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A philosophy and hierarchy for simulation of non-synoptic winds

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SUMMARY: (10 pt)
This abstract presents a philosophy and hierarchy for simulation of non-synoptic winds. Discussion of this philosophy and hierarchy prioritizes simulation of the flow parameters (e.g., wind profile) in part to determine their importance for wind loading. Flow parameters thought to be relevant for non-synoptic events are presented and methods to incorporate flow parameters (and their ranges) in the simulation are discussed.

Keywords: non-synoptic, transient, simulation, tornado, thunderstorm

1. BACKGROUND

Winds generated from non-synoptic events (i.e., tornadoes and thunderstorms) cause considerable damage in the United States and around the world. The winds are transient, which means that wind characteristics vary significantly in space and time and do not conform to ‘standard’ wind engineering models. Characteristics such as the wind profile, translation of the phenomena and vertical angle of attack have been shown to influence loading on buildings (e.g., Haan et al., 2010). There is a pressing need to simulate these events, but data is very limited in part due to their transience. Given their importance, and the lack of data, the emergence of large simulators and computational methods are going to be integral to better understanding these events and their impacts.

This abstract presents a philosophy and hierarchy for simulation of non-synoptic winds. Based on this philosophy and hierarchy, ‘target’ wind characteristics (i.e., flow parameters) are produced for use in simulation and a method to generate time histories that contain these targets is also discussed.

2. PHILOSOPHY

The philosophy is that simulating the flow parameters a non-synoptic event creates is of higher importance than recreating the phenomenon itself. As an example, generating the ‘nose’ profile shape of downbursts is more important than trying to exactly recreate a downburst or some physical feature (e.g., ring vortex) the properties of which have little or no full-scale validation.

The literature highlights multiple instances where the physical feature or phenomenon itself is not replicated currently. The work in Baker and Sterling (2019) show fundamental scaling relationships are not met for tornado simulation. Downburst simulation lacks little physical basis and does not incorporate microphysics which is a primary driver for downburst generation (e.g., Orf et al., 2014). Physical features are able to be generated (e.g., a ring vortex) but note these features have not been quantitatively validated for similarity. Flow parameters such as atmospheric pressure change on the other hand, have been able to be scaled.

This philosophy is generally how all simulation works at the present time. In the atmospheric boundary layer (ABL), obstacles like barriers, spires and blocks are utilized to generate 'targets' such as a mean wind speed profile and turbulence intensity profile. This **target-based** approach in essence focuses on the flow parameters that are thought or have been determined to be **important to wind loading** and generates them through any method possible.

3. HIERARCHY

The philosophy described above is illustrated by means of a hierarchy in Figure 1. This hierarchy is separated by storm type and each storm type serves as the 'top' of the hierarchy. Other storm types could be included, but in this example only tornadoes and thunderstorms are shown.

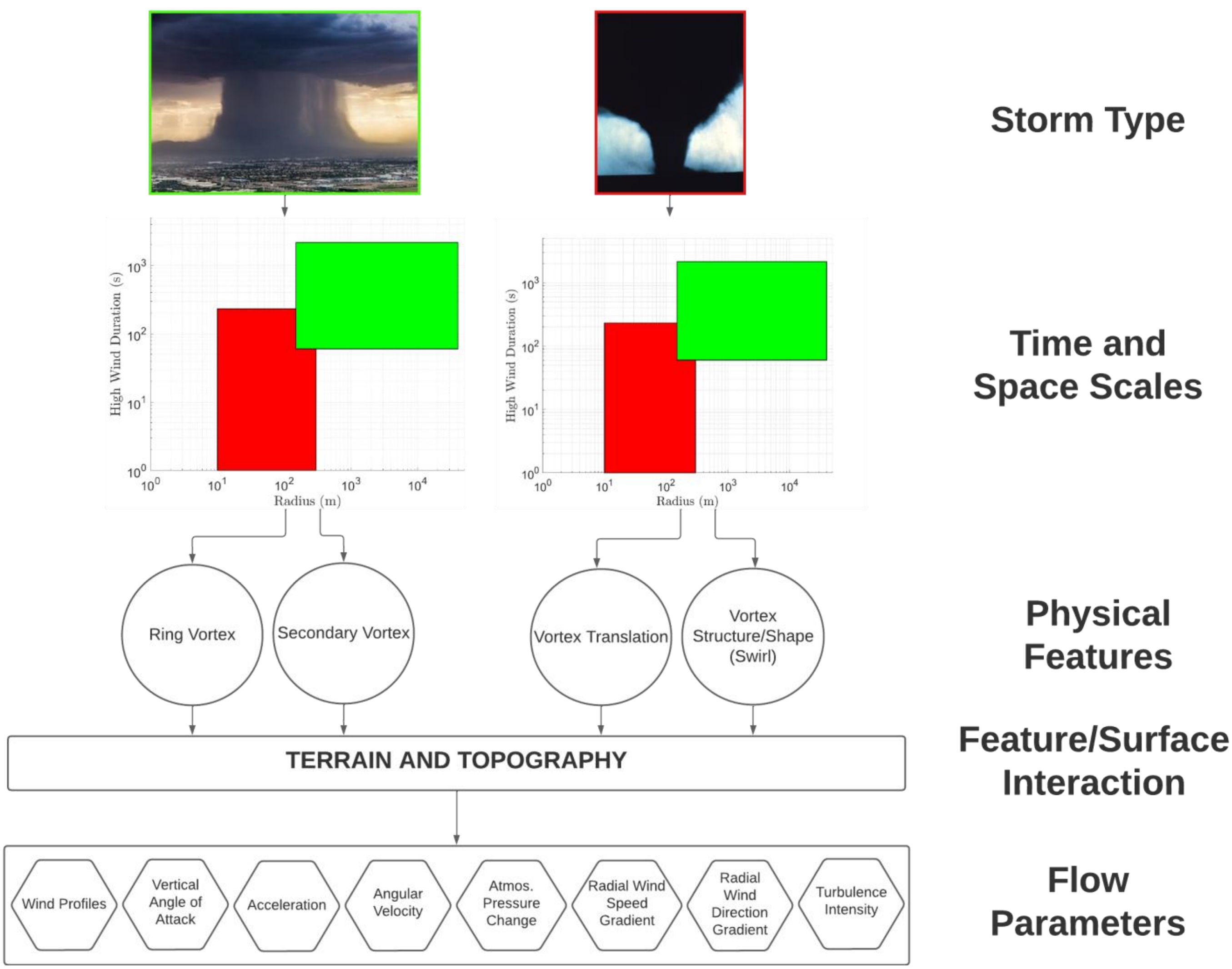

Figure 1. Simulation hierarchy for non-synoptic wind events.

Moving downward in the hierarchy reduces the difficulty in simulation and increases the importance to loading. The flow parameters are also easier to capture in the field and be 'matched' experimentally as you move downward in the hierarchy. A potential goal is working to 'move up' the hierarchy but to start at the bottom and work up based on the information available.

As an example of how the philosophy and hierarchy could work, translation speed of tornadoes has been found to be an important parameter in wind loading from tornado simulator studies. Translation speed modifies both the direction and intensity of the wind at different radial locations relative to the tornado center ($d\theta/dr$ and dU/dr respectively). Instead of trying to move a vortex at realistic translation speeds relative to vortex-induced speeds (which is difficult to do) replication of $d\theta/dr$ and dU/dr would be the first priority. Potential values of these and other parameters are discussed in Section 4. Cermak and Akins (1977) placed and angled plate in the wind tunnel to modify dU/dr and found differences in loading from ABL conditions. Trying to generate a vertical vortex (i.e., physical feature) would be an attempt to move up the hierarchy. In specialized tornado simulators which create a vertical vortex through a combination of inflow and outflow, three-dimensional flow can be created in which the angle of attack changes over a building dimension (e.g., $d\theta/dx$). This parameter would likely affect wind loading and in a largely one-dimensional flow in an ABL tunnel would have some difficulty being replicated. Ways to generate vertical vortices in ABL wind tunnels can and should be explored.

Ultimately, comparisons of experimental data to full-scale are needed to see if it the hierarchy is valid. At the very least, these comparisons will allow for identification of the most important physical features to *wind loading*. For example, if say a certain physical feature is absent from the simulation while the flow parameters are not, any differences in loading could be attributed to the physical feature.

4. DATA DRIVEN TARGETS

4.1. Target Parameters and Parameter Ranges

Section 3 and Figure 1 highlight specific flow parameters that could be utilized in the hierarchy. Table 1 shows an expanded list of target flow parameters and parameter ranges by storm type. The dU/dz column says 'Profile' whose targets which are wind speed normalized by a wind speed at a standard height of 10 m are not shown here. The ranges are based off field data (e.g., Lombardo, 2018), analytical models such as the Rankine vortex, existing documents (e.g., ASCE, 2022) and heuristic assessment. The parameter list is non-exhaustive, but an attempt was made to be thorough and include parameters known and/or thought to influence loading on structures. ABL parameters, most of which are approximately 0 when averaged over 10-120 minutes are also included for reference.

4.2. Target Time Histories

In addition to target parameters, there is a strong need to develop target non-synoptic time histories similar to those developed for earthquake and now performance-based wind engineering for ABL/hurricane. Key components of these time histories include but are not limited to: one or more flow parameters that fall within specified ranges, three-dimensional variation similar to the physical phenomena and spatiotemporal scales over which these phenomena occur (which can be scaled). A framework for simulating these time histories is based off, in part, work from Solari (2016) and Kwon and Kareem (2009).

Table 1. Non-exhaustive list of flow parameters separated by storm type

Flow Parameters (Version 2)										
Storm Type	β	$\frac{dU}{dz}$	$\frac{dU}{dt}$	Δp	$\frac{d\theta}{dt}$	$\frac{d\theta}{dr}$	$\frac{dw}{dt}$	V_T	$\frac{dU}{dr}$	R_{max}
Tornado	$\pm 30°$	Profile	$5-40$	$1-100$	$0.05-5$	$0.007-0.09$	$0-30$	$0-30$	$0.6-6.5$	$10-300$
Downburst	$\pm 15°$	Profile	$1-10$	$1-5$	$0.05-1$	?	$0-5$	$0-30$	0.06^+	650^+
***ABL (Ref.)**	≈ 0	Profile	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	N/A	≈ 0	Large

β = vertical angle attack (deg), U = velocity (m/s), z = height (m), t = time (s), p = pressure (mb), θ = horizontal angle of attack (rad), r = radius (m), w = vertical component (m/s), V_T = translation speed (m/s), R_{max} = radius of maximum wind (m)

5. CONCLUSIONS

This abstract presents a philosophy and hierarchy for simulation of non-synoptic winds. The philosophy discussed prioritizes the matching of flow parameters but a goal could be simulation of the entire event. The philosophy allows for boundary layer wind tunnels to simulate these targets and provides a framework for investigation of differences in wind loading from non-synoptic events. A non-exhaustive list of flow parameters and their ranges in non-synoptic events are presented and incorporation of these parameters in target time histories is underway. Ideally, integration of computational, experimental and field studies will help to refine the concepts discussed in this abstract.

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