NOTES AND CORRESPONDENCE

Comments on "Proposed Conceptual Taxonomy for Proper Identification and Classification of Tornado Events"

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Agee and Jones (Agee and Jones 2009, hereafter AJ09) have introduced a tornado classification scheme that they propose be adopted by the National Oceanic and Atmospheric Administration (NOAA) in order to improve the U.S. tornado database and aid climatological analyses and detection of climate change impacts on tornado occurrence. AJ09's classification scheme identifies tornadoes as being associated with a supercell (type I), a quasilinear convective system (QLCS; type II), or neither a supercell nor a QLCS (type III). Fifteen tornado subclassifications (Ia–Ic, IIa–IIf, and IIIa–IIIf) are included as well. We appreciate AJ09's attempt to refine U.S. tornado recording, but we are skeptical that their proposal will improve the U.S. tornado database. Although there are well-known limitations with the historical and even contemporary U.S. tornado database (e.g., Verbout et al. 2006; Doswell et al. 2009), our opinion is that there are major problems with AJ09's proposed tornado classification scheme.

The aspect of the proposed classification system with which we are most uneasy is the attempt to identify dynamical differences between tornado types, particularly the subclassifications. For example, AJ09's scheme considers (see their Table 1) whether or not a vortex sheet is present, whether vorticity is tilted by a downdraft, the degree to which horizontal vorticity is augmented by baroclinity, and the amount of stretching of preexisting boundary layer vertical vorticity. Although it would be wonderful to be able to record the dynamical circumstances behind every tornado, there are grave limitations in our ability to ascertain the dynamics responsible for tornadogenesis using operational data only [e.g., Weather Surveillance Radar-1988 Doppler (WSR-88D), aviation routine weather reports (METARs), and satellite]. One cannot even compute vorticity from such datasets, let alone evaluate its forcings. Assigning dynamical cause and effect is not always straightforward even when field experiment data are obtained, and such datasets are extremely rare. In 2009, for example, such a dataset was obtained for only one of the O(1000) tornadoes occurring on average in the United States each year.[1]

Classification problems (classification as types I, II, or III, let alone subclassification) would be posed by supercells that are embedded within QLCSs (AJ09 state on p. 616 that tornadoes developing in such situations would be type II, but there is no apparent dynamical basis for this choice) and supercells that produce landspouts (how will one assess whether preexisting vorticity was amplified by stretching alone, or whether a downdraft was responsible for the development of circulation at the surface?). Moreover, even tornadoes such as waterspouts/landspouts are often associated with mesocyclone radar signatures once the rotation that is amplified

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[1] A tornado near LaGrange, Wyoming, on 5 June 2009 was well sampled by mobile radars and a variety of in situ probes during the Second Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2).

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in the boundary layer has had sufficient time to be advected upward to a sufficiently high altitude to be sampled by the radar; the typical definition of a ''mesocyclone''—a deep, persistent column of significant rotation (e.g., Doswell and Burgess 1993)—does not specify how the rotation arises. Thus, mesocyclone detection alone may not be enough to distinguish type I tornadoes from type II and III tornadoes.

We also do not believe that gustnadoes should be included in tornado records, and we find AJ09's claim on p. 610 that ''most meteorologists would likely say that every vortex event associated in any manner with any type of thunderstorm or convective cloud is a tornado'' debatable. Though Alfred Wegener's tornado definition from 1917 is probably still the most practical (cf. Dotzek 2003), the American Meteorological Society's glossary definition (Glickman 2000) would indeed also permit many dust devils or gustnadoes to be counted as tornadoes, because it encompasses vortices at the ground merely *underneath* a cumuliform cloud (not necessarily cumulonimbus) and does not require *contact* with that cloud. In any event, gustnadoes are a practically ubiquitous aspect of strong convective outflows, for both severe and nonsevere progenitor convection.

In addition to the difficulties with trying to determine the dynamics responsible for tornadogenesis, we are also uncomfortable with the implication that the dynamics of tornadogenesis differ from one proposed tornado type to another (we believe that classification schemes are most useful when they discriminate between fundamentally different dynamical processes). For example, how can it be known that the dynamics of type I tornadoes always differ from the dynamics of type II tornadoes? Not only are supercells occasionally embedded within QLCSs, but many other vortices within QLCSs might be dynamically similar to the vortices that become tornadoes within supercell mesocyclone regions. For example, the counterrotating bookend vortices in a bow echo that straddle a downdraft maximum share similarities with the counterrotating vortices that straddle the rear-flank downdraft and hook echo in a supercell. It is tempting to speculate that the basic process of generating baroclinic vorticity within a cold pool, with subsequent lifting of the baroclinic vortex lines out of the outflow to produce a couplet of vertical vorticity, can operate on a range of scales from the line-end vortices of a QLCS to supercells. In fact, this is precisely what is suggested by the vortex line configurations documented in recent dual-Doppler observations and numerical simulations (Straka et al. 2007; Markowski et al. 2008; Markowski and Richardson 2009).

Though the three primary classifications appear to imply different dynamical processes responsible for tornadogenesis, it is unclear to us whether or not all of the tornado subclassifications are intended to identify different dynamical processes. Types Ia (tornadoes associated with a ''discrete supercell with mesocyclone''), Ib (tornadoes associated with a ''discrete minisupercell''), and Ic (tornadoes presumably due to shallow supercells in landfalling tropical cyclones) are almost certainly not dynamically different (there also is no guidance given for what constitutes a ''minisupercell''). The subclassifications of type II tornadoes may or may not have dynamical differences; recent simulations and field observations have suggested multiple mechanisms for mesovortex development in QLCSs (Trapp and Weisman 2003; Atkins et al. 2005; Wakimoto et al. 2006). Large ambient vertical vorticity is cited in the descriptions of both type Ic and IIf (QLCS tornadoes in a landfalling tropical cyclone) tornadoes, yet there is no evidence that these tornadoes arise from the concentration of ambient vertical vorticity (the ambient *horizontal* vorticity in landfalling tropical cyclone environments is even larger).

The dynamical differences among the type III subclassifications, if such differences are presumed by AJ09, are also unclear. We are skeptical that there are dynamical differences among types IIIa (''cumuliform cloud . . . with intense local updraft that converges and stretches vertical vorticity . . .''), IIIb (''similar to IIIa, but over water''), and IIIc (AJ09 refer to these as ''cold-air funnels'' on p. 616). In general, AJ09 appear to make a general distinction between tornadoes and waterspouts (p. 609) just based on the different underlying surface—we believe this is an outdated notion with little justification. Moreover, the misocyclones that have been documented to preexist such nonmesocyclonic tornadoes (Wakimoto and Wilson 1989; Roberts and Wilson 1995) likely originate from the same horizontal shear instability that is invoked as the mechanism for type IIId and IIIe tornadoes (Lee and Wilhelmson 1997). We do not understand why a type IIIf tornado (an anticyclonic tornado that forms near a stronger cyclonic tornado) necessarily would be dynamically different from a type Ia tornado if the type IIIf tornado develops beneath a supercell updraft in proximity to the rear-flank downdraft. We believe that it is probably also unwise to assume that type III tornadoes always form beneath weaker cumuliform clouds (p. 616); many waterspouts/landspouts are observed to form beneath rapidly growing cumulus congestus clouds (many of these likely have updrafts as strong as the updrafts associated with type I tornadoes).

Owing to the aforementioned issues raised above, we are unconvinced that AJ09's proposed classification would be a practical or valuable enhancement of the U.S. tornado database or other tornado databases worldwide. There may be other characteristics of the U.S. tornado database that would indeed benefit from a certain revision of current procedures, so AJ09's general approach to think of improvements to tornado recording by NOAA is indeed justified and of merit. The U.S. tornado record has a number of well-known problems, such as the fact that many tornadoes that occur in rural areas and do no or only little damage are assigned a default rating of F0 rather than remaining unrated or, equivalently, being rated ''F-unknown'' (using the ''Enhanced Fujita scale,'' EF-unknown instead of a default EF0). Another issue with long-term U.S. tornado records, particularly in using them to relate tornado trends to climate change as envisaged by AJ09, is shifting standards in tornado ratings (Verbout et al. 2006; Brooks and Dotzek 2008), whether intentional (e.g., the introduction of the EF scale) or unintentional [e.g., the National Weather Service (NWS) implementation of ''Quick Response Teams'' to survey damage that potentially exceeds EF3]. All of these issues are outside the scope of our comments and already have been discussed at length by Doswell et al. (2009) and Dotzek (2009). We believe that these issues impact our ability to assess long-term tornado trends and the possible effects of climate change much more adversely than does the lack of a tornado classification system like the one proposed by AJ09.

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