Reviewer #1

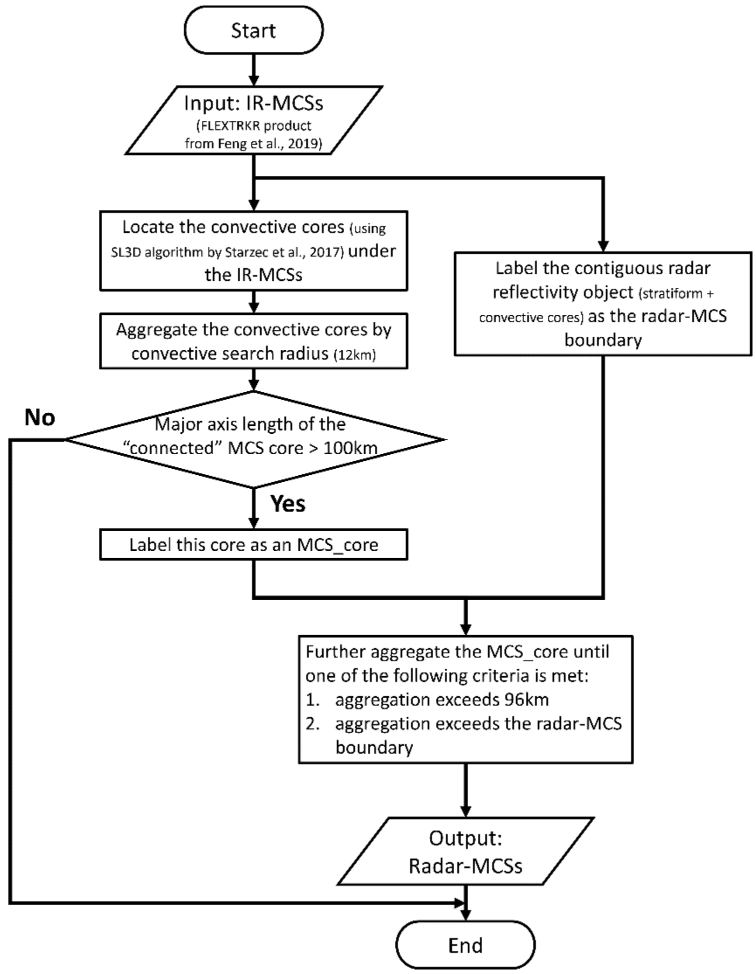
Summary: The authors use collocated ground based radar MCS features and geostationary satellite tracked MCSs to follow MCSs over the United States throughout their lifetimes and define their life stage. Collocated observations of hail and tornadoes are collocated to each MCS to study the climatological occurrence of MCS produced severe hail and tornadoes on a monthly and per lifecycle stage basis. These are also compared with observed hail and tornadoes from all events to determine the percent contribution to the occurrence of these hazards by MCSs. The paper is well written and thorough, and, for the most part, logically organized. It would benefit from clarification of a few points and additional discussion of the methods used. I therefore recommend minor revisions.

We thank the reviewer for recognizing our efforts and providing helpful suggestions and comments. Our point-by-point responses are provided as follows.

General Comments:

1. The methods section is lacking in a few key details, mostly descriptions of the datasets. This section should be expanded to include more technical details about how the datasets used are produced and how the derived quantities are defined. Specific examples are provided in the Specific Comments section.

Technical details have been added to section 2 as suggested. Figure 1 has been modified accordingly.



2. The introduction feels a bit jumbled and tends to jump from discussing hail to tornadoes and back within the same paragraph. It would read more smoothly and thus make the points of the introduction better if it were reorganized to discuss the findings of previous studies about hail and tornadoes separately, rather than concurrently.

The introduction has been modified to discuss hail and tornadoes separately.

Hail can be produced by a variety of convective organizations (Trapp et al. 2005; Gallus et al. 2008; Smith et al. 2012), commonly associated with supercell thunderstorms (Moller et al., 1994; Prein and Holland, 2018), but is also found in multicellular storms (Nelson 1987; Kennedy and Detwiler, 2003), pulse storms (isolate, short-lived thunderstorms forming in a weakly forced environment; Miller and Mote, 2017), and mesoscale convective systems (MCSs; Houze, 2004). As a result, supercells are typically considered the most prolific producers of hail relative to other modes of convection, such as ordinary cells, multi-cells, MCSs, and unclassifiable types of convection (Duda and Gallus, 2010). The environments that support hail-producing storms show strong and persistent updrafts (Blair et al., 2017), large convective available potential energy (CAPE), 0-6 km bulk wind shear (Craven et al., 2004), as well as 0-3 km storm-relative helicity (Prein and Holland, 2018), which are also observed within MCSs. Past studies on the relationship of hail with MCSs focused on quasi-linear convective systems (QLCSs; a subset of MCSs). Derived from a 22-year (1996-2017) observational dataset, 10% of severe hail events (with hailstone diameter greater than or equal to 1 inch) were attributed to QLCSs over the entire contiguous United States (CONUS) by Ashley et al. (2019). Using data from a shorter period (2003-2011), Smith et al. (2012) reported that 0.8% of significant severe hail events (with hailstone diameter greater than or equal to 2 inches) were produced by QLCSs.

Compared to the formation of hail, tornadogenesis may have different environmental conditions including high surface moisture supply and directional wind shear in the lowest 1-km (Rasmussen and Blanchard, 1998; Rasmussen, 2003), which are strongly associated with supercells (Smith et al., 2012; Schumacher and Rasmussen, 2020). As a result, Supercells are also known to be the most significant producers of tornadoes compared to other forms of convection, accounting for over 90% of tornado deaths in the contiguous United States (CONUS; Schoen and Ashley 2011; Brotzge et al. 2013). However, environments conducive to tornadogenesis are not exclusively limited to the isolated supercells. Some MCSs might produce tornados as revealed by observations (Nielsen and Schumacher, 2020) and numerical simulations (Nielsen and Schumacher, 2018). For example, a moist boundary layer with large, low-level vertical shear may induce supercell-like rotation within MCSs (Schumacher and Rasmussen, 2020). Past studies have attributed 13.8% to 21% of all tornadoes to QLCSs (Ashley et al., 2019; Smith et al., 2012). For significant tornadoes (with the Enhanced Fujita scale [EF] rating of 2-5), 20% of those events were linked to QLCSs from 2000 to 2008 (Grams et al., 2012). For the most extreme case, a QLCS has been reported for the unprecedented production of 76 tornadoes on 27 April 2011 (Knupp et al., 2014).

MCSs are considered the largest form of convective clouds (Houze, 2004) with spatial scales of 100s km and a lifespan of several hours to beyond a day (Houze, 2015; Feng et al., 2018, 2019). MCSs are commonly observed in many regions of the Earth (Wang et al., 2019a; Houze et al., 2019; Feng et al. 2021) and significantly impact precipitation, radiative forcing, and general circulation (Houze, 2018). Hazard-producing supercells, multi-cells and pulse storms can grow upscale and merge with nearby storms into an MCS. In addition, new quasi-linear or clustered convective features can be generated near pre-existing boundaries such as fronts or outflow boundaries, convectively generated gravity waves, or mesoscale convective vortices (Schumacher, 2009) within MCSs, and subsequently produce hail and tornadoes.

Specific Comments:

1. Line 27: The references of Moller et al 1994 and Nelson 1987 are quite old. It would be better to also include some newer references.

Newer references of Prein and Holland, 2018 and Kennedy and Detwiler, 2003 have been added.

Prein, A. F., and Holland, G. J.: Global estimates of damaging hail hazard. Wea. Climate Extremes, 22, 10–23, https://doi.org/10.1016/j.wace.2018.10.004, 2018.

Kennedy, P. C., and Detwiler, A. G.: A case study of the origin of hail in a multicell thunderstorm using in situ aircraft and polarimetric radar data. J. Appl. Meteor., 42, 1679–1690, doi:10.1175/1520-0450(2003)042<1679:ACSOTO>2.0.CO;2, 2003.

2. Line 86 “variety of sources”: Please include some examples. Trained spotters? Automated stations?

Examples are provided as ‘a variety of sources including local National Weather Service (NWS) services, public storm spotter networks, media reports, etc.’

3. Line 88 “Both hail and tornado reports are treated as point events…”: This is an example of a definition that needs further clarification. If the tornado strengthens, or the hail size increases, do you use the maximum or the initial strength/size? If the maximum, is the time and location still counted as the start time?

Clarification has been added as ‘Note that the data do not account for the temporal evolution of the hail and tornado events (i.e., the location and magnitude of the event was reported at its maximum intensity [National Weather Service, 2021]). An MCS could have multiple hail and tornado events and each event is distinguished.’

4. Line 88: How does the hail/tornado database determine if reports (especially hail) are continuous or if the hail stopped and started again? I.e. are there MCSs that have multiple hail point events associated with them and if so, is each event distinguished?

As clarified above, temporal evolution of hail and tornado events are not considered with the SPC reports. Yes, an MCS could have multiple hail and tornado events and each event is distinguished. This is also clarified now.

5. Line 96 “poorly identified”: Consider rewording this statement. This makes it sound like MCSs are rare and hard to detect, which is not the case.

This sentence has been rewritten as ‘there is a lack of an agreement regarding the specific observed variables and thresholds employed in the identification of MCSs.’

6. Line 106 “multiple properties”: Please provide examples if you want to keep this amount of detail (see next comment).

The details of HA2018a/b have been removed.

7. Line 124 “convective cores defined by…”: Why is the HA2018 method described in such detail if you are using S2017? Please either justify or remove this description.

The details of HA2018a have been removed.

8. Line 135 “maximum radar-MCS boundary”: What is this boundary?

The word ‘maximum’ is confusing and thus removed. Clarification has been added as ‘are marked as the radar-MCS boundary (i.e., the object that encloses the contiguous reflectivity objects).’

9. Line 147 “MCS dataset (hourly): Why is the MCS dataset limited to hourly resolution? Computational limitations? Or is one or more of the components of the dataset produced by others (please make this clearer if this is the case)?

It is the limitation of existing dataset used in FLEXTRKR. Both the 3D GridRad radar data and the Stage IV precipitation data used to create the MCS dataset were only available at hourly resolution at the time of their creation (Feng et al. 2019). Clarification has been added as ‘since there is a significant time difference between the MCS dataset (hourly; the temporal resolution of FLEXTRKR product that this study is based on) and the hazard reports (in minutes), it is critical to carefully examine how to match the two datasets temporally.’

10. Line 153 “missing rate”: It’s not clear what you mean by this or why it would decrease with decreasing time.

The missing rate has been defined in the previous sentence.

The missing rate decreases with decreasing ‘time interval within which the high-resolution hazard reports are matched to the hourly MCS dataset’ not ‘time’. Clarification has been added.

11. Line 166 “within the radar-MCS boundary but outside the MCS-core”: Are these events related to the temporal offset of the hail/tornado and radar observations? I.e the hail or tornado was produced by the core, but the core is moving rapidly enough to not be over this location at the radar-MCS timestamp?

We thank the reviewer for pointing this out. Clarification has been added as suggested. ‘It is important to note that the temporal offset between hazard reports and radar observations is not taken into account in this classification. Hence, instances of hail and tornadoes produced by fast-moving convective cores at sub-hourly scale are labelled as non-MCS-related or invalid records at the radar-MCS timestamp. It is also possible that spatiotemporal inaccuracies in the hazard report data (e.g., human-report errors, Trapp et al. 2006; Allen and Tippett, 2015) may affect the matching of the hazard reports and the radar features.’

12. Line 167 “reports without valid radar coverage”: Does the definition of radar-MCS and the subsequent collocation of the hazard reports to the radar-MCS not already remove these?

Yes, those reports without valid radar coverage are already removed. This sentence has been removed.

13. Lines 231-236: Latitude definitions would be helpful here to those not familiar with US geography.

Latitude definitions have been added as suggested. ‘’

14. Line 355-356 “severe hail to significant sever hail”: Please define (or remind of the definition) the sizes for these two categories

Reminder of the definition has been added.

Eastern U.S. (EUS; 110°W to 85°W)

Central U.S. (CUS; 85°W to 70°W)

Technical Corrections:

1. Line 49 “rotate”: rotation

Corrected as suggested.

2. Line 99 “Erroneous”: erroneous

Corrected as suggested.

3. Line 169 “sever”: severe

Corrected as suggested.

4. Line 323 “severe hail event/tornado at”: severe hail event/tornado, respectively, at

Corrected as suggested.

5. Line 351 “hazard”: hazards

Corrected as suggested.