A hybrid numerical framework for study of tornadic wind dynamics

Jun Cao
Toronto Metropolitan University, Canada
jcao@ryerson.ca

A tornado features kinematically combining three major co-existent components, namely, updraft, translation, and rotation, which involve all the three dimensions in space while transient in time. For numerical simulation of a tornado-building interaction scenario, it looks quite challenging to seek a set of physically-rational and meanwhile computationally-practical boundary conditions to incorporate in traditional CFD approaches; thus, little literature can be found, as of today, in three-dimensional (3D) computational tornado dynamics study. Inspired by the development of immersed boundary (IB) method, this study employed the re-tailored Rankine combined vortex model (RCVM) that applies the “relative motion” principle to the translational component of tornado, such that the building is viewed as “virtually” translating towards a “pinned” rotational flow that remains time-invariant at the far field region. This revision renders a steady-state kinematic condition applicable to the outer boundary of a large tornado simulation domain, successfully circumventing the boundary condition updating process that the original RCVM would have to suffer, and tremendously accelerating the computation. Here, this re-tailored RCVM was extended to its 3D version with the aid of logarithm law that describes the vertical flow evolution. Eventually, this tornado model was embedded in an academic high-order finite difference turbulent flow solver, resulting in a practical powerful 3D tornado-building interaction simulation tool. A case study examined the tornadic wind induced loadings on a prismatic building; over all three directions, the vertical force component was found dominant, which effectively suggests the uprooting effect as observed in many reported tornado disasters.