**Diagnosing Rainfall Variability Within A Series of Atmospheric Rivers over Northern California in February 2017**

**Parker Malek**

# Introduction

High intensity precipitation events are described by their unusually high rates of precipitation over a given duration of time. However, these events can also be distinguished by the various impacts that result from them. As known drivers of rapid and potentially hazardous changes in landscape through flash flooding, erosion, snow melting, landslides, and debris flows (IPCC, 2022), extreme high intensity precipitation (HIP) events can lead to high socioeconomic costs through their ability to simultaneously affect drinking water supplies, fishery health, and transportation infrastructure over short time periods. As studies have suggested that these kinds of precipitation events are likely to increase in intensity as the climate warms (Kunkel et al., 2013), understanding the synoptic and mesoscale physical characteristics of HIP events is critical for the development of future mitigation strategies and infrastructure improvements.

Previous research has investigated spatial and temporal patterns of high intensity precipitation along the West Coast of the US. For example, Ralph et al. (2006) and Neiman et al. (2011) used radar and streamflow data to analyze and document extreme precipitation events in California’s Russian River and Washington’s Olympic and Cascade Mountains. Guan et al. (2010) similarly analyzed precipitation data from the Sierra Nevada Mountain Range in California and found that the largest precipitation events were associated with atmospheric rivers (ARs), synoptic-scale (1000 km or larger) narrow bands of water vapor that can transport large amounts of moisture out of the tropics to the mid-latitudes. Atmospheric rivers account for a significant proportion of high impact hydrological events in the state of California (Young et al. 2017).

Within these large-scale systems, smaller mesoscale characterizations of HIP events have also been described. Because of California’s unique water resource dependencies on a few extreme precipitation events during the winter season, numerous studies have utilized the state’s topographic variability and large spatial extent to describe HIP events in relation to orographic drivers and AR storm-level summary analyses (Lamjiri et al. (2018); Cannon et al. (2017)). Additional work has been done to describe smaller scale meteorological features embedded within ARs that contribute to HIP events. Convective narrow cold frontal rainbands (NCFRs) are a characteristic of particularly sharp frontal boundaries and are often accompanied by strong gusty winds and brief but intense precipitation. Studies have shown that the “precipitation cores” formed within NCFRs are associated with high surface convergence and some of the highest rates of precipitation in storms where the phenomena are observed (Houze et al., 1976; Hobbs & Persson, 1982; Koch & Kocin, 1991). These systems have additionally been associated with many costly and destructive debris flow and landslide events in Southern California (Cannon et al., 2018; Oakley et al., 2017; Sukup et al., 2016, de Orla-Barile, 2022).

As the hydroclimate of California is dominated by wild swings in drought and non-drought years, similar annual extreme events within the state often impact the hydrologic and geomorphic response to precipitation by changing the physical relationships among rainfall, runoff, erosion, and hillslope stability. HIP events that trigger these landscape responses increase the risk of simultaneous disasters where water and emergency managers face increasingly dire tradeoffs between water quality, transportation networks, community safety and flood prevention. Recent studies (Agilan, et al., 2017; Chanaud et al., 2021) have found that precipitation intensity-duration-frequency (IDF) relationships have changed from the historical curve in many regions, with many of these changes found in higher intensity, shorter duration events. Because these curves are oftentimes used to design water control infrastructure, and the design of long-lifetime infrastructure is that the curves represent a stationary climate, non-stationarity implies risk to infrastructure and socioeconomic health.

Previous scholarly research has identified two distinct challenges associated with the current state of high intensity precipitation research:

1. **Poor understanding of processes that cause high intensity precipitation.**

It is known that the highest precipitation rates on earth are found in deep convective cells. However, the details of how convective elements organize or how strong rising motion embeds within larger precipitating systems (e.g. cyclones or fronts) are poorly understood and are critical for understanding how high rates persist long enough to cause significant impact (Poujol et al. 2021, Fowler et al. 2021). Furthermore, numerical climate models partially rely on the parameterization of these high resolution moist processes within storms, and it has been found that biases in storm track position and intensity are likely linked to uncertainties associated with these kinds of meso-scale processes (Shaw et al., 2016).

1. **Poor understanding of the landscape responses to high intensity precipitation.**

Rainfall intensity is known to affect land surface processes such as infiltration, runoff efficiency, erosion, and runoff/liquid water retention during rain-on-snow events and sensitivity to HIP has been well-studied via laboratory and computational experiments. However, landscape scale processes are less understood (I.E. flash flooding, debris flow and landslide initiation, mass erosion, stream network sediment loading, and snowpack loss) and may become exacerbated when events occur within disturbed regimes. Sequencing of intra-event HIP is known to modulate the above impacts, but little work has been performed to link the sequencing of HIP in real events to hydrological and geomorphic outcomes (Dunkerley et al., 2021).

Notable events have illustrated the socioeconomic impact of HIP. In 2017, the Oroville Dam Crisis in the state of California was in part triggered by a series of atmospheric river events that affected the region in early February. The pulses of high intensity precipitation within these AR events caused heavy damage to the primary and emergency spillway of the Oroville Dam, leading to the evacuation of 188,000 people and around $1 billion in damage-related repairs (Henn et al., 2020; Vano et al., 2018; White et al., 2019). Previous studies have characterized the meteorological events surrounding the crisis with the intent of improving station-based ensemble surface meteorological analyses, describing the runoff mechanisms that led to the crisis, and quantifying the effects of climate warming on increased precipitable water in AR systems, but the drivers of within-AR rainfall intensity has not been well-described for the event (Bunn et al, 2022; White et al, 2019; Michaelis et al., 2022).

# Study Objectives

This case study will provide synoptic and mesoscale characterizations of a series of landfalling ARs that triggered the February 2017 Oroville Dam Crisis in the state of California. Rain gauge, satellite-based, and reanalysis data will be used to identify high intensity, short duration precipitation pulses embedded within these ARs, and the local and synoptic-scale forcing characteristics attributed to these pulses will be identified and statistically described. Results will provide insight into how short duration high intensity precipitation propagates within larger storm systems and will expand our understanding of the mechanisms that drive high intensity precipitation variability from within-storm events.

Developing an understanding of the mesoscale features of HIP that occur within the events surrounding this crisis will address the above challenges by improving the ability to accurately project these events in future climates through dynamical and statistical means, highlighting critical uncertainty in detection and prediction, providing gains in predictive skill and scientific insight into the impact of HIP on changing landscapes, and generating new decision-support information to assist water and environmental resource managers in developing the next generation of adaptive management practices.

# Data and Methods

## Study Region

The Oroville Dam is located near the city of Oroville California. The city is on the geographic edge of the Yuba-Feather watershed region in Northern California. The watershed region consists of river systems that have a long history of catastrophic flooding, with five major floods resulting in 41 deaths since 1950 (FIRO). The region has the climatological propensity to be affected by extreme precipitation events that often lead to high socioeconomic impacts, with the Oroville Dam crisis being one of these high impact events. For this study, the Oroville municipal airport is used as an approximate location for the dam, with the dam being location around miles from the airport.

A map of the state of california

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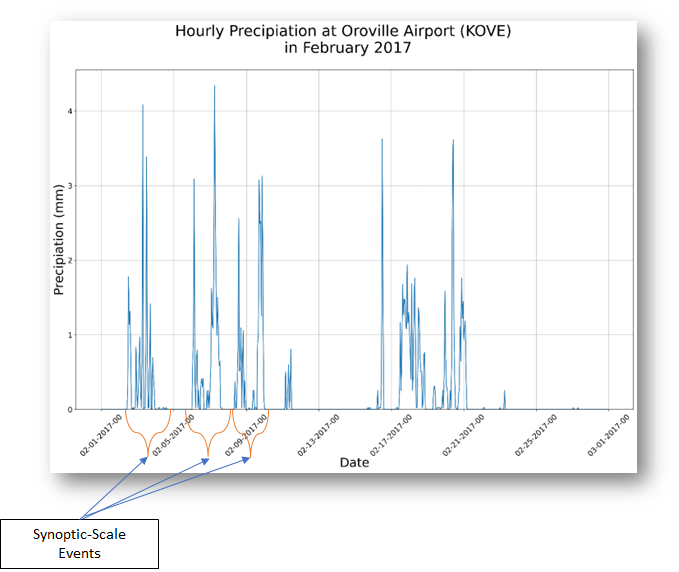
Figure 1. Location of Oroville, California

## MesoWest Station Data

This study utilizes rain gauge data to approximate precipitation around the Oroville Dam. The University of Utah’s MesoWest project provides access to archived weather observations across the United States, with extensive records of hourly precipitation available for many airport-based stations across the country. The station located at the Oroville Municipal Airport has an extensive record of hourly precipitation data and was used to pull precipitation records for February 2017. Raw precipitation data from MesoWest required resampling to consolidate precipitation values to the nearest hour. Data with multiple time stamps per hour were resampled using the mean value across each respective hour. Additional time series were constructed from California Data Exchange Center weather gaging stations within the watershed region to confirm the presence of similar synoptic-level pulses across the study region during the events flagged with the resampled airport time sers. (Figure 1).

|  |  |  |  |
| --- | --- | --- | --- |
| **Watershed Region Name** | **Station Name** | **Station Code** | **Years of Data Available** |
| Yuba-Feather | Oroville | kove | 24 |

Table 1. MesoWest sites selected for analysis



A graph showing the number of precipitation

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Figure 1a. Resampled hourly precipitation time series for Oroville Airport, California for February 2017. Example of synoptic scale events identified.

## Synoptic and Mesoscale Pulse Identification

A two-pronged approach is used to categorize pulses of precipitation for the study. Longer-term synoptic scale events are first identified visually from the monthly time series of rainfall events at Oroville Municipal Airport. This process identified 7 separate synoptic-level events. Within each of these synoptic level events, individual mesoscale pulses are identified through a similar visual process. Each individual pulse of precipitation will be the characterization factor for these mesoscale pulses, with each syntopic level event often containing multiple pulses (Figure 2). 9 Pulses were identified through this visual identification methodology.

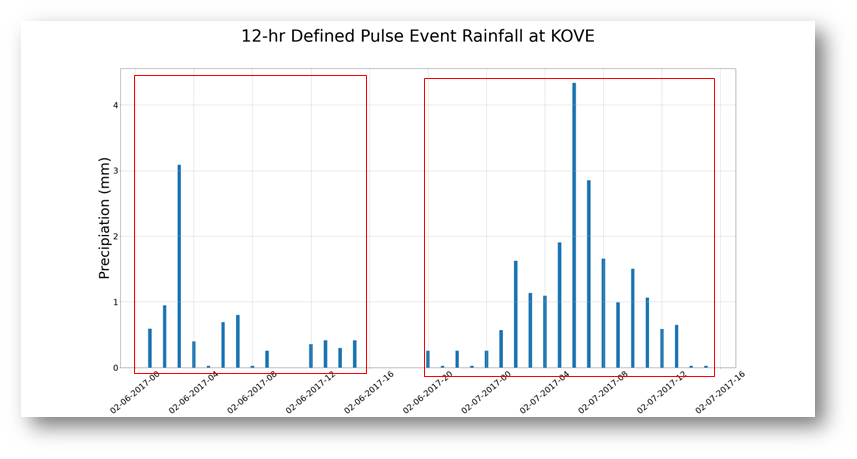


Figure 2. Example of “multimodal” pulses found within synoptic level event at Oroville Airport in February 2017

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Figure 3. Pulses found within synoptic level event at Oroville Airport in February 2017



|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Synoptic Event  #** | **Pulse Event  #** | **Event start date  (mm-dd-hh)** | **Event end date  (mm-dd-hh)** | **Total  Precipiation  (mm)** | **Average  Precipiation  (mm)** | **Maxium  Precipitation  (mm)** | **Day  Difference** |
| **1** | **1** | 02-02-11 | 02-04-14 | 22.02 | 0.42 | 4.08 | 2 days 3 hours |
| **2** | **2** | 02-06-00 | 02-06-08 | 6.56 | 0.82 | 3.09 | 8 hours |
| **2** | **3** | 02-06-22 | 02-07-15 | 20.55 | 1.14 | 4.34 | 17 hours |
| **3** | **4** | 02-08-07 | 02-08-22 | 8.51 | 0.57 | 2.56 | 15 hours |
| **3** | **5** | 02-09-08 | 02-10-00 | 17.03 | 1 | 3.13 | 16 hours |
| **4** | **6** | 02-11-03 | 02-11-11 | 2.45 | 0.27 | 0.81 | 8 hours |
| **5** | **7** | 02-16-06 | 02-16-13 | 6.06 | 0.76 | 3.63 | 7 hours |
| **6** | **8** | 02-17-05 | 02-18-18 | 28.76 | 0.8 | 1.94 | 1 day 13 hours |
| **7** | **9** | 02-19-06 | 02-21-04 | 24.28 | 0.52 | 3.61 | 1 day 22 hours |

Table 1. Pulse statistics at Oroville Airport in February 2017

## Methods and Data

### NEXRAD Doppler Radar

The Next Generation Weather Radar (NEXRAD) is a network of 160 high-resolution Doppler radar sites that detects precipitation and atmospheric movement and disseminates data in approximately 5-minute intervals from each site. NEXRAD enables severe storm prediction and is used by researchers and commercial enterprises to study and address the impact of weather across multiple sectors. The NEXRAD radar stations located at Beale Air Force Base in Yuba City, California and Sacramento NWS office was used to identify sub-hourly mesoscale features associated with each precipitation pulse identified in this study.

### MERRA II Reanalysis

Synoptic-scale characterizations of the storm systems that affected the region in February 2017 was used to describe the large-scale patterns influencing the precipitation pulses identified with the above methodology. Reanalysis data from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2, 0.5° x 0.625° grid resolution) was used as a diagnostic tool to describe the flow of moisture into the region during these events. The direction and magnitude of this high-level moisture profile will provide information on which locations within the region are more affected by pulses of high intensity rainfall. Because the directionality and intensity of moisture is the primary driver at the synoptic-scale, MERRA-2’s integrated water vapor transport was used for this characterization effort. In addition to IVT, 850 hPa temperature and sea level pressure from MERRA II was also used to detect frontal passages and centers of low pressure moving over the region during these precipitation pulses.

### ERA5 Reanalysis

Wind magnitude derived from ECMWF Reanalysis v5 (ERA5, 0.25° x 0.25° grid resolution) 10-meter U and V components were used to represent surface level winds during the pulse events. Directionality of surface level winds provided information on system locations during the time of the heaviest precipitation for each pulse. Wind quivers are overlayed over SLP and 850 hPa temperatures from MERRA II.

# Characterization Results:

Meteorological drivers were identified for the pulses identified in this study. Primary drivers of precipitation are categorized into convective, frontal, and narrow cold frontal rain bands.

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Several meteorological drivers were identified for the pulses identified in this study. Primary drivers of precipitation are categorized into convective, frontal, and narrow cold frontal rain bands. Pulses 1,4,6,and 8 exhibit….

|  |  |
| --- | --- |
| Pulse | Primary driver of precip  Mesoscale features  No mesoscale categorize  Start categorize whether there are mesoscale features that are identifiable.  Convective features NCFR/ non-organized.  Whether mesoscale frontrol wave.  Look to see if AR’s have mesoscale frontal wave. |
| 1 | Convective/NCFR |
| 2 | NCFR |
| 3 | frontal |
| 4 | convective/frontal |
| 5 | NCFR/Frontal |
| 6 | convective/none |
| 7 | NCFR |
| 8 | convective |
| 9 | frontal |



# Discussion and Broader Implications

The characterization of mesoscale within-event precipitation pulses have implications for the advancement of both numerical weather forecasting and increased quality of climate model parameterization. The Center for Western Weather and Water Extremes Forecast Informed Reservoir Operations will be able to use these results to help develop more informed strategies for efficiently managing reservoir levels throughout California during extreme rainfall events. As high intensity precipitation is not well understood in numerical models and poorly represented in longer-term climate data (Stephens et al., 2019, Martin et al., 2018, Suzuki et al., 2015, Dunkerley et al., 2010), the characterization of these pulses will advance our understanding of the meteorological mechanisms that drive short-term, high intensity precipitation and contribute knowledge to the high resolution hydrometeorological processes that are required as inputs into many climate models. The public will also see benefits from the research proposed as understanding the local mechanisms underlying these extreme events will allow for the improvement of warning systems in vulnerable communities and can assist in the development of preemptive mitigation strategies to save property and lives.

There are opportunities for future research with this proposed project. All data being used is available for the full spatial extent of the United States. A geographic expansion of the pulse identification methodologies presented in this study would shed light on how these high intensity precipitation pulses change across the country. The characterizations described in this study have the potential to provide the groundwork for an algorithmic approach to identifying within-storm precipitation pulses.

Below is a proposed timeline for the project, based on credits needed and deliverables expected:

|  |  |  |  |
| --- | --- | --- | --- |
| **MS in Geography  objective timeline** | **Fall 2024** | **Winter 2024**  **(Defend Thesis Proposal)** | **Spring 2024 or Fall 2025  (Defend Thesis)** |
| **Action Items** | Continue developing Thesis Proposal | Continue research/Masters Thesis | Defend Thesis |

Table 3. Proposed research timeline

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