# Vortex of Awesomeness

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DreamWorks Animation

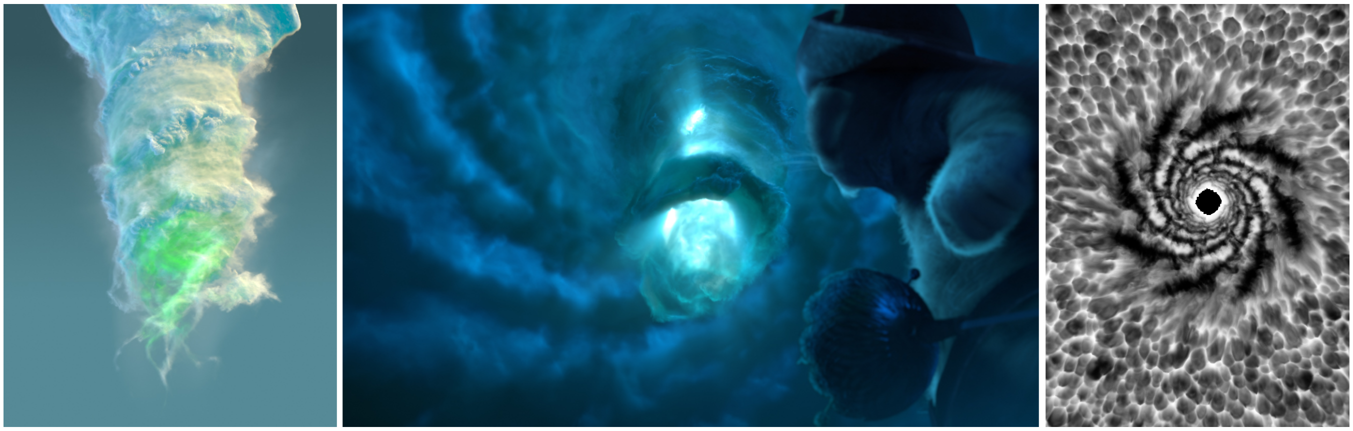

**Figure 1:** *A massive tornado and ominous cloud layer animated using high-resolution fluid simulations and curve-based volume warping: (left) simulated vortex core, (center) final integrated elements, and (right) mammatus cloud layer and swirling transition zone.*

In DreamWorks Animation's *Puss In Boots*, the classic tale of planting magic beans that grow into a giant beanstalk are kicked off with storm clouds and a massive tornado. The production team was asked to produce a sequence where a large-scale, turbulent vortex forms in the sky and descends to the ground. The main elements included the simulated vortex core representing the tornado, a separate simulated cloud layer above, and a transition layer of wispy, swirling clouds. In this talk we describe the techniques we used to setup and control the simulated hero elements, run fast fluid simulations at resolutions as high as 100-200 million voxels, and respond quickly to art direction using curve-based volume warping while iterating on the final look of the scene.

## Tornado

The tornado uses a combination of simulated and procedural techniques. Procedurally generated clouds shape the funnel core and establish the foundation of the effect. We use simulated cloud wisps and turbulent fluid layers to add realism and visual interest. This hybrid approach of combining procedural and simulated elements is a key feature of both the look and art directability of the tornado.

Simulated elements were generated using a fast volumetric fluid solver with the following key features: divergence control, explicit fluid viscosity, and velocity dissipation [Henderson 2012]. The tornado is visualized using an advected scalar field representing cloud density. A key visual feature of the tornado comes from turbulent billows that erupt along the edge of the rotating core. These were created by specifying pockets of localized positive divergence, which creates a local source of velocity and density. The billows fade back into the rotating core once divergence is removed. The location and timing of these events can be controlled precisely by animating the divergence control volume. Turbulence is introduced using a combination of external forces and high-frequency, spatially varying velocity dissipation, both constructed from layers of Perlin noise sampled at different frequencies.

We show that by using a low-dissipation advection scheme and a fixed fluid viscosity to maintain a small-scale cutoff, we are able to achieve good correspondence between simulations at low and high resolution, allowing faster design iterations at low resolution. Using a fast FFT-based Poisson solver we are able to run our most detailed simulations at resolution of $N = 400^2 \times 1000$ in only 10-15 secs per step on a system with dual Intel Xeon X5670 processors. This corresponds to more than one voxel per pixel in the final rendered images.



## Sky Layer

The sky is modeled as a layer of *mammatocumulus* clouds forming a cellular pattern above the tornado. We animate the formation of these patterns by creating a thin layer of cloud density at the top of the grid and evolving the system with negative buoyancy. This simulates the Rayleigh-Taylor instability that forms between fluid layers with different densities, and is also the physical effect used in a traditional cloud tank. We can create sharply defined cellular patterns by using minimal viscosity and a high grid resolution of $N = 1200^2 \times 100$. The size and distribution of the lobes in the mammatus layer are easily controlled by using Perlin noise to create variation in the initial density distribution.

We join the tornado and mammatus cloud layer using a swirling layer of smaller cloud elements that are deformed using animated curves. A total of eight variations were instanced around the core of the tornado. The curve deformation technique allows direct artistic control in shaping the swirl. The curves used for deformation were also used to create a directional force to drive motion within the mammatus cloud layer, creating a more seamless transition.

We found that deformation and procedurally generated elements alone could appear too mechanical, but combining high-resolution simulated elements and animation techniques maintained a highly organic look in the fully integrated results.

## References

HENDERSON, R. 2012. Scalable fluid simulation in linear time on shared memory multiprocessors. ACM Siggraph Digital Production Symposium (DigiPro 2012).