NOAA Storm Events in Literature

```r
library(noaastormevents)
library(tidyverse)
library(viridis)
library(lubridate)
library(dendextend)
library(kableExtra)
events_2019 <- create_storm_data(date_range = c("2019-01-01", "2019-12-31"))
```

Introduction

[BA: I absolutely agree with your points here. These will make a nice Intro. Regarding your question about distinguishing this from the Gall paper, I think our key contribution will be showing how many of these concerns/mechanisms for bias exist specifically in the NOAA Storm Events database. They more used examples from other studies that illustrated some of the biases. We can really hone in on how they play out in the Storm Events database specifically. I've added an Issue on the GitHub page suggesting one new analysis we can do for long-term trends. I'll add some more as I go through the draft as I think of any.

Also, I love the point you have here about understanding the quirks. Disaster databases aren't perfect reflections of when and where severe weather events happened. I don't think that they ever will be (at least not in the near future, and we certainly can't go back to fix records of past events to be perfect, although there have been some helpful re-analysis projects like Chris Landsea's reanalysis of hurricanes that try to make the data more consisent over time [and this would be a nice example to add to the temporal bias section! I've added an Issue on this.])

I also strongly agree with the idea that, if we know the quirks, we can build tools to help address them. Bias correction is one thing that's been done to try to address long-term temporal bias in tornado studies. This might be an example for us to use. Also, even having the tools to *get* the data is helpful. We might want to frame the "tools" idea in two parts: (1) tools to access and explore the data (which we've made through the package) and (2) tools to help adjust or account for the mechanisms that might otherwise lead to bias (we don't have these in the package yet, but this could be room for future development.)]

Opening

Severe weather events currently cause extensive monetary loss, property and crop damage, interruptions in commerce, and human injury and fatality. Since 1980, the US has experienced 273 weather and climate disasters that each left over $1 billion in damages (Environmental Information, n.d.). In total, these events cost the US over $1.790 trillion and caused 14,223 deaths (Environmental Information, n.d.).

Scientists expect the impacts of weather events to worsen over time as a result of climate change. For example, the increasing presence of greenhouse gases in the atmosphere leads to increasing annual and extreme temperatures. Extreme temperatures lead to a wide range of health complications. Extreme heat can lead to heat cramps, heat exhaustion, heatstroke, and hyperthermia, while extreme cold leads to hypothermia and frosbite (Crimmins and L. Ziska 2016). Extreme temperatures also exacerbate health conditions related to cardiovascular disease, respiratory disease, cerebrovascular disease, and diabetes (Crimmins and L. Ziska

2016). The continually increasing extreme temperatures will increase the number of temperature related illnesses and deaths in the US per year.

Climate change is also projected to increase the number and severity of extreme natural disasters. In specific, scientists expect the number of naturally ocurring wildfires to increase (Crimmins and L. Ziska 2016). Wildfires emit particulate matter and ozone precursors which decrease air quality. Low air quality harms the human respiratory and cardiovascular systems and decreases overall well being and productivity. Other natural disasters threaten physical and mental health resulting from "damage to property, destruction of assets, loss of infrastructure and public services, social and economic impacts, environmental degradation, and other factors" (Crimmins and L. Ziska 2016).

[BA: This is great. As we draft this, we will want to make sure we aren't too negative about the data—these are huge and helpful databases, that have taken loads of work to collect. However, the process of recording this data is evolving, and our technologies are advancing, which are all very good things but which leave remnants in the data that researchers who want to use it need to understand to use it appropriately.

Also, it we want to focus our opening on one direciton, I think the key one you've identified is "it is very important to understand how hazards impact humans" (health, agriculture, commerce, etc.). I think this would be a great focus for the opening. It's nice and broad, and we could talk a bit about how anticipated changes in patterns of these hazards is expected with climate change, and how this, in combination with the large impacts we see from some events in the present, make it critical that we understand their impacts better, both the scale of those impacts and the pathways from the hazard to the impact. For the present-day impact, we might want to talk some about the billion dollar disasters that the US expereiences each year (see https://www.ncdc.noaa.gov/billions/ for more on this). For future threats, we could look at the US Climate and Health Assessment (https://health2016.globalchange.gov/) and some of the IPCC reports (for example, https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/changes-in-impacts-of-climate-extremes-human-systems-and-ecosystems/).

]

Funnel

The current impacts of disasters combined with the anticipated increases in their severity and occurence make it critical that we understand the patterns and scale of weather hazards. Continued disaster data collection and research will improve scientists' ability to predict these events and avoid such large fallout and loss.

Several organizations currently collect disaster data in the US including the National Weather Service, NCEI, and FEMA. Using this disaster data is common in interdisciplinary research because natural hazards impact several fields of study: economics, epidemiology, atmospheric science, agriculture, etc.

The American Meteorological Society has published various papers analyzing fatalities associated with weather events (Terti et al. 2017, Ashley and Mote (2005), Ashley and Black (2008), Gensini and Ashley (2010)). Ashley and Black examined the cause, spatial distributions, and fatalies caused by nonconvective high-wind events in the US from 1980 to 2005. This study found that fatalies associated with nonconvective high-wind events often occur in boats or vehicles. These fatalities are most likely to occur on the West Coast or Northeast because of extratropical cyclones. These areas of the US have large forests and bodies of water with high population densities that are opportune to being highly affected by high winds (Ashley and Black 2008). Keeping these vulnerabilities in mind, the study outlines possible improvements to high wind warning systems in the areas. These improvements aim to protect people most likely to be injured or killed by nonconvective high-wind events.

Ashley and Mote conducted a similar study examining derecho events in the US from 1986 to 2003 (Ashley and Mote 2005). Derechoes are often overlooked when examining impactful weather events. However, this study revelead how they actually produce damage comparable to tornadoes and hurricanes. Derechoes caused 153 fatalities and over 2,600 injuries over the 18 year span of this study. They were also responsible for as much or more monetary loss than some hurricane and tornado events over the time span. Their study helps to draw attention to this type of weather event in hopes to advance derecho risk assesments.

Both of these studies, in part, used data from the National Oceanic & Atmospheric Administration (NOAA) Storm Events database to conduct research. This database currently contains information on 48 different storms, significant weather phenomena, rare/unusual weather, and other significant meteorological events across the United States. NOAA has been recording weather information since 1950 and storing it csv files for each year. NOAA has changed its recording strategies several times from only recording tornado events starting in 1950 to its current 48 event types. Following these changes, they have reformatted and standardized events types without changing any specific values or details ("Storm Events Database," n.d.).

The database assigns each weather phenomenon with a location, date, event type, event ID, episode ID, property damage estimate, crop damage estimate, county name, state, event narative, and episode narrative. The database categorizes large storms as episodes which contain several individual events. For example, a hurricane will be given one episode ID, and the rain, wind, floods, etc. associated with that hurricane will be given event IDs that fall under that episode.

The US National Weather Service (NWS) collects weather data for NOAA from storm trackers, federal agencies, the media, the public, and several other sources. The NWS then uses this data to create the NOAA Storm Events database that is released as a monthly publication.

This data allows scientists to examine how weather events impact human life and how we can reduce or avoid these impacts. However, storing disaster data does not go without limitations. This is because the process of recording disaster data and the technology we use to do it are constantly evolving. These factors make it incumbant that scientists understand the biases and limitations in weather datasets to use large amounts of data appropately and portray new findings accurately.

[TK: other studies I could include-

- Galateia terti, isabelle ruin, sandrine anquetin, and Jonathan J. Gourley: A SITUATION-BASED ANALYSIS OF FLASH FLOOD FATALITIES IN THE UNITED STATES
- Victor A. Gensini and Walker S. Ashley: An examination of rip current fatalities in the United States]

Challenge

Gall et al. wrote a paper covering six major biases associated with major disaster databases used in the US (Gall, Borden, and Cutter 2009). In our paper, we will focus on the NOAA Storm Events database and investigate the presence of mechanisms that could lead to these major biases in the data. We used the noaastormevents package in R to dissect these issues and examine evidence of bias in several hazard types.

[BA: This is a great start on the Challenge! I recommend that we move the last sentence ("It is important to…") into the end of our funnel. This will nicely set readers up to agree that this study is important and something they want to read. The first sentence ("Gall et al…") could also move to the funnel. So, then, our funnel might be:

(1) To better understand the scale and pathways of human impacts from disasters, we need thorough data recording disaster events; (2) NOAA Storm Events provides this for certain types of disasters in the US (define which ones, plus some more describing the history and content of this database); (3) however, as with any disaster database, there are quirks that have arisen from the recording and collection process of creating this database; (4) to appropriately use this database, it is critical for researchers to understand and, if possible, account for these quirks (we can try to find a better word than "quirks" at some point, but we can use it as a placeholder now). These points would cover a few paragraphs and nicely funnel us down to our challenge in the last paragraph of the introduction.

For the challenge itself, I think your middle two sentences ("In this paper…" and "We introduce") work for now, but I think we might want to edit these to strengthen them as we edit. Right now, they're a bit too focused on the descriptive, where really we're moving, with our analysis of the data, more toward an active investigation to identify evidence in this dataset of mechanisms/quirks that could lead to several types of bias previously identified as things to look out for in disaster databases (through the Gall paper and others). I think that focus on an active investigation will sound stronger.]

What is the Storm Events Database

[BA: This description is great. I think this part could probably go in the "funnel" of the Introduction.]

The National Oceanic & Atmospheric Administration (NOAA) Storm Events database collects information on storms, significant weather phenomena, rare or unusual weather, and other significant meteorological events across the United States. NOAA stores this information in csv files for each year. It has been recording weather information since 1950. However, the database has undergone several changes since then. In 1950, NOAA only recorded tornado events and now it records 48 different event types. Following these changes, the NOAA Storm Events website states that they have reformatted and standardized events types without changing any specific values or details ("Storm Events Database," n.d.).

The database assigns each weather phenomenon with a location, date, event type, event ID, episode ID, property damage estimate, crop damage estimate, county name, state, event narative, and episode narrative. The database categorizes large storms as episodes which contain several individual events. For example, a hurricane will be given one episode ID, and the rain, wind, floods, etc associated with that hurricane will be given event IDs that fall under that episode.

The US National Weather Service (NWS) collects weather data from storm trackers, federal agencies, the media, the public, and several other sources. The NWS then uses this data to create the NOAA Storm Events database that is released as a monthly publication.

[BA: I think that one of the things it's important to understand about this database is how they record with a hierarchy, so there will be different listings for one storm both across several types of hazards and several geographic locations. For example, a big hurricane is one storm system but would result in listings for lots of counties and for multiple hazards (storm surge, wind, extreme rain, etc.) within some of those counties. They've got ID numbers that help in joining together different listings for the same storm. It might be helpful for us to add a figure somewhere early in the draft to explain this aspect of how listings are included in the database. You could take a look through the noaastormevents to see if there's a figure or illustration there that might make a good starting point for helping to illustrate that.]

[BA: For this description, it would be helpful to have some more references on its history. For early history, since this was mainly the tornado database, info about it might be under a different name for the database. I'll try to find some papers we could look into to get some more of these details and references to add.]

What is NOAA Storm Events

We used the noaastormevents package in R to dissect these issues and examine evidence of bias in several hazard types.

[TK: do these next two paragraphs go into too much detail for the introduction?]

> The database assigns each weather phenomenon with a location, date, event type, event ID, episode ID, property damage estimate, crop damage estimate, county name, state, event narrative, and episode narrative.
>
> The US National Weather Service (NWS) collects weather data for NOAA from storm trackers, federal agencies, the media, the public, and several other sources. The NWS then uses this data to create the NOAA Storm Events database that is released as a monthly publication.

Use of Storm Events Database in research on societal impacts

[BA: Let's add some examples of papers in which this database was used to identify storm exposures, and then the paper was looking at how they impacted humans.]

Concerns with Storm Events Database

[BA: Could we start on a paragraph here that gives an introduction to this section about potential biases? One thing here would be to talk about the idea of the probability of an event being recorded given that it happens.]

Though the NOAA Storm Events database is quite extensive, several biases affect its data. These biases fall under five major categories which are common in weather data. These include hazard bias, temporal bias, threshold bias, accounting bias, and geographic bias. These biases result from various factors including structural changes over time, reporting errors, inherent bias, and others.

[BA: Great! The above paragraph definitely belongs in the "funnel" of our Introduction, I think.]

The Storm Events website gives a disclaimer that "an effort is made to use the best available information but because of time and resource constraints, information from [the] sources may be unverified by the NWS" ("Storm Data Faq Page," n.d.).

- extensive database

- several changes over time (in both *which events* are reported and also *what details of reported events* are included. For example, I think that the reports for tornadoes include estimates of intensity, and the scale used for this has changed over time, from no scale (I think) to the Fujita scale to the enhanced Fujita scale. I think there's been some work to smooth over these changes (i.e., re-analysis), but I'm sure it could still cause issues.)
- not all events may be reported, some may be double counted [Could you explain this point some more? Perhaps add an example?]
- lots of sources
- inherent bias in data collection in this specific field (some of this is because it's over such a long time period—over 50 years for some event types)

[BA: Maybe it would be helpful for us to start a small table here that lists each type of bias that we cover and a short description of each? We can start that as an itemized list, because that will be easier to format right now, and then convert it to a table later.]

- **hazard bias:** [Add a short definition / description]
- **temporal bias:** [Add a short definition / description]
- **threshold bias:** [Add a short definition / description]
- **accounting bias:** [Add a short definition / description]
- **geographic bias:** [Add a short definition / description]

Hazard Bias

Societal responses to environmental hazards

"Hazard is the broadest term and reflects a source of danger or the potential for harm. Risk is the likelihood or probability of a risk ocurring.

Hazards include risk (e.g. probability), impact (or magnitude) and contextual (sociopolitical) elements. In other words, hazards are threats to people and the things they value). They are therfore socially constructed, where people contibute to, exaverbate and modify them.

Hazards can vary bby culture, gender, race, socioeconomic status and political structure. Disasters, on the other hand are singular hazard events (like those mentioned in the introduction above) that have a profound impact on local people or places"

Revisiting the definition of "hazard" and the importance of reducing vulnerability

"One view is that hazards are reducible to the physical events that trigger disasters." "The second, and currently more popular, perspective on hazards acknowledges the role of the physical environment but also acknowledges the complex relationship between hazards and human activity."

"It is apparent that most individuals assume a hazard to be the latent threat or active agent that triggers disasters. This view is not incorrect, and, understandably, it is widely used. However, the desire to put this definition of hazards at the center of EM presents unrecognized challenges for the field. Problems inevitably arise when we rely heavily on this concept because it inadvertently downplays human culpability for disasters."

"hazards may be geophysical, atmospheric, or biological in origin. Other research makes similar references, giving the impression that these potentialities are reducible to their sources (environmental, climatological, geophysical, biological, technological, or civil/conflict origin)"

"A disaster is usually described as an event that has a large impact on society, and, because our subject matter is limited to natural hazards, it is geophysical events that create disasters."

"A disaster might be defined loosely as a hazardous event that significantly disrupts the workings of society."

[BA: I think there might be a few different things going on with this one. Let's talk about how we can make sure we bring these different elements together in describing this type of bias. Here are some of the elements that seemed to me to be coming up here: (1) some types of events might be more likely to be recorded than others; (2) some types of hazards within an event might be more likely to be recorded than others; (3) for some types of events, maybe there's some encouragement to list it as a single event; (4) for the events that are listed, they can differ a lot in severity, and there's not much information in the database to help figure out how severe they are; (5) some of the listings are coming from different sources (e.g., media rather than the NWS)]

[BA: Could we be more precise with this statement? For example, is this likely to always (or almost always) be an underreporting rather than an overreporting? Also, for this type of bias, maybe we want to clarify that, even when storms are entered into the database, all of their associated hazards might not be entered. That's what's going on with this type of bias, right? If I've understood this correctly, maybe move towards something like, "The Storm Events database aims to record listings for all hazards brought by a particular storm event. However, in some cases, when a storm event is recorded certain types of hazards within the storm can tend to go unreported." Have I gotten the idea right here?].

Introduction

Within the Storm Events database, there may be inaccurate recording in the number of certain hazard types. The Storm Events database aims to record listings for all hazards brought by a particular storm event. However, in some cases, when a storm event is recorded certain types of hazards within the storm can tend to go unreported.

[BA: We may want to add something like, "and, in general, the probability that an event is recorded here might differ by type of event." I'm thinking that this type of hazard would especially come into play for a study where you're trying to *compare* the frequency of two or more hazards with each other, or even trying to see how each is related with an outcome. We might want to see if we can find some examples of studies that have used this database while looking at two or more types of hazards, to help us in thinking through how a reporting bias that's different by type of hazard might bias the results. Many of our example studies focus on one type of hazard (e.g., tornadoes, rip tides), but maybe we can find some that consider two or more in the same study?]

[BA: For our definition of hazard bias—is it that the probability of an event being record if it happens varies by event type/hazard, and also that the quality and quantity about information provided for a recorded event might also vary by event type/hazard? In other words, some hazards may be less likely to be reported as an event in this database, and when an event is recorded, the information recorded for it might be more comprehensive, accurate, and precise for some types of hazards compared to others.]

P (event recorded | event happened)

This guidance depends on event type, though, because later that say:

"The chosen event name should be the one that most accurately describes the meteorological event leading to fatalities, injuries, damage, etc. However, significant events, such as tornadoes, having no impact or causing no damage, should also be included in Storm Data."

So it sounds like they are trying to catch every tornado. I think this would create hazard bias, right? The probability of an event being recorded if it happens would be higher for tornadoes than other types of events, based on this standard.

The probability that an event is recorded might differ by event type. This could result from several mechanisms. First, the US government has certain programs that focus on specific hazards more than others. For example, the NWS is obliged to provide monetary loss estimates for any flood event even if the damage assessment is a 'guesstimate' (Gall, Borden, and Cutter 2009). This leads to a higher probability of reporting for flood events in Storm Data because of how they get information.

[TK: I need to look into the flood insurance program to see if this also has an effect]

Additionally, certain characteristics of event types influence how easy or difficult it is to obtain information about the event.

[Would these points help explain our observations from the data? For example, why hail is frequent but sneakerwaves and sleet are rare?] For example, it is more difficult to obtain information [any information (e.g., they aren't recorded at all) or loss information specifically (e.g., they are reported, but the info on the losses isn't good)?] on event types that do not cause much physical damage or monetary loss [Do we have a reference for this? Otherwise, we might need to soften the language in this sentence].

This is because insurance companies typically keep strict records of monetary damages caused by weather events [for all types of hazards, or just certain types? In practice in our data, it looks like not a lot of events are reported by insurance companies, so we might want to think about how that plays in with this idea.]. If this is lacking, then the NWS struggles to find exact damage amounts [any info on alternative sources they use?]. Drought hazards exemplify this issue; they are notoriously underreported because there is a lack of physical damage and it is hard to quantify spatial and monetary losses (Gall, Borden, and Cutter 2009). Avalanches also showcase this issue as they typically occur in remote locations with little physical damage or fatalities. [TK: I just made this assumption, so I need to check the literature]

On the other hand, hurricanes or tornadoes that pass through large cities will cause high amounts of physical damage and fatalities. This would attract the attention of insurance companies and produce clear records of damages.

[TK: I still want to consider the idea that event severity may affect the probability (events that happen closer to larger populations of people may have a higher likelihood of being reported than an event that is in a more secluded area) . I'm still debating if that would go here or under threshold bias. Points you have brought up: * if a certain type of event tends to happen in well-populated versus less-populated areas (or even if it's large enough that its coverage includes at least some well-populated areas, like a hurricane often does) * more severe events are more likely to be included and different types of hazards having different probabilities of being reported Examples from R * damages and fatalities from avalanches or droughts vs tornado or hurricane

I also still need to look into a tornado paper that we think mentions this idea of severity. This is stemming off of the quote from gensini "fatal weather events are more likely to be reported due to enhanced media attention" (Gensini and Ashley 2010)]

Associated Hazards

Even when severe weather events are entered into the database, all of their associated hazards might not be entered or their events may be double counted [BA: Do we have any examples of how double-counting might happen in Storm Events?]. NOAA records one large event as an episode and all of its associated hazards as events under than episode. The NWS documentation goes into detail on this recording structure.

> "2.9.1 Episode Narrative. Generate an episode with a narrative; otherwise individual events cannot be entered into the Storm Data software. An episode narrative describes the entire episode in a general fashion, and briefly describes the synoptic meteorology associated with the episode. Information in the episode narrative can be very useful for researchers and other users of Storm Data. This narrative does not need to be long or elaborate, rather make it brief and informative. An example would be "A strong cold front passed through the Washington, D.C. area, triggering several instances of damaging thunderstorm winds and large, baseball-size hail." "To ensure events being logged in a single episode are part of the same synoptic meteorological system, events within the same episode may begin no more than five (5) calendar days apart. This will enable the Storm Data preparer to properly document events that double back into a specific region or events that are very slow moving. Examples include Hurricane and Winter Storm events." (NWS, n.d.)

[Here are more quotes from that section that I might want to weave in:

> The episode narrative will appear in the Storm Data publication after all events contained within the episode. The episode narrative does not appear in the examples shown in Appendix A, which is reserved for only event narratives. Additionally, a brief summary of fatalities and injuries should be part of the episode narrative for zone-based events.
>
> 2.9.2 Event Narrative. Detailed information pertaining specifically to the event and not the overall episode will appear in an event narrative. The event narrative describes the significance or impact of an event within an episode. An event narrative is required for all Tornado events, all Thunderstorm Wind events, and all Lightning events, whether over land or marine zones.
> This narrative will appear immediately below the header-strip in the publication and should contain descriptive information about the times, locations, and severity of destruction of property, trees, crops, power lines, roads, bridges, etc. Additionally, a brief summary of fatalities and injuries should be part of the event narrative for county-based and marine zone-based events. For Thunderstorm Wind events with estimated gusts, use sentences such as "Several trees were toppled by powerful downburst gusts."]

[BA: This might provide an example of how the quantity and quality of information provided could vary by event type. First, it sounds like for some types of reporting, the *episode* gets the narrative, but not separate narratives for each event, while for some events (like tornadoes), each *event* might get a narrative. Also, for fatalities and injuries, it sounds like the estimates are given at the *episode level* for forecast zone-based events but then at the *event level* for county-based events. This could be a place for us to talk about how some events are reported by county versus some by forecast zone, and then we could talk about how this could lead to differences across hazard types in the granularity of information reported (including the spatial scale in which the info is reported). Related to this idea, I think that some event types include latitude and longitude locations (even starting and ending points), while some do not include more detailed location information beyond the area they're reported for (county or forecast zone). This would be another case of where there's a different amount of information available for different types of hazards listed in the database, and we could use our data to show that (it might also be listed in the NOAA manual which events lat/long should be reported for). Another point on this idea of different amount/quality of information on different hazards might be that some hazards are recorded based on clear ways to measure intensity (for example, using a well-defined scale, as is done for tornadoes with the Fujita scale), while others don't. The NOAA guidebook might have some details on this in terms of telling people to use specific scales to report some types of events.]

[BA: There's some helpful language in the exerpts you've quoted here about how events are grouped together into episodes, including that they're part of the "same synoptic meteorological system" and must have start dates within 5 days of each other. This information would be helpful to include in the paragraph or paragraphs where we talk about what "episodes" are in this database.]

Categorizing these events and episodes can be unclear. Events could get double counted outside of the episode. Gall et. all provides an example that hurricane wind, storm surge, and a tornado that were all caused by a hurricane could be counted as three separate events even though they all stemmed from one hurricane (Gall, Borden, and Cutter 2009).

[TK: This idea was also mentioned in the Konisky article ("one episode can correlates to mulitple events") so I want to look into that again) (Konisky, Hughes, and Kaylor 2016)]

[BA: Yes, definitely let's check the Konsiky article. We might want to think, too, if we'd consider it "double-counting" if multiple types of hazards are listed as separate events under the same larger episode. I think we want to talk about this idea of multiple events from an episode in the same county or forecast zone, but I'm not sure that "double-counting" is the right word, as long as the data user understands how the data's set up. I'd think of double-counting more as when something is unintentionally listed twice, whereas in this case they've got a system they're following.]

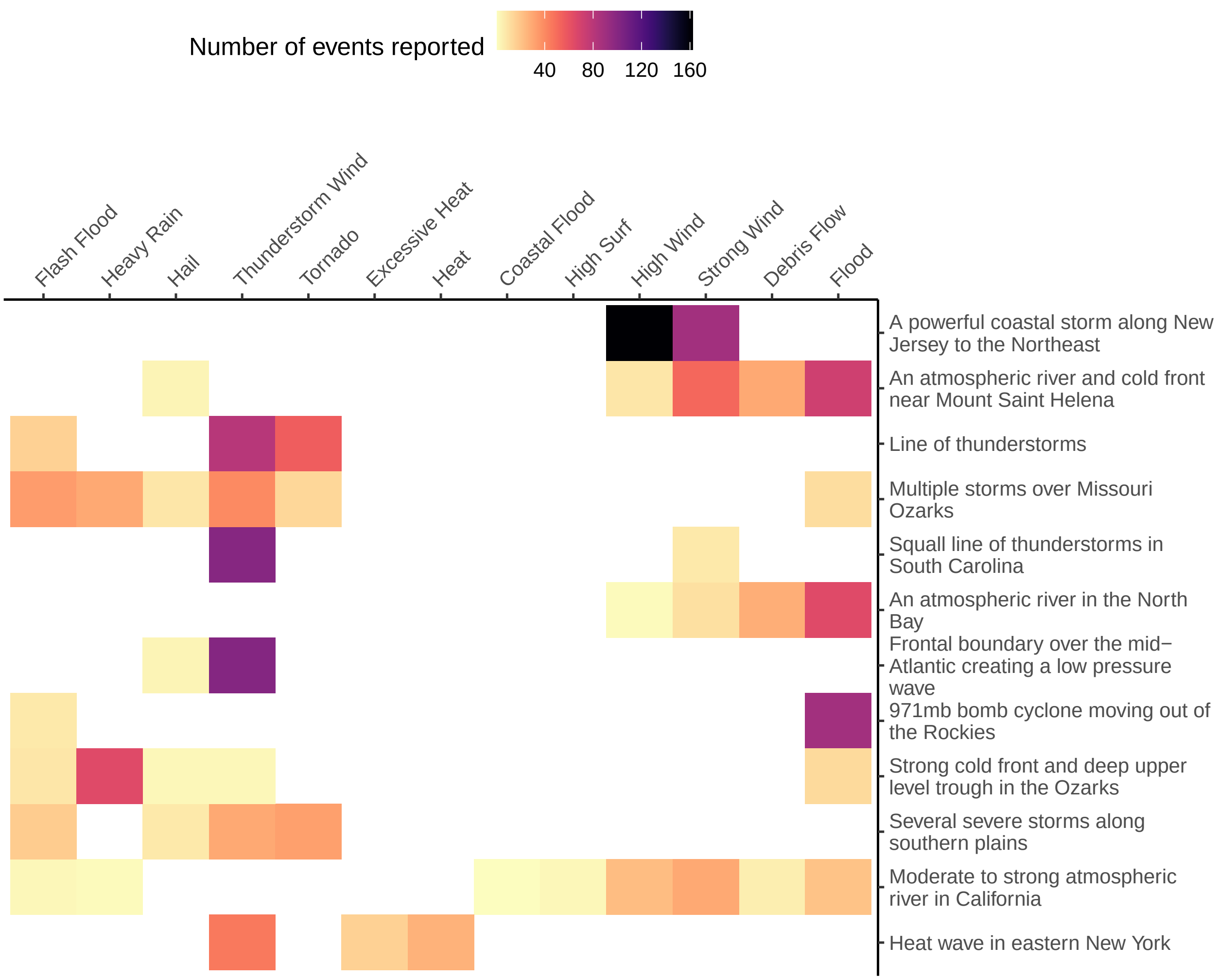
To showcase this idea, for the episodes with the most events in 2019, the following graph shows the number of events reported for the episode. This figure demonstrates how one large weather 'episode' can include several other events types. For example, Episode 133801 in this figure indicates several reports of flood, debris flow, strong winds, high wind, and hail. All of these different event types occurred as a result of one large storm labelled episode 133801. This unique episode ID helps related events from getting double counted as separate entities.

[BA: See Issue #8 in the GitHub repo for a suggestion of finding some better labels rather than using the Episode numbers here. Also, we could look at the Episode narrative for this specific episode to add to our description of the larger (synoptic) weather system that caused all these listed hazards (flood, debris flow, strong winds, high wind, and hail). It looks like it was something called an "atmospheric river" and it had a cold front associated with it. It would also be nice to list what part of the country this was in (somewhere around Washington State, I think, because the Episode narrative mentions Mount Saint Helena).]

[BA: Also, in the above paragraph (or near it), we could add in some of the details from the quotes you pulled from the NOAA guidebook, like that an episode is capturing events from the same larger (synoptic) weather system and that they are supposed to have start dates within a few days (5) of each other.]

Number of events reported per episode ID:

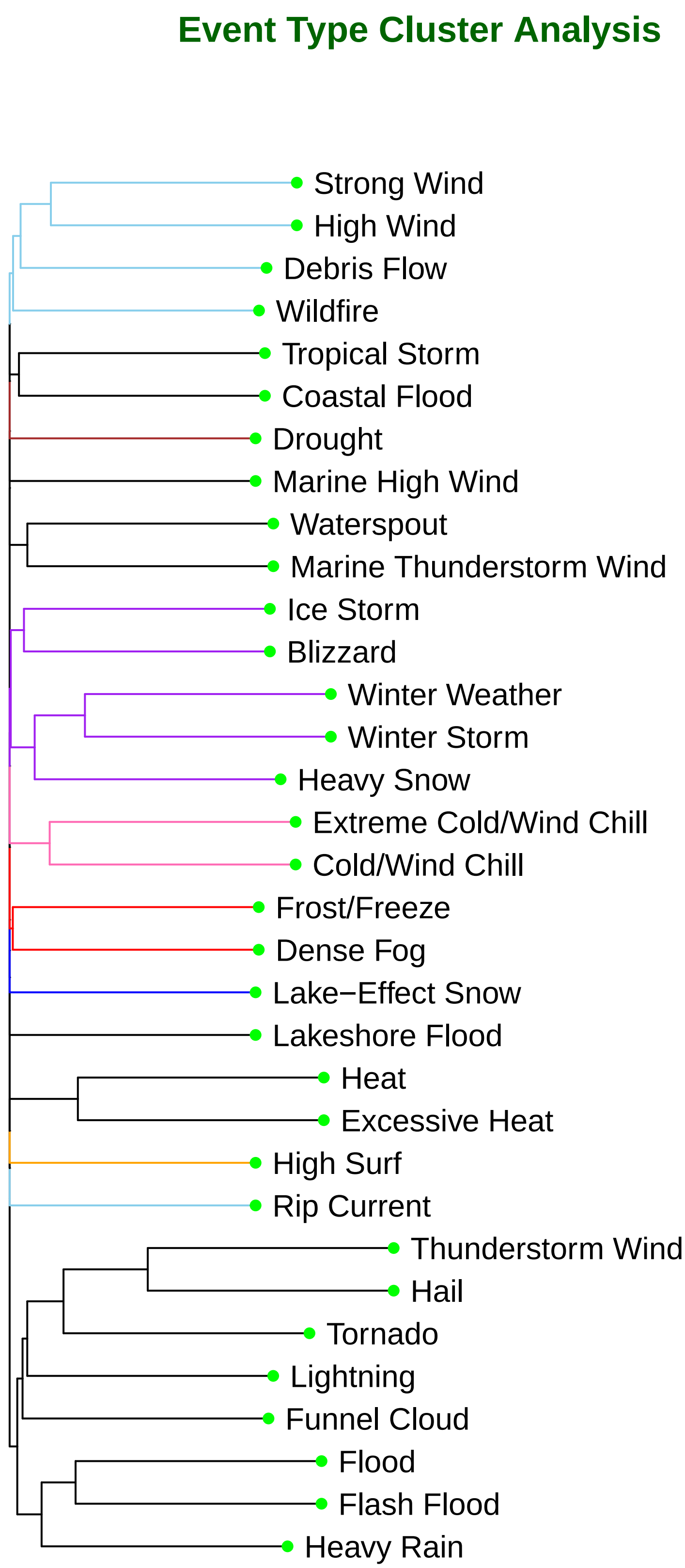
```
## `summarise()` ungrouping output (override with `.groups` argument)

## `summarise()` regrouping output by 'EPISODE_ID' (override with `.groups` argument)

## Joining, by = "EPISODE_ID"

## `summarise()` regrouping output by 'EPISODE_ID' (override with `.groups` argument)
```



Cluster Analysis

Once we removed event types with less that 50 listings in 2019, we did a cluster analysis of event types, to group events that are more likely to occur together within an episode. The following plot shows the resulting cluster structure of these event types. The figure shows that there are certain event types which are very commonly reported together such as high wind and strong wind or heat and excessive heat. These types of events are likely to be reported together becuase they are likely to occur at the same time. It is important to keep these trends in mind as there may be overlap or uncertainty in how to categorize what happened during an episode.

```
## `summarise()` regrouping output by 'EPISODE_ID' (override with `.groups` argument)
```



3. difficulty of sorting events

- this could include the ideas of severity and source [BA: For the source part, we could look at how different types of events vary in their probability of being reported by different sources (I think we'd talked about that idea for another section, too). There's some code in the Details vignette we can start from for that.]

- there is also limited information on event severity or distinction between events within the database (Luh et al. 2015). The NOAA Storm Data Disclaimer states that "Some information appearing in Storm Data may be provided by or gathered from sources outside the National Weather Service (NWS), such as the media, law enforcement and/or other government agencies, private companies, individuals, etc. ("Storm Data Faq Page," n.d.)
- Definitional differences (Gall, Borden, and Cutter 2009) [BA: Could you add some more details or explanation on this point? I'm not sure I get it yet.]
  - this seems to be more of problem when comparing events across databases. The Gall Losses article gives the example of hurricane-induced storm surges. In SHELDUS, a storm surge gets categorized under "coastal hazards"" and Storm Events categorizes them under "ocean and lake surf". So if someone was trying to detail a large events like a massive hurricane using multiple databases this could create a problem. [BA: Maybe this also comes into play for the different source? Would the media use the same criteria for identifying a disaster as a National Weather Service office? If not, and if the media tend to report certain types of disasters more often than others, than this could maybe create some bias.]
- NOAA Storm Events defines the types of events that are allowed in the data set. This can be found under Table 1 of Section 2.1.1 of NWS Directive 10-1605 at http://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf.

Event Type:

```
## `summarise()` ungrouping output (override with `.groups` argument)
```

Event type	Number of events in 2019
Thunderstorm Wind	18,635
Hail	9,015
Flood	4,951
Flash Flood	4,093
Winter Weather	3,808
High Wind	3,790
Winter Storm	3,354
Heavy Snow	2,886
Marine Thunderstorm Wind	2,502
Tornado	1,732
Strong Wind	1,591
Heavy Rain	1,441
Heat	1,301
Extreme Cold/Wind Chill	1,065
Drought	1,007
Excessive Heat	889
Blizzard	852
Frost/Freeze	654
Dense Fog	652
Cold/Wind Chill	470
High Surf	468
Funnel Cloud	348
Lightning	343
Coastal Flood	240
Ice Storm	200
Wildfire	197
Debris Flow	185
Waterspout	183
Lakeshore Flood	146
Tropical Storm	143
Lake-Effect Snow	78
Marine High Wind	77
Rip Current	74
Avalanche	44
Dust Storm	40
Marine Tropical Storm	37
Marine Hail	32
Tropical Depression	26
Storm Surge/Tide	25
Marine Strong Wind	17
Astronomical Low Tide	16
Hurricane	10
Dust Devil	8
Freezing Fog	6
Marine Hurricane/Typhoon	6
Marine Tropical Depression	4
Seiche	4
Sneakerwave	3
Dense Smoke	2
Sleet	1
Volcanic Ashfall	1

Temporal Bias

[BA: We might want to start with this type of bias, and then geographic bias. I think those two are very easy for people to grasp. Then, when we talk about other types of biases, we might want to talk about them just in terms of things that might cause differences within a certain period of time and location, so we can separate them from geographic and temporal issues. There are a few examples that could really fall into several categories (for example, the flood insurance question, which has a time component to it since policies changed over time), so we might want to discuss any time-related things in this section and start with it.]

[BA: Potential reasons for temporal bias: (1) We've gotten better at "seeing" extreme weather as it happens—radar, larger networks of monitors, etc. There may be some good examples from measuring tornadoes of this idea, where the improvement in weather monitoring has helped increase the number of reported events; (2) Some changes have increased the chance that we notice / report events when they happen. For example, population growth over time in some areas might mean there's a higher chance that an event that happens in that area gets reported. (3) Some temporal changes are structural, in terms of the database changing it's "rules" for what it recorded. The expansion from just tornadoes to other types of events is an example here. This is one where we can help control for any bias, since there's clear documentation on some of those changes. However, I wonder if there's still some kind of lead in period, where it takes them a little while once they start adding an event to succeed in recording most or all of them? We could maybe check how the rate of recording changes with time for tornadoes versus some of the "new" events in the database in the late 1990s.]

[BA: I like that we distinguish between the idea of long-term trends in the probability of an event being recorded in the database (e.g., from one decade to the next) versus seasonal time trends (e.g., winter versus summer). We probably want to explicitly write a few sentences introducing that idea that temporal bias can operate at different time scales.]

Introduction to Temporal Bias:

Within the NOAA Storm Events database, there are comparable differences in event and loss recording over time. Temporal bias is helpful in describing and understanding these changes within the database. There are long term patterns of temporal bias that may be caused by changes in measuring and recording events and losses. There are also seasonal patterns within the database that relate to unique attributes and temporality of certain weather events.

Long Term Trends:

Long term temporal bias arises because technology is getting better at detecting storm events, population size is growing in high hazard areas, and the NWS has changed their recording strategies and monetary loss acounting.

Scientists have improved radar and expanded networks of monitors and so they detect more extreme weather events. The advancement of doppler radar and dual-polarization radar technology has increased our ability to detect tornado events ("SEVERE Weather 101: Tornado Detection," n.d.). Forcasters and storm spotters have also discovered patterns that help them recognize tornado formation. These advancements increase the tornadoes detected. Verbout et. al states that "the number of tornadoes reported in the United States has doubled from about 600 per year in the 1950s to around 1200 in the 2000s"(Verbout et al. 2006). Technology increases this reported number rather than meteorological changes.

[BA: Great! This is a great explanation of this idea that we may be able to "see" more events as we go along. There may be some papers in the climate change field on this topic, too. It turns out that this change in technology makes it hard to determine if there has been clear evidence of a trend in frequency of some types of extreme events. This comes up a lot with hurricane research, because we missed a lot of storms that didn't make landfall early in the twentieth century and we don't miss them now. I can see if I can find a couple of papers along those lines that we could add in here.]

Increasing population size and land development also contribute to increased event reporting over time. Population growth increases the probability that an event in an area gets reported. This is because events are reported to the NWS by trained spotters, the public, law enforcement, broadcast media, social media, local and county officials, etc. When the number of these individuals increases in an area, so does the likelihood that they will see and report an event.

How events are reported

Here is a link to the National Weather Service's information on how to become a storm spotter: Storm Spotter

Acronyms: ASOS= "Automated Surface Observing System (ASOS) units are automated sensor suites that are designed to serve meteorological and aviation observing needs"

Mesonet= "portmanteau of mesoscale network, a network of (typically) automated weather and environmental monitoring stations designed to observe mesoscale meteorological phenomena"

COOP Obbserver= The National Weather Service (NWS) Cooperative Observer Program (Coop) is truly the Nation's weather and climate observing network of, by and for the people. More than 8,700 volunteers take observations on farms, in urban and suburban areas, National Parks, seashores, and mountaintops. The data are truly representative of where people live, work and play.

AWOS= Automated Weather Observing System (AWOS) is a fully configurable airport weather system that provides continuous, real time information and reports on airport weather conditions. AWOS stations are mostly operated, maintained and controlled by aviation service providers.

CoCoRaHS= The Community Collaborative Rain, Hail and Snow Network, or CoCoRaHS, is a network of volunteer weather observers in the United States, Canada, and the Bahamas that take daily readings of precipitation and report them to a central data store over the internet.

SNOTEL= snow telemetry

RAWS= The Remote Automatic Weather Stations system is a network of automated weather stations run by the U.S. Forest Service and Bureau of Land Management and monitored by the National Interagency Fire Center, mainly to observe potential wildfire conditions.

CMAN Station= The Coastal-Marine Automated Network (C-MAN) is a meteorological observation network along the coastal United States.

AWSS= automated weather sensor system

WLON= a radio station

SHAVE project= Severe Hazards Analysis & Verification Experiment

[TK: I did not find much information about these sources in the NWS NOAA documentation. However, from my research it appears that several of these sources seem to be communities of people that are reporting events. This leads to more questions about how objective the reporting is from these groups. There may be differences in how certain people classify certain events.]

Number of evennts reported by source type

```
## `summarise()` ungrouping output (override with `.groups` argument)
```

Source of event report	Number of events reported in 2019
Trained Spotter	9,742
Public	8,378
Emergency Manager	6,061
Mesonet	5,717
Law Enforcement	4,061
ASOS	3,169
COOP Observer	2,758
911 Call Center	2,615
Broadcast Media	2,358
Social Media	2,065
AWOS	2,029
Department of Highways	1,917
River/Stream Gage	1,761
NWS Storm Survey	1,749
State Official	1,748
Official NWS Observations	1,424
CoCoRaHS	1,330
Fire Department/Rescue	1,187
Amateur Radio	1,176
Drought Monitor	958
NWS Employee	901
Buoy	590
SNOTEL	484
Other Federal Agency	479
Storm Chaser	447
County Official	443
RAWS	402
C-MAN Station	396
Utility Company	393
Newspaper	274
Park/Forest Service	244
Unknown	194
Local Official	71
AWSS	29
Mariner	22
Lifeguard	21
Post Office	20
Tribal Official	14
Coast Guard	9
Airplane Pilot	7
Insurance Company	5
WLON	3
SHAVE Project	1

Automated observation systems:

Mesonet ASOS AWOS River/Stream Gage Drought Monitor (we should check that this is from automated equipment, otherwise it should go in a different category) Buoy SNOTEL (we should check that this is from automated equipment, otherwise it should go in a different category) RAWS C-MAN Station AWSS

Officials or emergency response/agency:

Emergency Manager Law Enforcement 911 Call Center Department of Highways State Official Fire Department / Rescue NWS Employee Other Federal Agency County Official Park/Forest Service Local official Lifeguard Post Office Tribal Official Coast Guard

Trained volunteers:

Trained spotter COOP Observer (I wasn't sure here—is this a trained volunteer similar to a trained spotter?) CoCoRaHS (I think this is a network from trained volunteers collecting precipitation, right?) Storm Chaser (I think we would consider them "trained"? If not, could be move to general public) Media: Broadcast Media Newspaper WLON (I'm guessing this really should have been coded in the data as "Broadcast Media")

Company or general public:

Public Social Media Amateur Radio Utility Company Mariner Airplane Pilot Insurance Company

[BA: Whatever we do, we should take clear notes so we can report how we handled this. Also, we should add this as an example in temporal bias, in terms of changes in typical ways of reporting over time. If you were working with this data and didn't know this, and wanted to get a subset of data just with "Thunderstorm Wind", this could cause problems. You might filter just to event_types of "Thunderstorm Wind", and that would be find for earlier in the data and also for recent years, but you'd miss loads of things in this period with these unconventional event types.]

More Points for Long Term Trends

[TK:

*include information from the US census

- Here is link to the population data: US census data
- Here is a link to the locations of National Weather Service offices across the US: NWS locations]

[BA: We may want to remind the readers here of the role that storm trackers / reporters play in reporting some of these events. I think that for some types of events, people can volunteer as "spotters" and get some training and then be able to report events they see. I think in one vignette, there's some code that helps in seeing how many of the event reports come from those types of inputs. The population size question could be really important there. Also, I wonder if there's any link between how close National Weather Service offices are and the population density? If so, maybe that is another link with population size / density?]

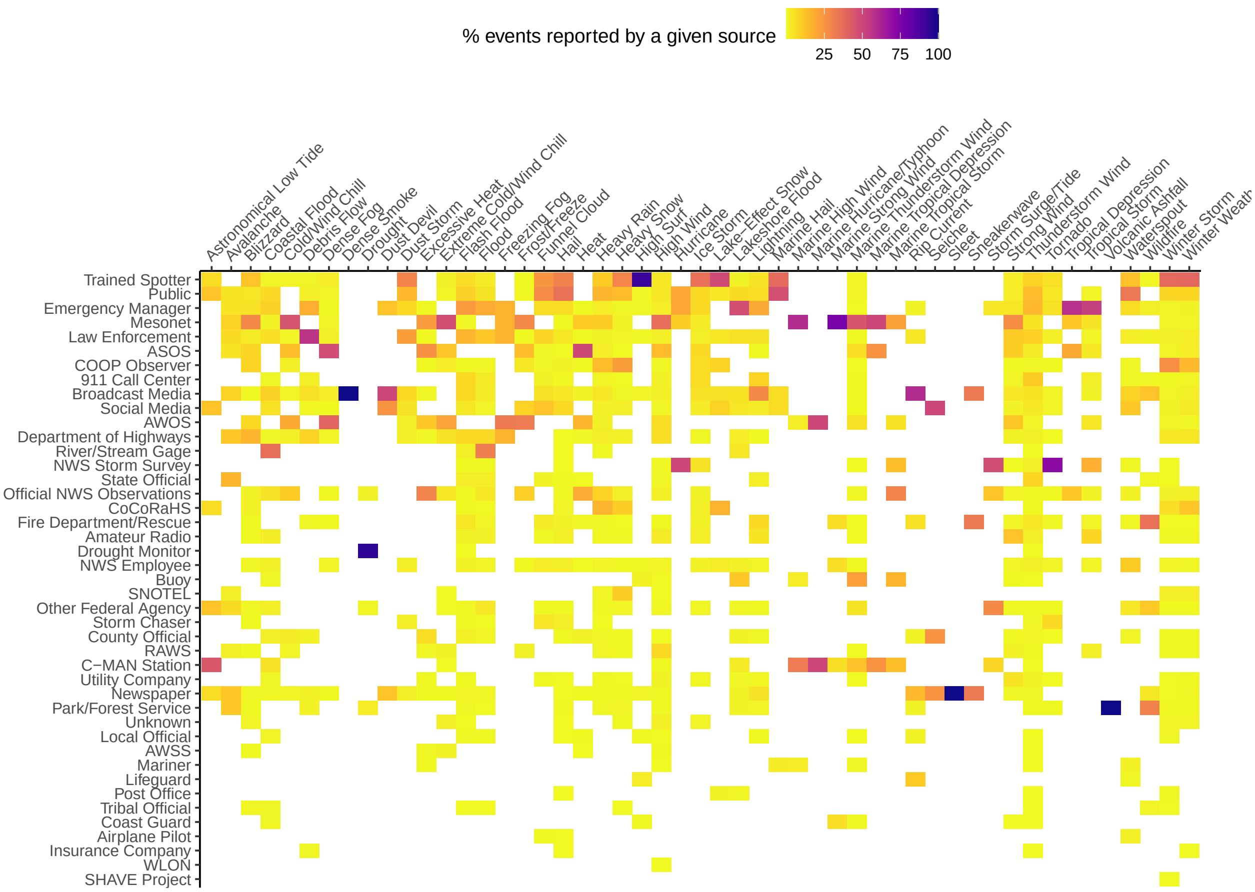
Breakdown of percentage of events reported by a given source:

The following graph shows, for each type of event in 2019, the percent reported by each source. Both axes of the plot are ordered by overall frequency (i.e., overall number of each type of event and overall number of reports from each source).

For some types of events, reporting is dominated by a specific source. For example, most high surf reports come from trained spotters, while most drought reports come from drought monitors and most tornado reports come from the NWS Storm Survey. Another example is that rip currents are mostly reported by broadcast media and newspapers. This may be because rip currents can pose a serious danger to humans and cause death in certain instances. These instances are more likely to make the news than other types of general events.

For other types of events, reporting sources are more diversified.

Additionally, certain sources are more influential in reporting certain events. For example, the public often reports hail and marine hail events. This may be because the public is usually highly affected by this type of weather event.



Some temporal changes are structural, in terms of the database changing what types of events are recorded. Since 1950, the database has undergone two major changes in event recording. The first change occured in 1954 when the NOAA database starting recording thunderstorm wind and hail in addition to the tornado events it had already been recording (“Storm Events Database,” n.d.).Fourty-two years later, the database started recording all 48 event types that it continues to record today (“Storm Events Database,” n.d.).

These major changes were also influenced by smaller changes in funding and policy. One of these changes occured between 1976 and 1979 when the NWS received reduced funding from the US government that decreased flood damage data collection (Downton, Miller, and Pielke Jr 2005). This decreased flood data collection may have produced an artificially low number of recorded floods during that time. To counteract this, in 1983, Congress began to require The US Army Corps of Engineers to provide yearly flood damage reports in contract with the NWS (Downton, Miller, and Pielke Jr 2005). This could have the opposite effect in that the data may provide a more consistent report of flood damage that would not have otherwise been reported. These changes pose inconsistensies in the number of certain storm events over large periods of time.

[BA: We might want to add some examples, here or in one of the more general sections, about how these issues are common across a lot of disaster databases. I’ve added a few papers that talk about common problems for disaster database, rather than just NOAA Storm Events, and those might help in rounding out our discussion.]

Seasonal Trends:

Although certain weather events truly exhibit seasonal differences in their meteorology, other factors related to temporal bias may artificially inflate or deflate the number of certain events recorded throughout the year. One of these factors is how the timing of a weather event's hazardous outcomes could attract more attention. The media and the public are more likely to report a weather event when it directly physically affects them. One example of this occurs with rip currents. NOAA exhibits higher rates of rip currents in the summer versus the winter. Gensini and Ashley also found that "summer season weekends are shown to have the most [rip current] fatalities than any other time of the year" (Gensini and Ashley 2010). However, the probablity of a rip current occuring during summer or on the weekend may not be inherently higher. It may be that more people attend the beach and swim in the ocean during the summer and on the weekends and are thus more likely to experience and/or report a rip current. Humans experience the hazardous outcome more in the summer and thus will be more likely to report it during that time.

- Seasonal Differences in number of events reported
  - Example of rip currents in summer vs winter
- Direct quote: The strength of rip currents can be seasonal. During hurricane season (from June to November) there is a greater chance for rip currents to develop.("Rip Current," n.d.)
- Rip currents are related to several envrionmental factors including waves (surf heights, period, direction), beach (slope, orientation, material), water levels (tidal cycle, tide ranges), winds (affect wave breaking) and wind-driven currents alongshore, others like local coastal configuration and beach and promontories by natural or human made. ("Rip Currents: A Natural Killer on Beaches," n.d.)
- "The most likely scenario for rip hazards is not high surf but high exposure of beachgoers in the warm water of the summer-fall period. When low-energy, longer-period waves (significant wave heights of 0.5 -1.5 meters in 10-15 second sequences) lead to the highest number of rip incidents. During spring/neap tides or very low daily tidal cycles, a mass rescue event can occur, with hundreds of rescues in several locations on a beach, or at several beaches under the same conditions." ("Rip Currents: A Natural Killer on Beaches," n.d.)
- "societal factors (e.g., weekends and holidays) that could change the risk of a rip current fatality. For example, low and high pressure systems off the east coast of the United States can produce onshore flow to many surf zones. Both systems may invoke a high rip current formation risk on the LURCS, but swimmers will be more inclined to enter the water on days when a high pressure system is offshore. The clear skies generally associated with large-scale subsidence of a high pressure system would provide beachgoers with favorable weather for beach activities as opposed to a day amid a low pressure system with stratus clouds and precipitation occurring" (Gensini and Ashley 2010)
- create table of number reported by lifeguards or media vs month of the year
  - other events that are more or less reported? [BA: We might want to talk about the idea of some events that truly are seasonal in their occurrence, like avalanches and hurricanes, versus some that happen year-round but have varying chance of being reported. Also, you can look through the package vignette and see if you see any other examples of things that might not be reported evenly throughout the year.]
  - coastal flood? high surf? waterspout?

[BA: I'm not sure if you saw it yet, but I added in another paper on rip currents that to the "literature" folder that might be another helpful reference for this section.]

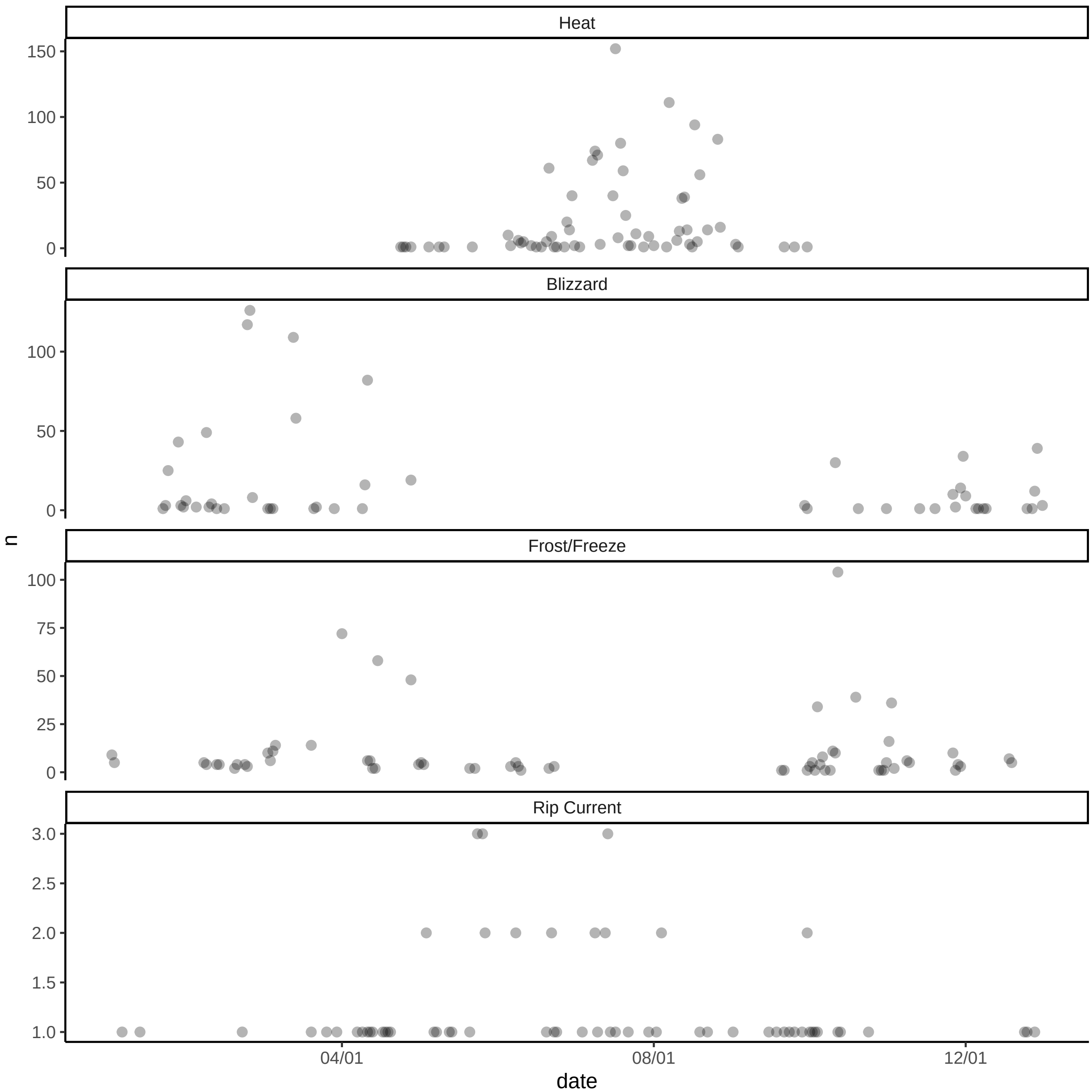
How start dates for events are distributed over the year

[I don't know if we've explained yet that events are listed with a start and end date. We might want to explain that here.] Here are how the start dates for listings for each event type are distributed over the year (event types are ordered by decreasing total count during the year; note that the y-axes vary depending on the range of events by date for each event type):

Many event types are clearly seasonal (e.g., winter weather, winter storms, heavy snow, cold, extreme cold, blizzards, ice storms, lake-effect snow, and avalanches are all much more common during winter months, while heat and extreme heat are typically limimted to summer months). However, for some events, reporting seasonal patterns might be based not just on the true pattern of events but also on the timing of important exposures and impacts of the events. For example, rip currents have many more listings during the spring and summer, which may be related to events being more likely to be listed when more people are swimming. Frost event listings are particularly high at the start and end of the frost season, rather than in the middle of winter, which may be related to the impacts of frost on crops being higher in spring and fall than during the winter. If working with this data, it important to keep in mind that the data are based on reporting, and there may be related influences on the probability of an event being reported and included in the data that differ from using data from something like a weather station.

[BA: Could you check on Google Scholar and see if we could find out anything from the literature to support our idea here that you're going to get frost through the winter, but that the most economically damaging frost comes near the edges of the frost season.]

```
## `summarise()` regrouping output by 'date' (override with `.groups` argument)
```



Current techniques for improvement (re-analysis)

Many atmospheric scientists have recognized this concept of temporal bias in weather data and have revisted data and recording strategies in an attempt to account for it.

For example, Christopher Landsea et al. has published work on hurricane data reanalysis. In this work, he reanalyzes the National Hurricane Center's North Atlantic hurricane database (HURDAT) across several years (Landsea et al. 2008, Landsea et al. (2012), Landsea et al. (2014), Delgado, Landsea, and Willoughby (2018)). HURDAT is the main archive of tropical cyclones of the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico.

Landsea examines HURDAT's record of hurricanes and tropical cyclones to determine their accuracy and readjust if necessary. This readjustment involves removing recorded hurricanes or tropical cyclones, adding them, and/or editing the recorded track or intensity. The goal of this work is to correct systemic biases and random errors in the data in order to make the data comparable over time.

Hagen and Landsea conducted a similar study in which they investigated if the 10 most recent Category 5 hurricanes would still have been classified as so if they had occured during the mid-twentieth century (1944–53) using the available monitoring technology at the time (A. B. Hagen and Landsea 2012). The 10 most recent Category 5 hurricanes start with hurricane Andrew in 1992 and end with hurricane Felix in 2007. The study looks at all recorded observations for these hurricanes and then removes ones that were obtained from technology (i.e. satellite data, air reconnaissance) not available during the time period in question. Using the new subset of observations, the authors re-categorized the hurricanes. This process concluded that only two of the most recent Category 5 hurricanes would hace been classified as so if they had occured during the late 1940s. It is more likely that all of these hurricanes would have instead been classified as Category 4 hurricanes.

This study hopes to determine how much advanced monitoring contriutes to the increasing prevalence of intense hurricanes. This determination thus helps in finding the true effect climate change or other factors have on this increasing prevalence.

In terms of recording tecnhniques, scientists have worked to improve the current process of tornado monitoring. In the late 1970s the NWS officially adopted the Fujita scale for ranking tornadoes. The Fujita scale was developed as a result of T. Theodore Fujita and Pearson's efforts to provide damage assessments for tornadoes in a systematic manner by determining their airflow characteristics (Edwards et al. 2010). The scale provides path width and length ratings on a 0-5 scale and provides damage amounts on a scale of F0-F5.

Over the years, concerns arose about the effectiveness of the Fujita scale. Scientists then developed the enhanced Fujita (EF) scale to estimate wind speeds for degrees of damage (?) across 28 damage indicators (?). This enhanced scale serves to increase precision and accuracy for tornado and thunderstorm wind event recording. The NWS adopted this scale in 2007 (Edwards et al. 2013).

Threshold Bias

[TK: To consider: Earlier in hazard bias, I discuss event severity by type and how a more severe event may be more likely to be reported. I might want to move those examples here to focus on the role severity plays. Or I could get rid of this section and weave these ideas into other areas.]

The varying severity of an event creates threshold bias in the storm events database. Events of larger maginutude and/or damage to human health are better documented, while events of smaller magnitude are less reported becasue less people are affected (Gall, Borden, and Cutter 2009). Small events may even be excluded due to threshold criteria in the database (Gall, Borden, and Cutter 2009). For example, if a flood has received a presidential disaster declaration, FEMA storm survey teams go to the scene and provide extra damage assessments (Downton, Miller, and Pielke Jr 2005).

- Events of smaller magnitude are less reported becasue less people are affected (Gall, Borden, and Cutter 2009)
  - may even be excluded due to threshold criteria (Gall, Borden, and Cutter 2009)
  - verify this under NOAA disclaimer

Accounting Bias

Introduction/How damages are reported

There are discrepencies in how monetary losses and damage information are collected in the NWS storm events database that lead to accounting bias.

This is a quote from the NWS documentation on how estimates are recorded. Not sure if we should include it here or abbove when we describe the database:

“Estimates should be in the form of US Dollar values and rounded to three significant digits, followed by the magnitude of the value (i.e., 1.55 Billion $USD for $1,550,000,000). Values used to signify magnitude include: Thousand $USD, Million $USD, and Billion $USD. If additional precision is available, it may be provided in the narrative part of the entry. When damage is due to more than one element of the storm, indicate, when possible, the amount of damage caused by each element. If the dollar amount of damage is unknown, or not available, check the “no information available” box.”

[BA: Overall for this section, I know that there seemed to be some odd things occasionally cropping up in the data from the `noaastormevents` package when you look at damages. You might want to look through the “Details” vignette for anything that specifically talks about damages. I think there were occasionally cases, like Hurricane Floyd in 1999 in North Carolina, where it looked like a lot of the damage was maybe reported for the capital county (the county with Raleigh in it) rather than coastal counties (coastal counties were reported, too, but the numbers were lower, I think). That raised some questions for me about whether sometimes general damages were reported for the state, and just recorded in the capital location, versus in the county where the damage occurred. Also, it may be interesting to see, both from the data and the documentation, (1) whether they split up the total costs across different events in an episode (for example, if there are reports of multiple events during a hurricane for a county, where do they record the damage?) and (2) how different costs are from county to county for the same episode (and particularly for counties that are close to each other but across state lines—do the damages tend to be more similar within a state than between two states?).]

Inaccuracies in reporting

The National Weather Service Documentation states that “property damage estimates should be entered as actual dollar amounts, if a reasonably accurate estimate from an insurance company or other qualified individual is available” (NWS, n.d.). It also states that “if this estimate is not available, then the preparer has two choices: either check the“no information available” box, or make an estimate” (NWS, n.d.).

The only exception to this rule is that the NWS is required to provide monetary damage amounts for flood events by the U.S. Army Corps of Engineers (NWS, n.d.). Otherwise, the Storm Data preparer is only encouraged to report monetary damage estimates. These estimates can be obtained from emergency managers, U.S. Geological Survey, U.S. Army Corps of Engineers, utility companies, and newspaper articles.

The estimates of damage to insured property are typically obtained from local field office reports that often lack quality and accuracy control (Downton, Miller, and Pielke Jr 2005).

[BA: It would be interesting to see if damages are more likely to be reported based on (1) who reports the event and (2) what type of event it is. We could write some code to check this in our data.]

Difficulty of quanitfying damages

The estimates are comprised of direct and indirect monetary losses. Direct monetary losses from damage to infrastructure, buildings, crops, etc. are easier to quanitfy than indirect losses like lost revenue, business closures, societal losses, environmental damage (Gall, Borden, and Cutter 2009).

“Insurance company records include only insured property, and records of the Federal Emergency Management Agency (FEMA) include only property that qualifies for federal assistance in presi- dentially declared disasters. Few state and local governments maintain damage records beyond those required by FEMA; only in newspaper archives from cities and towns across the nation might one find more complete historical reporting of local flood damage.” (Downton, Miller, and Pielke Jr 2005)

Monetary losses can also be categorized into community, state, regional, and global levels which can further complicate the precision of the recording (Gall, Borden, and Cutter 2009).

Structural changes in how NOAA reports damages

Until 1994, damage estimates were recorded on a logarithmic scale (Downton, Miller, and Pielke Jr 2005). NOAA now records damage estimates in thousands of dollars. [BA: Could you clarify this a bit? I'm not sure what is meant here by the use of a logarithmic scale. Is this in terms of how they rounded the estimates?]

- pull up loss data for events pre and post 1995?

"From 1976 through 1979, NWS reports indicate that reduction of funding led to cutbacks in the compilation of flood damage data. Data collection continued as in prior years, but there appears to have been less checking and updating of initial damage infor- mation. Further, publication of annual summaries ceased. In 1980, compilation of flood damage estimates was discontinued entirely." (Downton, Miller, and Pielke Jr 2005)

"NWS policies on what losses to include have changed some- what over the years. Damage estimates published through 1975 focused primarily on damage to property and crops, but included some indirect losses. Present policy is to focus exclusively on physical damage to property and crops. Until 1992, separate estimates were given for property and agricultural damage, but in 1993 that distinction was eliminated." (Downton, Miller, and Pielke Jr 2005)

- provide example/tabble of how NOAA records financial losses

Change in value of the US dollar over time

The value of a dollar has changed over time. This can be addressed by normalizing any dollar measurements to a certain year to prevent bias. [It might be helpful to add some examples of studies that do this. I think there are some from Roger Pielke that look at hurricane damages over time in the US that normalize the damages. We could (briefly) include an explanation of how they do that.]

Geographic Bias

Introduction

Another area of concern in the NOAA storm events database arises with geographic bias which explains the idea that there may be inconsistencies in the recording of events due to geographic location. First, there may be differences in the supply of information from different regions based on population differences or locations of weather stations. Secondly, structural changes in the database create differences in how location data is obtained and recorded.

Location / Density of people

The reporting of events can be affected by the geographic location of the event itself (Luh et al. 2015). In an urban area, more people may be present to witness/experience a storm event than in a rural area.

- probably a tornado example we can include here [Somewhere we think there's a paper on that]

The reporting of events can be affected by geographic location based on whether or not people are present to record the event. The supply of information is greater in areas closer to the weather event (Konisky, Hughes, and Kaylor 2016). [BA: You could go more into the rural / urban question here. Would the luh2015vulnerability reference be a good example to include for this idea? The tornado example could also go here probably.]

- this idea is stated in the context of a study about correlations between weather events and public attitudes about climate change. This idea might be helpful in describing geographic bias as more concern is shown towards extreme weather in areas that are more strongly affected?

[TK: More things get reported where there are more people? Any papers on changes in numbers of media reports of disasters?]

Structural

Geographic bias also results from structural changes at the county or state level. In 1995, the NWS changed its reporting strategy from loss estimates by climate region to loss estimates in specific counties where the event occurred (Gall, Borden, and Cutter 2009). This type of change could lead to excluding loss data or double counting events (Gall, Borden, and Cutter 2009). The NOAA website even provides a disclaimer that "the source data ingested into the database are widely varied and leads to many questions about the precision and accuracy of the location data" ("Storm Data Faq Page," n.d.).

- script for checking event location pre and post 1995?

[BA: If this is a change that would happen over time, do we want to consider moving it to temporal? Or might it happen at different times in different places? For this, maybe we want to include a map of climate regions? I think a lot of readers might not know how large or small those are off the top of their heads. Also, I really like the idea of comparing event reports before and after this change. Can we see that, before the change, they followed the boundaries of the climate region?]

"47.3 Tornadoes Crossing CWA Boundaries. Tornadoes crossing state lines or boundaries of WFO CWA responsibility will be coordinated between WFOs. The preparer will ensure that the exact location where a tornado crosses a county, parish, or state line, is incorporated into the event narrative. Sharp-turning tornadoes may need to be segmented into individual pieces to adequately describe the path of that event. However, segmenting a tornado within the same county/parish is not permitted since this practice may lead to confusion and over-counting of tornadoes by the Storm Prediction Center, NCEI, and Storm Data users. It is recommended that the preparer encode only one beginning and ending point for the tornado path within each county/parish affected, and provide detailed information in the event narrative about the intermediate locations where the tornado turned sharply." ### Aggregation of reporting

When a location is entered for an event in the NOAA Storm Events database, inconsistencies may arise between where the event actually occured and the location that is recorded in the database. Currently, the smallest unit of aggregation to use all parts of the database are called Weather Forecasting Offices. Each office covers a geographic area of the US and there are currently about 122 nationwide (Konisky, Hughes, and Kaylor 2016). These geographic areas overlap with county outlines but do not always directly coincide. It is unclear exactly how NOAA decides when to assign an event to a county or a Weather Forecasting Office. In regards to this decision, the NWS documentation states that "a hydrometeorological event will be referenced, minimally, to the nearest hundredth of a mile, to the geographical center (not from the village/city boundaries or limits) of a particular village/city, airport, inland lake, or location providing that the reference point is documented in the Storm Data software location database" (NWS, n.d.).

[BA: In this section, we may also want to talk about how some events might be very localized (for example, a flash flood, or even storm surge that's only near the coast of the county), but the county-level reporting of the event means that all the county gets classified as experiencing or not experiencing the event. I think that sometimes the "Narratives" of the events give details that you could use to find out exactly what parts of the county were affected, and some events like tornadoes give the starting and ending latitude and longitude, so you can figure out the path and where that was in the county. However, overall, it's much easier from the database to get an idea of an event occurrance for the county as a whole rather than for locations within the county.] [We may want to talk a bit about the idea of ecological bias here.] [Maybe want to talk about spatial alignment.]

- include zone and fips script here?

Forecast Zone versus County

The NOAA Storm Events database also uses forecast zones as another unit of aggregation. Forecast zones are created as subsets of counties for more specific location data. Specific types of events are typically either always reported for a county (`CZTYPE` of "C") or always reported for a forecast zone (`CZTYPE` of "Z") (see table below)**. Events typically reported by county include floods, tornado-like events, and a few other events often related to thunderstorms. Events typically reported by forecast zone include severe winter weather, extreme heat, events related to the water or coast, and a few others ("High Wind", "Dense Fog", "Strong Wind", "Wildfire", "Dust Storm", "Dense Smoke").

This demonstrates the difficulty of narrowing down where exactly certain events occured. It is important to keep in mind that some events might be very localized (for example, a flash flood, or even storm surge that's only near the coast of the county), but the county-level reporting of the event means that the whole county gets classified as experiencing or not experiencing the event.

```
## `summarise()` regrouping output by 'CZ_TYPE' (override with `.groups` argument)
```

Event type	County	Forecast Zone	Total	% county
Thunderstorm Wind	18,635	0	18,635	100%
Hail	9,015	0	9,015	100%
Flood	4,951	0	4,951	100%
Flash Flood	4,093	0	4,093	100%
Tornado	1,732	0	1,732	100%
Heavy Rain	1,441	0	1,441	100%
Funnel Cloud	348	0	348	100%
Lightning	343	0	343	100%
Debris Flow	185	0	185	100%
Dust Devil	8	0	8	100%
Heat	1	1,300	1,301	0%
High Wind	1	3,789	3,790	0%
Winter Weather	0	3,808	3,808	0%
Winter Storm	0	3,354	3,354	0%
Heavy Snow	0	2,886	2,886	0%
Marine Thunderstorm Wind	0	2,502	2,502	0%
Strong Wind	0	1,591	1,591	0%
Extreme Cold/Wind Chill	0	1,065	1,065	0%
Drought	0	1,007	1,007	0%
Excessive Heat	0	889	889	0%
Blizzard	0	852	852	0%
Frost/Freeze	0	654	654	0%
Dense Fog	0	652	652	0%
Cold/Wind Chill	0	470	470	0%
High Surf	0	468	468	0%
Coastal Flood	0	240	240	0%
Ice Storm	0	200	200	0%
Wildfire	0	197	197	0%
Waterspout	0	183	183	0%
Lakeshore Flood	0	146	146	0%
Tropical Storm	0	143	143	0%
Lake-Effect Snow	0	78	78	0%
Marine High Wind	0	77	77	0%
Rip Current	0	74	74	0%
Avalanche	0	44	44	0%
Dust Storm	0	40	40	0%
Marine Tropical Storm	0	37	37	0%
Marine Hail	0	32	32	0%
Tropical Depression	0	26	26	0%
Storm Surge/Tide	0	25	25	0%
Marine Strong Wind	0	17	17	0%
Astronomical Low Tide	0	16	16	0%
Hurricane	0	10	10	0%
Freezing Fog	0	6	6	0%
Marine Hurricane/Typhoon	0	6	6	0%
Marine Tropical Depression	0	4	4	0%
Seiche	0	4	4	0%
Sneakerwave	0	3	3	0%
Dense Smoke	0	2	2	0%
Sleet	0	1	1	0%
Volcanic Ashfall	0	1	1	0%

Systemic Bias

[TK: I haven't been able to find a lot of support or evidence for this type of bias. Maybe this could be a good place to describe how these problems span many databases.]

Limitations of this paper

- Some of the examples may not be examples of bias but actual meteorological phenomena that we don't fully understand.
- I hope that I have researched my examples enough that I am making accurate claims in the eyes of an atmospheric scientist.

- There may be more forms of bias present in this data that we do not claim
- May be even other factors at play that make the data appear as it is

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