STANDARDIZING THE DEFINITION OF A "PULSE" THUNDERSTORM

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Table ES1. Survey of pulse-referencing research and educational documents published between 1979 and 2015. Although more texts reference pulse thunderstorms than those shown here, they do not include enough descriptive detail to yield useful insight.

No.	Source	Type of source	Purpose	Excerpt
1	Wilk et al. (1979)	FAA training document	Radar detection of thunderstorm	No longer available, but similar to Burgess and Lemon's (1990) definition (L. Lemon 2015, personal communication).
2	Doswell (1985)	NOAA technical memorandum	Severe thunderstorm identification	"Perhaps the most common severe weather producer among the secondary classes is the so-called pulse storm. Such a storm…closely resembles an ordinary non-severe thunderstorm cell in many respects…In essence, it is a cell which, for some reason, possesses **briefly** an intense updraft. This strong updraft lasts only a short time, during and immediately after the storm produces a short episode of severe weather and then dissipates (hence, its name)."
3	Burgess and Lemon (1990)	Textbook	General meteorological education	"It closely resembles the ordinary thunderstorm with a few notable exceptions. In many cases, the thunderstorm cell that becomes severe is a member of an ordinary cell complex although it can exist in isolation. The intense updraft is relatively short-lived, taking the form of a single bubble or pulse. Thus, the first-echo height (6–9 km) is higher than for the ordinary cell. The area of more intense reflectivities (50+ dBZ) is also much higher, persistent, and maintains continuity with descent to the ground. As the core descends to the ground, high winds (often classic downbursts) and brief large hail may occur. The duration of severe weather and the total storm lifetime are short. Succeeding storm cells in the pulse storm are ordinary… The pulse storm environment is frequently characterized by low shear, relatively deep moisture, and high instability."

Table ES1. Continued.				
No.	**Source**	**Type of source**	**Purpose**	**Excerpt**
4	Stewart (1991)	NOAA technical memorandum	Severe thunderstorm identification	"a technique has been proposed to assist operational meteorologists in forecasting the gust potential of air-mass (pulse-type) thunderstorms in near real-time situations."
5	Howard et al. (1997)	Journal article	Radar performance	"The idealized reflectivity structure we used depicts the life cycle of a 'pulse'-type, single-cell thunderstorm (Doswell 1985). Pulse-type storms are common in moderately unstable, weakly sheared environments and have short-lived, strong updrafts. We focus primarily on this type of storm due to their frequency in central Arizona and because they often produce severe, short-lived downburst winds…"
6	Cerniglia and Snyder (2002)	NWS technical attachment	Severe thunderstorm identification	"The [radar] data were sorted into storm types to extract severe and non-severe pulse storms. All events that were organized along a line, squall line, front, bow echo, or that were tornadic, were eliminated. Storms that contained a mesocyclone, whether algorithm or user defined, at any point prior to the severe report were also eliminated."
7	Fowle and Roebber (2003)	Journal article	Model verification	"The second stage was the verification of convective mode. Observed storms were categorized as linear, multicellular, or isolated (pulse storms)…The isolated storm mode was defined by a reflectivity area greater than 40 dBZ that had a spatial coverage of less than 500 km^2."
8	Smith et al. (2004)	Journal article	Severe thunderstorm identification	"This makes severe outflows from these 'pulse' thunderstorms difficult for weather forecasters to issue warnings for…"
9	Beasley et al. (2008)	Conference paper	Lightning/electric field analysis	"Because isolated, air-mass, or 'pulse' thunderstorms are the most likely type to develop…"
10	Guillot et al. (2008)	Conference paper	Storm mode classification	"'pulse storms', defined for this study as any thunderstorm that is strong or severe but does not possess a mesocyclone and rotating updraft."
11	Miller and Petrolito (2008)	NWS technical attachment	Severe thunderstorm identification	"This paper illustrates how the WSR-88D All-Tilts Display was used to make a Severe Thunderstorm Warning (SVR) decision for a pulse thunderstorm…" "A pulse severe thunderstorm developed rapidly over central Edgefield County, South Carolina…"
12	Ashley and Gilson (2009)	Journal article	Lightning fatality analysis	"Unorganized, pulse-style convection includes storms that do not fit the above MCS or supercell definitions and subjectively appear to lack any spatial or temporal organization in reflectivity data."
13	Lakshmanan and Smith (2009)	Journal article	Storm cell identification	"difficult to issue tornado warnings when the tornadoes are associated with short-lived pulse storms…"
14	Radar signatures for severe convective weather (UCAR 2010)	COMET MetEd	General meteorological education	"Multicellular pulse thunderstorms: in weaker deep layer shear environments storms tend to be multicellular in nature with several collocated updrafts in different stages of development. At any one scan it may seem as though one of the pulse storms is a single cell with one dominant reflectivity signature, but it may merely be one or more short-lived cells developing and dissipating within a scan or two (~20 minutes)."

Table ES1. Continued.				
No.	**Source**	**Type of source**	**Purpose**	**Excerpt**
15	Markowski and Richardson (2010)	Textbook	General meteorological education	"Thus, single-cell convection tends to occur near and shortly after the time of maximum daytime heating (when CIN [convective inhibition] is smallest and CAPE [convective available potential energy] is largest) and tends to dissipate quickly after sunset. It only occasionally produces hail or wind gusts that could be characterized as severe. When severe weather is produced, it is generally of the pulse variety—short lived, usually marginal (e.g., a brief wind gust above 25 m s^{-1}), and difficult to issue warnings for."
16	JetStream—Online School for Weather (NWS 2016a)	Online tutorial	General meteorological education	"Also called a 'pulse' thunderstorm, the ordinary cell consists of a one-time updraft and one-time downdraft."
17	Frugis and Wasula (2011)	NWS technical attachment	Severe thunderstorm identification	"Storms were classified as pulse (ordinary), multicell or supercell."
18	Lack and Fox (2012)	Journal article	Storm mode classification	"An important distinction is made between air mass thunderstorms and pulse thunderstorms. Although similar in structure, the pulse thunderstorm has characteristics that allow for the rapid formation of hail and/or the possibility for a severe downburst."
19	Tropical severe local storms (UCAR 2012)	COMET MetEd	General meteorological education	"The single cell or ordinary pulse thunderstorm evolution can be described by three stages: *cumulus, mature*, and *dissipating*."
20	Bluestein (2013)	Textbook	General meteorological education	"Storms that behave like ordinary cells and consist of only one cell are sometimes referred to as 'pulse'-type, single-cell convective storms."
21	A convective storm matrix: buoyancy/shear dependencies (UCAR 2013)	COMET MetEd	General meteorological education	"Ordinary cells that produce these bursts of severe weather are often referred to as pulse storms."
22	Miller et al. (2015)	Journal article	Storm mode classification	"single-cell thunderstorms capable of producing severe weather, also termed pulse storms…"
23	Stull (2015)	Textbook	General meteorological education	"Air-mass thunderstorms that produce short duration severe weather (heavy precipitation, strong winds, lightning, etc.) during the mature stage are called pulse storms."

Table ES2. Entries for common disorganized convection terms taken from the NWS (2016b) and AMS (2016) glossaries.			
No.	**Source**	**Term**	**Definition**
1	AMS *Glossary of Meteorology*	Ordinary cell	"The most basic component of a convective storm, consisting of a single main updraft that is usually quickly replaced by a downdraft once precipitation begins. Ordinary cells are especially observed in environments with weak vertical wind shear, and typically have lifetimes of 30–50 minutes. Ordinary cells are the primary component of multicell storms."
2	NWS Glossary	Single-cell thunderstorm	"This type of thunderstorm develops in weak vertical wind shear environments. On a hodograph, this would appear as a closely grouped set of random dots around the center of the graph. They are characterized by a single updraft core and a single downdraft that descends into the same area as the updraft. The downdraft and its outflow boundary then cut off the thunderstorm inflow. This causes the updraft and the thunderstorm to dissipate. Single cell thunderstorms are short-lived. They only last about ½ hour to an hour. These thunderstorms will occasionally become severe (¾-in. hail,* wind gusts in the excess of 58 miles an hour, or a tornado), but only briefly. In this case, they are called Pulse Severe Thunderstorms."
3	NWS Glossary	Airmass thunderstorm	"Generally, a thunderstorm not associated with a front or other type of synoptic-scale forcing mechanism. Air mass thunderstorms typically are associated with warm, humid air in the summer months; they develop during the afternoon in response to insolation, and dissipate rather quickly after sunset. They generally are less likely to be severe than other types of thunderstorms, but they still are capable of producing downbursts, brief heavy rain, and (in extreme cases) hail over ¾-in. in diameter. Since all thunderstorms are associated with some type of forcing mechanism, synoptic-scale or otherwise, the existence of true air-mass thunderstorms is debatable."
4	NWS Glossary	Pulse storm	"A thunderstorm within which a brief period (pulse) of strong updraft occurs, during and immediately after which the storm produces a short episode of severe weather. These storms generally are not tornado producers, but often produce large hail and/or damaging winds…."
5	NWS Glossary	Pulse severe thunderstorms	"Single cell thunderstorms which produce brief periods of severe weather (¾-in. hail,* wind gusts in the excess of 58 miles an hour, or a tornado)."

* Since the establishment of its glossary, the NWS increased the severe hail criterion from 0.75 to 1.0 in.

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