Assessing Climate Change and Whiplash Events in National Parks

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ABSTRACT

National Parks have experienced extensive devastation from extreme weather events. This includes precipitation whiplash events which are defined by the rapid shift of opposing precipitation extremes and is a recent and growing topic in the field of meteorology. These events have been linked to increased risk of flash flooding, droughts, and wildfires which have devastating effects to National Parks. Previous studies have noted that whiplash events are projected to become more frequent and intense due to climate change. As such, it is necessary for park managers to create plans and adapt to these extreme weather events. However, the underlying knowledge on the conditions behind these events, needed to develop these plans, are under-researched in comparison to the individual dry and wet extremes that make up the event. The purpose of this study is to fill this gap by analyzing precipitation whiplash events at two specific National Parks–Alibates Flint Quarries National Monument, and Pecos National Historic Park– to better understand the historical frequency and conditions surrounding whiplash events. This study first identifies 16 historical triple whiplash events for each park using the Standardized Precipitation Evapotranspiration Index between 1981 and 2021, before examining their characteristics, evolution, and driving mechanisms. Both parks experienced similar whiplash characteristics of duration and increases in frequency within the historical period. A significant difference in the driving factors and patterns for the conditions of whiplash events was also experienced between the two parks. Evidence of the North American Oscillation (NAO) system was found at ALFL while PECO has evidence of being driven by less large-scale dynamics. These findings indicate a need for the National Parks to create park specific assessments and tools to better plan for whiplash events.

1. INTRODUCTION

On 13 June 2022, heavy rainfall and snowmelt created a 1 in 500 year flood event at Yellowstone National Park (NPS 2023). This event closed down the park, destroyed multiple entrance roads, power lines, and other park critical infrastructure, caused multiple rockslides and mudslides, and required $60M USD in Emergency Relief Federally Owned Roads - Quick Release (ERFO-QR) funding (NPS 2023). This flood is just one of many to occur in the U.S. costing around $179.8 and $496.0 billion each year in 2023 dollars (JEC 2024). Flooding ranks first among the weather-related causes of property damage in the United States, while also being the second largest weather-related cause of death worldwide (Dong et al. 2011). On the other hand, droughts are just as critical and important to National Parks and the US. Droughts can cause plant stress, increase wildfire risk, and reduce water resources (Mullens and Engström 2025; NIDIS 2022). Droughts can also facilitate conditions to better suit invasive species which can completely change a national park's ecosystem. A drought from 2002 to 2003 in Bandelier National Park in New Mexico led to the death of most pinyon pine trees in the park's extensive pinyon-juniper woodlands (NPS 2021). Later, fires further changed the park's landscape resulting in widespread conversion of pinyon-juniper and ponderosa forest to oak-locust shrublands. Understanding how extreme conditions such as floods and droughts occur can help park managers create strategies to prepare for these events in the future.

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While floods and drought have been researched extensively, studies tend to evaluate these events separately. However, when floods and drought occur in rapid succession, their impacts can compound on each other that differ or may even exceed what either event might have done independently (Mullens and Engström 2025). Subsequently, this occurrence of rapid succession, known as whiplash events, is an under-researched topic in the meteorological field. This is in part due to the recent coining of the term, the undefined nature of the term and key characteristics (i.e droughts), and the diversity of terms used to refer to such events (Mullens and Engström 2025; Rezvani et al. 2023; Zhang et al. 2025). For our use, whiplash events are a compound event that occurs when an extreme immediately follows another with little to no break in between (Puxley et al. 2024). Typically of opposing extremes, the rapid shifting or 'flip' of extremes occurs within a short time span. The short time period of the events can lead to compounding impacts that may differ or even exceed what the events might have done individually (Mullens and Engström 2025). In terms of precipitation whiplash events, these two extremes are the opposing precipitation extremes of anomalously wet and dry periods. Transitions between extreme dry to wet periods can lead to an increased risk of flooding especially flash flooding, landslides, erosion, and runoff (Zhang et al. 2025). On the other hand, transitions between extreme wet to dry periods can lead to flash droughts as well as increased risk of wildfires due to greening of vegetation (Puxley et al. 2024). Both types of events make it harder for water resource managers as the two extremes have widely different and even opposing water strategies to manage (Götte and Brunner 2024; Mullens and Engström 2025; Goodrich and Ellis 2008).

One of the most researched aspects of whiplash events is how they are predicted to change in frequency and magnitude in a changing climate (Mullens and Engström 2025). Swain et al. (2025) found that whiplash events have increased on average globally by 31–66% for subseasonal whiplash events and 8–31% for interannual whiplash events since the mid twentieth century. Furthermore, dry and wet periods are predicted to not only get longer and more intense, but also transition faster between the two (Rezvani et al. 2023). Both extreme wet and dry periods have a positive relationship with temperature. Warmer air has a greater capacity to hold moisture due to the Clausius-Clapeyron relation while also increasing evapotranspiration. More moisture in the atmosphere may lead to increased precipitation, leading to more extreme wet periods. On the other hand, increases in evapotranspiration can lead to prolonged and more frequent drought occurrences if the moisture deficits from the increased evapotranspiration is not offset by increases in precipitation (Rezvani et al. 2023). Understanding how whiplash events are defined and have occurred historically leads to better analysis of how they might change in the future. This is imperative for climate change studies that focus on these types of extreme events to get a better grasp on how they will change in the future.

One organization that greatly benefits from understanding how whiplash events change due to climate change is the National Parks. The threat of climate change on the National Parks Service (NPS) is not a new topic. In fact, climate change disproportionately affects National Parks as a higher number of parks are located in extreme environments including the Arctic and the arid southwestern US (Gonzalez 2020). Climate change can alter and threaten natural, cultural, and historical resources: infrastructure, ecosystems, and wildlife: as well as visitor experiences and behavior at the parks (NPS 2021). In more extreme cases, the warming climate can completely alter a park's landscape, some of which is already visible with the melting of glaciers and permafrost at multiple parks (Gonzalez 2020). Established in 2010, the NPS Climate Change Response Program (CCRP) has worked to research, address, and adapt to the threat of climate change across the parks. One of the ways that the NPS adapts to climate change is through a process known as scenario planning. Scenario planning helps parks make short- and long-term decisions that avoid surprises and costly mistakes (CCRP 2024b). The process involves park managers considering multiple plausible future conditions and the uncertainty of those projections. Understanding and furthering the science and knowledge of precipitation whiplash events helps decision makers to determine more plausible future scenarios to better inform future decisions to prepare for them.

The purpose of this study is to analyze precipitation whiplash events at the National Parks in order to better understand the characteristics, evolution and conditions of precipitation whiplash events in the parks. Specifically, we are looking at two parks in particular: Alibates Flint Quarries

National Monument, and Pecos National Historic Park. This project hopes to use these two parks as an example as a starting point for park specific analysis of whiplash events conditions in National Parks.

2. DATA & METHODS

2.1 *Parks of Interest*

Located in the Southern Plains Inventory and Monitoring Network, Pecos National Historic Park (PECO) and Albites Flint Quarries National Monument (ALFL) are no stranger to extreme weather. The Southern Plains Inventory and Monitoring Network region is characterized in its unpredictability with a higher frequency of extremes including drought, fires, and other severe weather (Davey 2007). The region also has a sharp zonal precipitation gradient that can fluctuate on sub-seasonal to interannual scales (Puxley et al. 2024). ALFL is located in the high plains region of the panhandle of Texas. PECO on the other hand is located in a valley in the mountainous part of the high desert region of northern New Mexico. Both parks historically have an arid, semi arid climate that falls within the North American Monsoon. The North American Monsoon is notable in being one of the main precipitation mechanics for the two parks, especially PECO. Alongside the North American Monsoon, the El Nino-Southern Oscillation (ENSO) influence in the region adds to the uncertainty and variability of precipitation at the parks (Davey 2007). Another teleconnection to pay attention to is the North Atlantic Oscillation (NAO).

PECO climate generally experiences hot, dry summers with milder and cooler winters. Due in part to the park being located nearly 7,000 ft in elevation, the park averages around 508.0 mm of snowfall each year (NPS 2024a). At PECO, precipitation is highly variable in its mechanics. In New Mexico, there is a recorded inverse relationship between winter precipitation and North American Monsoon precipitation the following season (NOAA 2018). Nearly 40-50% of the northern portion of the state's annual precipitation occurs during the North American Monsoon monthly period (July, August, September). However, the North American Monsoon is characteristically highly variable in both annual precipitation as well as day-to-day precipitation. At PECO specifically, the park averages around 228.6 mm of rainfall during this period (NPS 2024b). The location of PECO in a valley can introduce variability in precipitation amounts even with the surrounding area due to local phenomena such as rain shadowing. Similarly, ALFL generally experiences hot, dry summers with milder winters. ALFL's annual average precipitation is 500.9 mm of rainfall calculated from a 1991-2020 dataset (PRISM 2024). On average, winter at the park tends to be dryer while the North American Monsoon monthly period tends to be wetter with an average 35% of the annual precipitation.

Both parks have already noticed changes in their climate. Done in part of a climate future study, the parks analyzed their historical climate trends since 1895 (CCRP 2024a; CCRP 2024b). Both parks noted a warming trend in temperature, with a noticeable increase of warming after 1970. An overall decrease in annual precipitation also occurred since 1970, though there has been a noticeable change in extreme conditions with an increase in the amount of rain falling in the heaviest rain events (top 1%) since 1958 (17% for PECO and 21% for ALFL). While the average amount of rainfall has decreased, the rain events themselves have become more compacted and extreme at both parks. When looking at two specific future scenarios, Warm Wet and Hot Dry climate futures, PECO's climate future study found that drought duration and severity are projected to increase and the drought-free interval is projected to decrease, relative to the past climatology. Similar drought projections were noted in ALFL's climate future summary. While this is great information to get an understanding of the climate of these specific parks, these future summaries can only point to the direction that annual trends are occurring, more information is needed for district events including whiplash events.

2.2 *Data*

The dataset used to locate whiplash events at the specific parks was the Parameter Regression on Independent Slopes Model (PRISM) (PRISM Climate Group 2019). PRISM is a high-resolution spatial climate data that uses observation in-situ point measurements in its statistical mapping system that is on a daily time scale. The product is produced by the PRISM Climate Group at Oregon State University at a 800km spatial resolution for its daily products. PRISM is most notably used as the United States Department of Agriculture (USDA)'s official climatological data (Daly 2019).

The variables used to determine events of interest were the daily precipitation, daily maximum temperature, daily minimum temperature, and daily dew point temperature. These variables were obtained through the PRISM Explorer tool for the years 1981–2021, using the latitude and longitude values of each park unit's visitor center to determine the data grid cell. In order to analyze the conditions surrounding the established historical whiplash events at each park we used the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) dataset (Hersbach et al. 2020). We obtained 500 hPa geopotential heights as well as calculated the geopotential height anomalies for each day using a calculated daily long-term average over the dataset. Due to ERA5 producing on an hourly timescale, daily means were calculated for each day at each park.

2.3 *Defining Historical Whiplash Events*

In order to properly define whiplash events, it is necessary to define its compound parts. To locate extreme dry and wet periods needed to determine historical whiplash events within the period of 1981-2021, we calculated the Standardized Precipitation Evapotranspiration Index (SPEI) for each park. SPEI is a multiscalar drought index that uses climatic water balance over time to assess conditions (EDO 2020). It is a modified extension of the widely used Standardized Precipitation Index (SPI) which is the standard drought index of the World Meteorological Organization (WMO). In comparison to the SPI, which relies solely on precipitation data, SPEI factors in potential evapotranspiration (PET) to determine drought. This allows the SPEI to capture the impact of rising temperature on water demand, which is an important relationship in climate studies. Furthermore, Chen et al. (2022) found that increased PET and precipitation variability are the main factors that accelerate whiplash event transitions in North America, showcasing the need to factor both into consideration. A simplified version of the SPEI was calculated through the SPEI python package for a calculated 3 and 6 month timescale (SPEI-3, SPEI-6) (Vonk 2024). The shorter timescale of values was chosen to account for short-term droughts in the historical record. In order to estimate the PET, this project used the Hargreaves method which accounts for latitude in its calculations through the Pyet python package (Vremec 2023). Using a threshold approach, we located each historical whiplash event using a common threshold defined for an extreme wet (SPEI > 1.0) period and extreme dry (SPEI < -1.0) period. These thresholds were chosen due to their wide use in previous studies on whiplash events (Chen et al. 2022; Mullens and Engström 2025). In this study we are defining a precipitation whiplash event as a triple 'flipping' of precipitation extremes within a subseasonal scale. Both extremes are being analyzed to locate an extreme wet-dry-wet event (WDW) and an extreme dry-wet-dry event (DWD) within a total timescale of 6 months. We looked at these triple events in particular as they are a more extreme version of the more studied wet-dry and dry-wet events due to essentially being both events compounded on a timescale similar to most analyzed whiplash events. The start date for each event is defined as the last day the SPEI is above/below the initial period threshold. The peak intensity date is defined as the date with the greatest magnitude of SPEI within the middle period. Finally, the end date is the date that the SPEI reaches the initial period threshold again.

2.4 *Analyzing Whiplash Events*

To analyze the whiplash events conditions at each park, we created geopotential height and geopotential height anomaly composites at the 500 hPa pressure level for each event type start, peak, and end dates. The geopotential heights and geopotential height anomalies were averaged over all similar events for each determined date of the event for each park. These composites were evaluated as part of the analysis to determine how the circulations and flow patterns evolved for each event.

3. RESULTS

3.1 *Park SPEI Graphs*

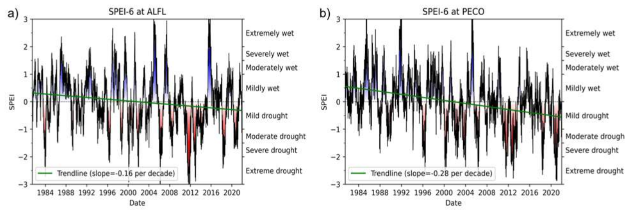

FIG. 1. Plots displaying the calculated SPEI-6 for Albites Flint Quarries National Monument (ALFL) (a) and Pecos National Historic Park (PECOS) (b) from 1981-2021 with calculated trendline (per decade).

Examining the calculated SPEI-6 for both ALFL and PECO, certain trends are apparent in how each park climate has changed over our dataset (Figure 1). Both National Parks present a drying trend represented by the decreasing slope of the trendline on the graphs. While ALFL has a more variable yet slightly decreasing trend of -0.16 SPEI per decade (Fig. 1a), PECOS has a more significant overall decreasing trend of -0.28 SPEI per decade (Fig. 1b). Since 2012, both parks experienced a series of droughts though while ALFL had a couple strong extreme wet periods helping the park recover, PECO did not to the same extent emphasize the overall decreasing trend.

3.2 *Whiplash Timeseries*

When mapping out the historical whiplash events over time, a few trends are evident. Both parks historically experienced 16 triple whiplash events as well as the same amount of each type of event with 5 WDW events and 11 DWD events. At both parks, more whiplash events occurred after the year 2000 indicating an increased trend in the frequency of events (Figure 2). Furthermore, the number of WDW events after 2000 dropped drastically in both parks with only two events in ALFL (Fig. 2a) and no events in PECOS (Fig. 2b). On the other hand, the number of DWD events increases after 2000, with 8 out of the total 11 DWD events in ALFL and 9 out of 11 DWD events in PECO.

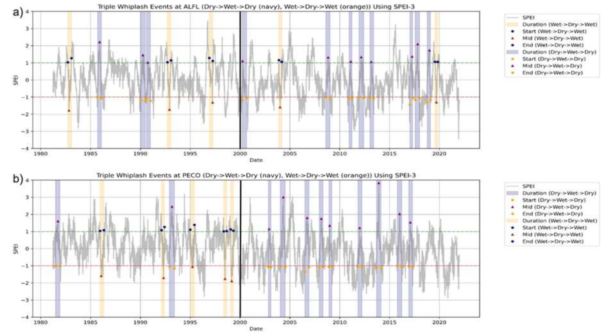

FIG. 2. Plots of time series of triple whiplash events and calculated SPEI-3 at Albites Flint Quarries National Monument (ALFL) (a) and Pecos National Historic Park (PECO) (b) from 1981-2021. Wet-Dry-Wet (WDW) events are highlighted in yellow while Dry-Wet-Dry (DWD) events are highlighted in blue. The black line is located at the year 2000 representing the midpoint of the dataset.

3.3 *Whiplash Event Statistics*

Another way to look at whiplash events is through their average intensities and durations is through statistics. At ALFL, WDW events on average transitioned faster than the DWD events alongside having a shorter average duration of 116 days and 142 days respectively (Table 1) Similarly, at PECO, WDW events last on average 120 days versus 147 days for DWD events (Table 2) Both parks experience similar peak intensity of WDW events (-1.55 for ALFL and -1.60 for PECO; Tables 1 and 2). For DWD events, however, PECO has a much higher average peak intensity of 1.97 than ALFL (1.43). PECO DWD events also have over double the variability in peak intensity compared to ALFL DWD events. The shortest recorded transition between the two extreme periods was 4 days during the peak to end transition of a WDW event at ALFL.

Table 1. Table displaying for Albites Flint Quarries National Monument (ALFL) Wet-Dry-Wet (WDW) triple whiplash event and Dry-Wet-Dry (DWD) triple whiplash event. The table shows the calculated average, maximum, minimum, and standard deviation for each event type peak intensity value, start date to peak date transition (SP), peak date to end date transition (PE),

and total event duration for each event type. All durations are in days.

WDW	Peak Intensity	SP Transition (Days)	PE Transition (Days)	Total Duration (Days)
Average	-1.55	66	50	116
Max	-1.30	121	92	131
Min	-1.79	39	4	99
Std	0.23	34	31	15
DWD	**Peak Intensity**	**SP Transition (Days)**	**PE Transition (Days)**	**Total Duration (Days)**
Average	1.43	68	74	142
Max	2.22	90	152	176
Min	1.02	11	20	101
Std	0.41	24	35	24

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Table 2. Table displaying for Pecos National Historic Park (PECOS) Wet-Dry-Wet (WDW) triple whiplash event and Dry-Wet-Dry (DWD) triple whiplash event. The table shows the calculated average, maximum, minimum, and standard deviation for each event type peak intensity value, start date to peak date transition (SP), peak date to end date transition (PE), and total event duration for each event type. All durations are in days.

WDW	Peak Intensity	SP Transition (Days)	PE Transition (Days)	Total Duration (Days)
Average	-1.60	59	61	120
Max	-1.06	87	89	152
Min	-1.89	35	32	97
Std	0.32	22	20	23
DWD	**Peak Intensity**	**SP Transition (Days)**	**PE Transition (Days)**	**Total Duration (Days)**
Average	1.97	71	76	147
Max	3.83	107	88	178
Min	1.14	27	64	96
Std	0.83	26	8	26

3.4 *Composites (6 figs in one):*

ALFL:

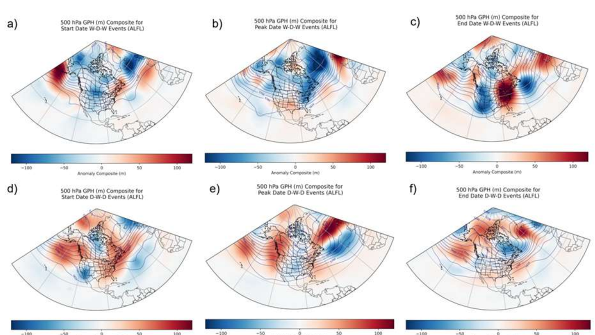

FIG. 3. Series of geopotential height (GPH) and height anomaly composites for Wet-Dry-Wet (WDW) whiplash events and Dry-Wet-Dry (DWD) whiplash events for Albites Flint Quarries National Monument (ALFL) from 1981-2021 at 500 hPA pressure level.

In order to understand the conditions surrounding whiplash events at each park, figure 3 for ALFL and figure 4 for PECO, shows an upper air map at 500 hPa of the geopotential height and geopotential height anomalies at each park. These composites can be used to analyze the circulation and flow patterns in each type of whiplash events at the park. The ALFL WDW start date composite (Fig. 3a) has a trough over central US with positive geopotential height anomalies in the Northeast US. In the nearby Atlantic, the composite also indicates a positive NAO pattern. The peak date composite of the WDW event (Fig. 3b) has zonal flow with a slightly higher than average geopotential height in the US Southern Great Plains and anomalous troughing along the Atlantic coast. The end date composite of the WDW event at ALFL (Fig. 3c) has a highly amplified pattern across North America with a strong ridge in the Eastern US and below-normal heights in the Western US. Note that ALFL park is located in the transition between these two high amplitude features.

The ALFL DWD start date composite (Fig. 3d) has zonal flow and above-normal heights in the Eastern US. In the Southwest US a cutoff anomalous trough is present. The peak date composite of the DWD event (Fig. 3e) has a trough over the central US and anomalous ridging along the Northwest Pacific coast as well as positive geopotential heights anomalies along the Atlantic coast. In the nearby Atlantic, the composite also indicates a negative NAO pattern. The end date composite of the DWD event at ALFL (Fig. 3f) is mostly zonal flow with a trough and below-normal heights located over the Hudson bay. An anomalous ridge is located over Greenland and the Northern Atlantic. A weak trough is located over the Northwest and the US Northern Plains and slightly above-normal heights in Texas.

PECO:

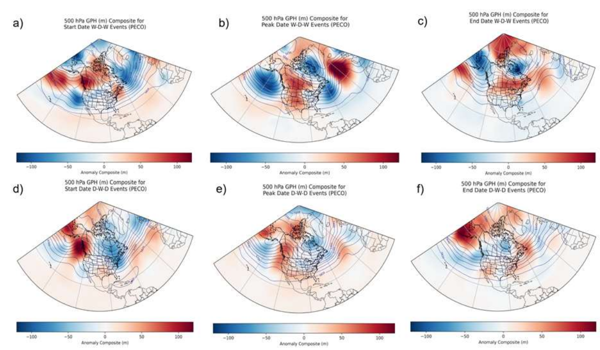

FIG. 4. Series of geopotential height (GPH) and height anomaly composites for Wet-Dry-Wet (WDW) whiplash events and Dry-Wet-Dry (DWD) whiplash events for Pecos National Historic Park (PECO) from 1981-2021 at 500 hPA pressure level.

The PECO WDW start date composite (Fig. 4a) has zonal flow over the central US with positive geopotential height anomalies in the Northeast US. An anomalous ridge is located in the Northwest Pacific coast. In the Pacific a cutoff anomalous trough is present. The peak date composite of the WDW event (Fig. 4b) has a strong ridge over the central US as well as the Atlantic. A trough is located off the eastern Atlantic coast and in the northern Pacific. The end date composite of the WDW event at PECO (Fig. 4c) has a weak cutoff trough located over Texas. A weak ridge and positive geopotential height anomalies is located in central Canada. An area of below-normal heights is situated over the Labrador Sea as well as Alaska with a trough.

The PECO DWD start date composite (Fig. 4d) has zonal flow over the Atlantic. A strong anomalous ridge is located in the Northern Pacific while a trough is in the Northeast US. A weak cutoff trough is located over California and a slightly higher than average geopotential height in the US Southern Great Plains. The peak date composite of the DWD event (Fig. 4e) at PECO has a strong ridge over the Northwest Pacific coast. Mostly zonal flow over the US with below-normal heights in the Great Lakes Region and above-normal heights in the Southern US. A ridge is located in the Atlantic and a trough is located in the Central Pacific. The end date composite of the DWD event at PECO (Fig. 4f) has a weak trough in the Great Plains as well as a weak ridge over the Western US. The rest of the US is mostly zonal with slightly above-normal heights along the East Coast.

4. DISCUSSION & CONCLUSION

Understanding the characteristics and driving factors of whiplash events at the National Parks is important in informing how to better plan for them. The use of scenario planning at the National Parks means that a greater understanding of how events occur and their potential impacts can produce more realistic scenarios for managers to plan for. Consistent with previous studies, we found that both ALFL and PECO climates are trending drier over our dataset (Fig.1). PECO in particular has a more significant trend than ALFL which in turn experiences more variability in recent extremes. This matches the climate futures done at both parks that showcase a dryer but more extreme conditions at the parks (CCRP 2024a; CCRP 2024b).

We found that the two parks historically experienced 16 triple whiplash events each as well as the same amount of each type of event with 5 WDW events and 11 DWD events. We attributed these similarities to coincidence and not any other factor for this study. It is noted that while a couple whiplash events overlap between the two parks, no whiplash events fully overlap with another. There is also a need to point out that there is most likely bias present in our results due to the small sample size of events found at the parks. Overall, both parks experience more historical DWD events than WDW events. Thus, both parks are more susceptible to back to back extreme dry periods than wet periods. This can be in part due to the semi-arid climate of the region being more susceptible to dry extremes than wet extremes. Another factor that may be linked is the drying trend experienced by the two parks (Fig. 1). This could be a potential connection to the noted near depletion of DWD whiplash events after 2000 (Fig. 2). While ALFL experienced two WDW events after 2000 (Fig. 2a), PECO has experienced no new WDW events after 2000 (Fig. 2b) while also having the more significant drying trend of the two parks (Fig. 1b).

In comparison, there is a present increase in frequency of total whiplash events after 2000, as well as of DWD events at the parks (Fig. 2). The increase in overall frequency matches a noticed trend in other studies on whiplash events (Swain et al. 2025; Chen et al. 2022; Rezvani et al. 2023). While many of these studies cite climate change as part of the contributing factors in the frequency trend, we are unable to link the two phenomena in this study. In terms of the characteristics of the whiplash events, both parks experienced similar events with a few key differences. Both parks have similar average total duration for each type of event with PECO noting a slightly longer average duration (Tables 1 and 2). Likewise, the average peak intensity of WDW events at the parks are also similar with PECO having a slightly higher average. For DWD events however, PECO experiences on average more intense wet periods within the total event compared to ALFL. Furthermore, PECO DWD event's peak intensity is over double the variability than ALFL. The similarities in characteristics of the whiplash events at the parks may be due to their close location to each other as well as their similar climates. A final characteristic to note is that WDW events have a shorter transition between extremes as well as a shorter duration compared to DWD events at both parks. The shortest transition seen at the parks is a 4 day period between the peak date and end date of a WDW event at ALFL (Table 1). This showcases the key characteristic of whiplash events rapidly ‘flipping’ between extremes. This particular transition was courtesy of a month-long period of no recorded rain at the park followed by a 2 day rain event totaling roughly 64.3 mm or 13% of ALFL’s annual average rainfall (PRISM Climate Group 2019).

When looking at whiplash events conditions, ALFL composites show signs of the park’s events being driven by more large-scale dynamics (Fig. 3). Wet periods at the park show a pattern of a trough situated over the central US while dry periods have a pattern of above average geopotential heights over Texas for the park. These patterns line up with previous work done on drought and anomalous wet periods patterns in the Southern Great Plains (Dong et al. 2011; Mullens and Engström 2025). The NAO is notably present is multiple ALFL composites showing an influence on precipitation at the park with a positive pattern featured in the start date of the WDW event and a strong negative pattern on the peak date of our DWD event (Figs. 3a,e). PECO composites on the other hand tend to be more zonal, with weaker flow patterns (Fig. 4). Both the peak dry period of the WDW and the end period of the DWD events feature a ridge over the park. However, patterns between individual composites are not as prominent as was at ALFL. One part that could contribute to this is the terrain at PECO park. Being located in a valley among the mountainous region of New Mexico, PECO could experience local scale processes such as rain shadowing that could influence how synoptic patterns bring precipitation to the park. The most notable finding though was how different the composites are for the two parks even for similar events. Despite both parks being located in the same region and having similar semi-arid climates, each park has different factors that influence whiplash events. This shows a need for the National Parks to use park specific tools to assess events like whiplash events in future planning.

As stated previously, whiplash events are an understudied area of research especially with National Parks. As such for future work, it might be good to expand to try to find what other conditions are affecting whiplash events, in particular the ENSO which was not looked at in this study. There is also a need to look at how whiplash events are predicted to change in the future at the parks. It would be worth studying if the historical increase in frequency of whiplash events found in this study continues and what effect climate change might have on them. Another area to study is seeing if other parks in the region experience similar trends and conditions surrounding whiplash events, as this study points out a need for more park specific instead of regional assessments of whiplash events at the National Parks.

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