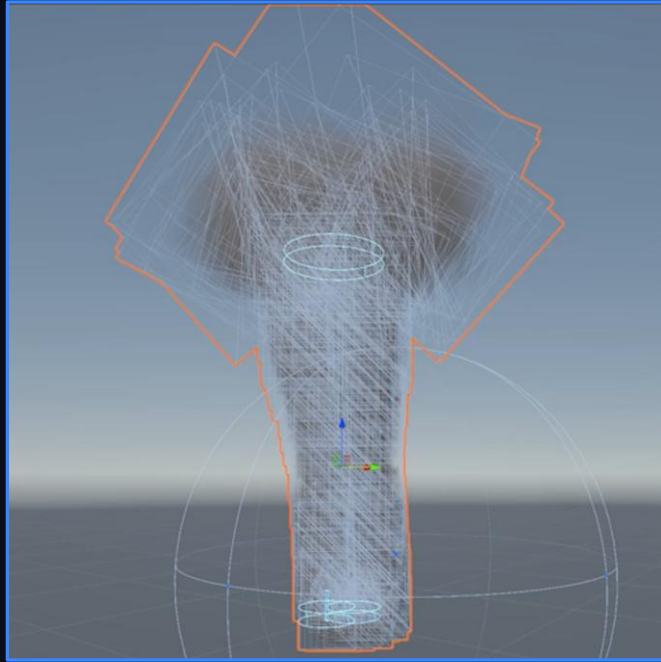
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METHODOLOGY & SYSTEM DESIGN

Built in Unity 6 and Blender using physics-based simulation and cross-platform VR tools



KEY SIMULATION COMPONENTS

Tornado
Physics

VFX Graph
Funnel

Debris
System

3D Spatial
Audio

EF Scale
Controls

DEMONSTRATION



INTERACTIVE CONTROLS

EF Scale (0–5)

Debris Density

Funnel Width

Wind Speed

FINDINGS & IMPACT

ANTICIPATED FINDINGS

Immersive 3D environments significantly improve spatial comprehension of tornado structure and scale **compared to conventional flat representations**. Interactive controls enable users to build intuitive understanding of the relationship between tornado intensity and physical structure.

METEOROLOGY EDUCATION

Spatial understanding of vortex dynamics and tornado structure for students at all levels. Replaces static diagrams with embodied experience.

EMERGENCY RESPONSE TRAINING

First responders and emergency managers can experience tornado scenarios safely, improving spatial decision-making under pressure.

PUBLIC SAFETY COMMUNICATION

Translate abstract meteorological warnings into visceral spatial understanding, improving public risk perception and preparedness behavior.

Contributes to an underrepresented area of research: immersive environments as tools for geographic and environmental visualization