UCLA Center for Climate Science

Sub-seasonal Clustering of Atmospheric Rivers over the Western US

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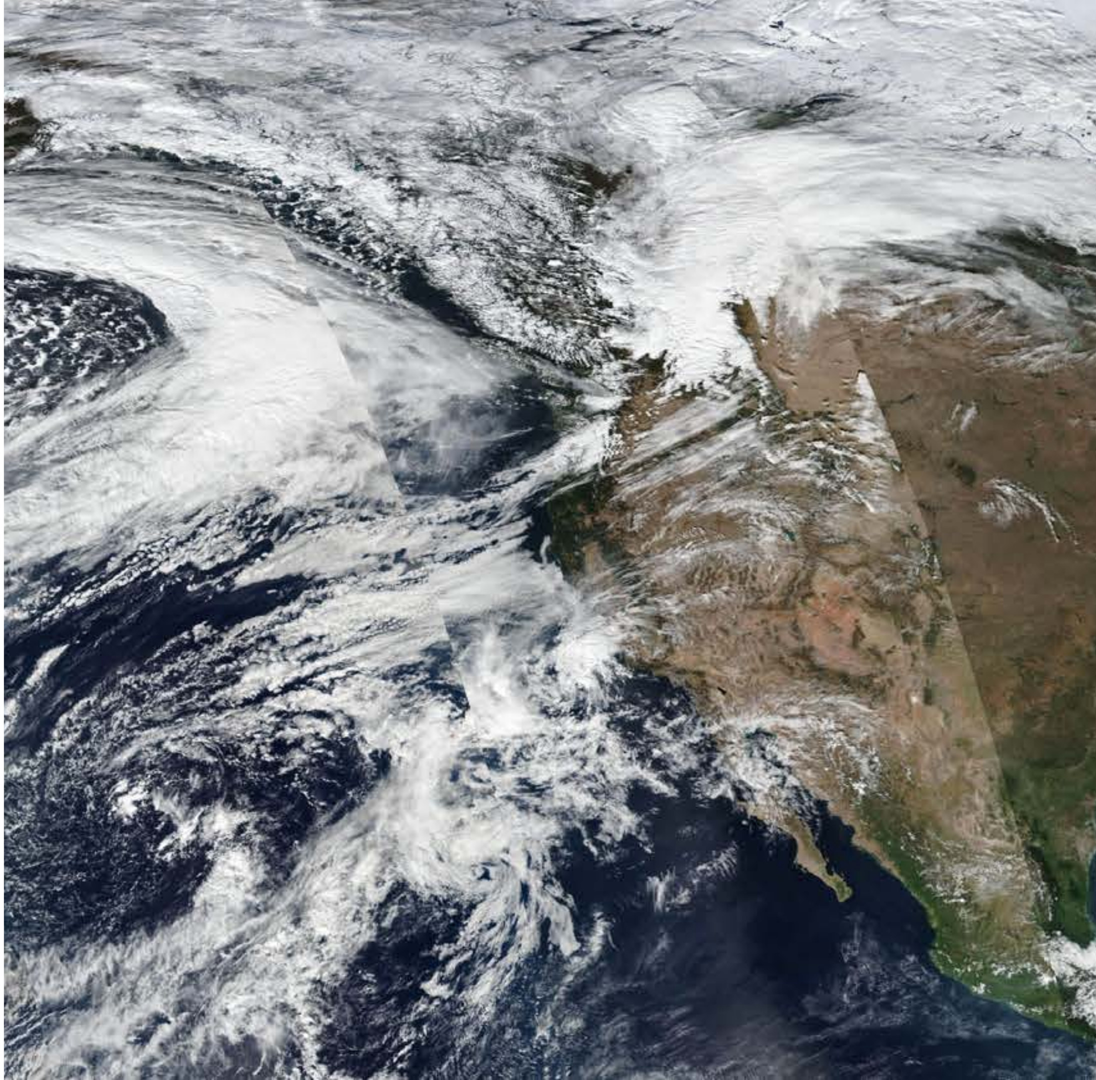


Background & Motivation

*The **temporal clustering of ARs** refers to the passage of multiple ARs over a fixed location within a given period of time*

Motivation: prolonged and exacerbated hydrologic impacts associated with successive ARs

Precedent-setting flooding events:

- *The Great Flood of 1861-62*
- *2017 Oroville Dam Crisis*

Amplified AR impacts due to close temporal proximity → water resource management challenges

Sacramento's K street during 1861-62 flood

Source: Null & Hulbert, 2007

Oroville Dam Crisis

Image: NY Times

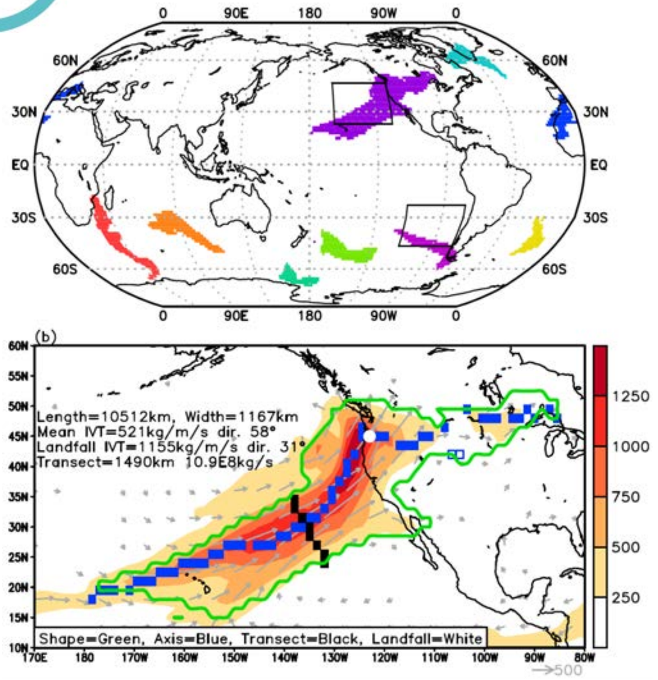
Research Objectives

Overarching Goal: Investigate the ***occurrence and character of AR clustering*** *and associated precipitation across the western US*

Research Tasks:

1. Quantify statistically significant AR clustering timescales
2. Identify AR clusters and examine basic characteristics
3. Evaluate link between AR clusters and associated precipitation

Data



Source: Guan et al. 2018

Example output from the AR detection algorithm depicting how the object's size and shape requirements are viewed within the algorithm

Atmospheric Rivers

- ERA5; 1979-2020; hourly; 1° x 1° grid
- Guan & Waliser (2015) AR Catalogue
  - Objective detection algorithm
    - Percentile-based IVT thresholding & geometric/directional requirements
- AR Events: ≥8 consecutive hours of AR conditions

Precipitation

- Dynamically downscaled WRF-driven ERA5 reanalysis
  - Hourly; 9-km grid

Results focus on AR occurrence during December, January, February (DJF)

Ripley's K Function

How many events occur on average within a given time interval of an event for a particular season?

OBSERVED AR EVENT TIME SERIES

DETERMINE STATISTICAL SIGNIFICANCE

$$\hat{K}(t) = \frac{1}{n}\sum_{i=1}^{n}\sum_{j\neq i} I_{|ti-tj|\leq t}$$

n: *total number of events*

t_i: *time of an extreme event*

t_j: *time of all other events*

I: *indicator function*

SYNTHETIC TIME SERIES → 1000 Monte Carlo simulations

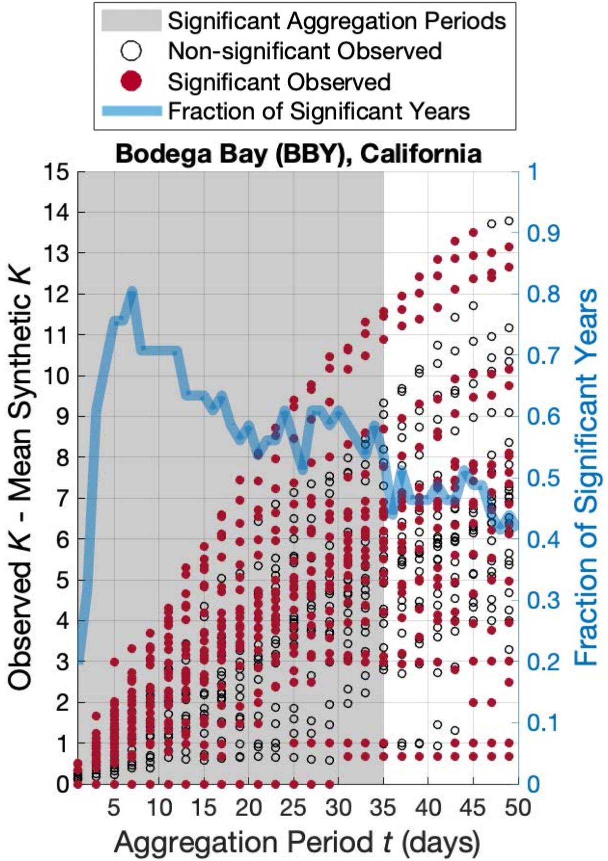
- Same average event density as observed
- Timing between events drawn from Poisson distribution
- Temporal randomness with clustering only by chance

COMPARE OBSERVED CLUSTERING TO WHAT IS EXPECTED BY CHANCE → *If the observed K falls within the top 5% of the synthetic, we consider it to represent significant clustering*

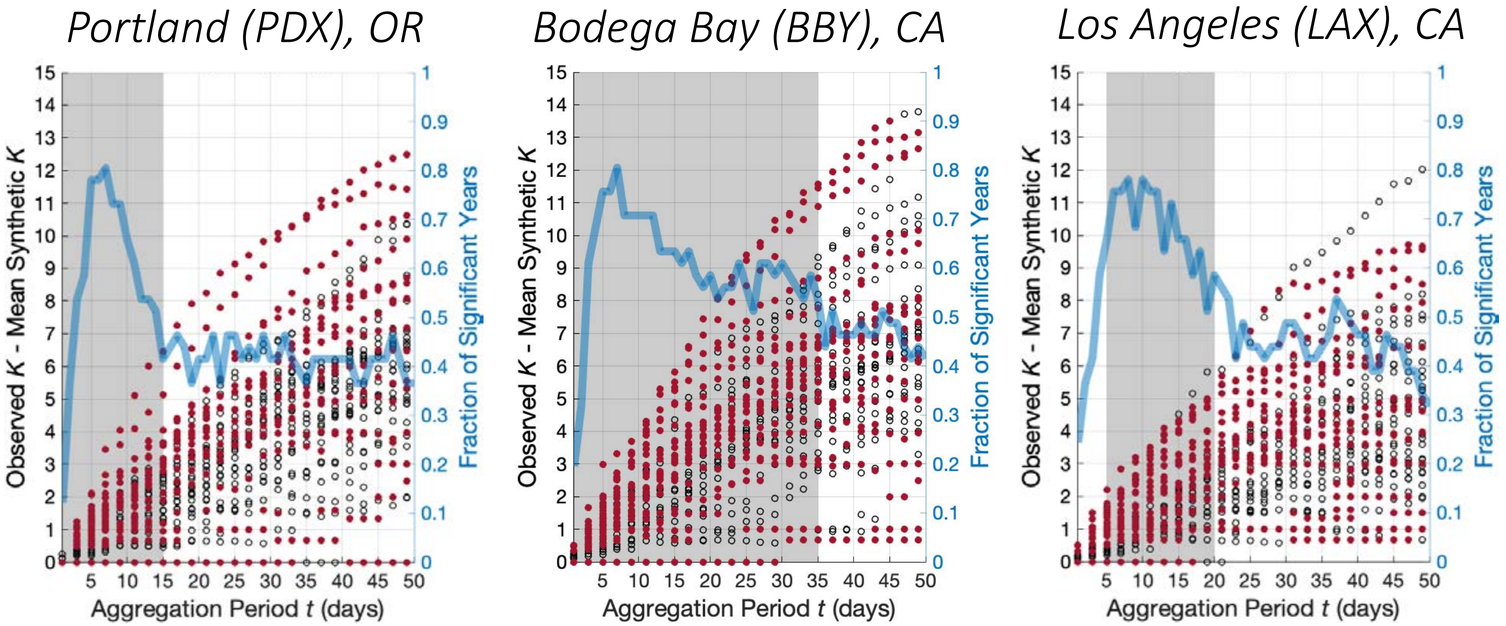
OUTPUT → *statistically significant AR clustering timescales*

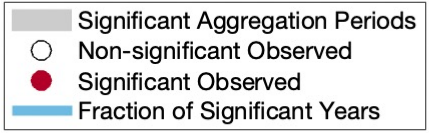
Detecting Significant Clustering

- *Ripley's K is applied to each winter season (1979 -2020) individually for aggregation periods ranging from 1 to 50 days (circles)*
- *Significance determined at the 95% confidence level (shaded circles)*
- *At least 50% of the seasons must show significance (blue line)*
- *At BBY there is a high degree of clustering on time scales up to 35 days (gray shading)*



Significant Clustering Timescales



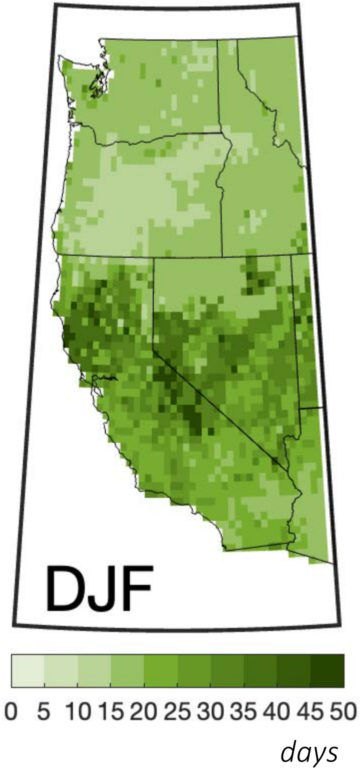


- *Positive difference between observed and average synthetic K*
- *ARs cluster at a greater-than-random rate with variability in the range of significant timescales*

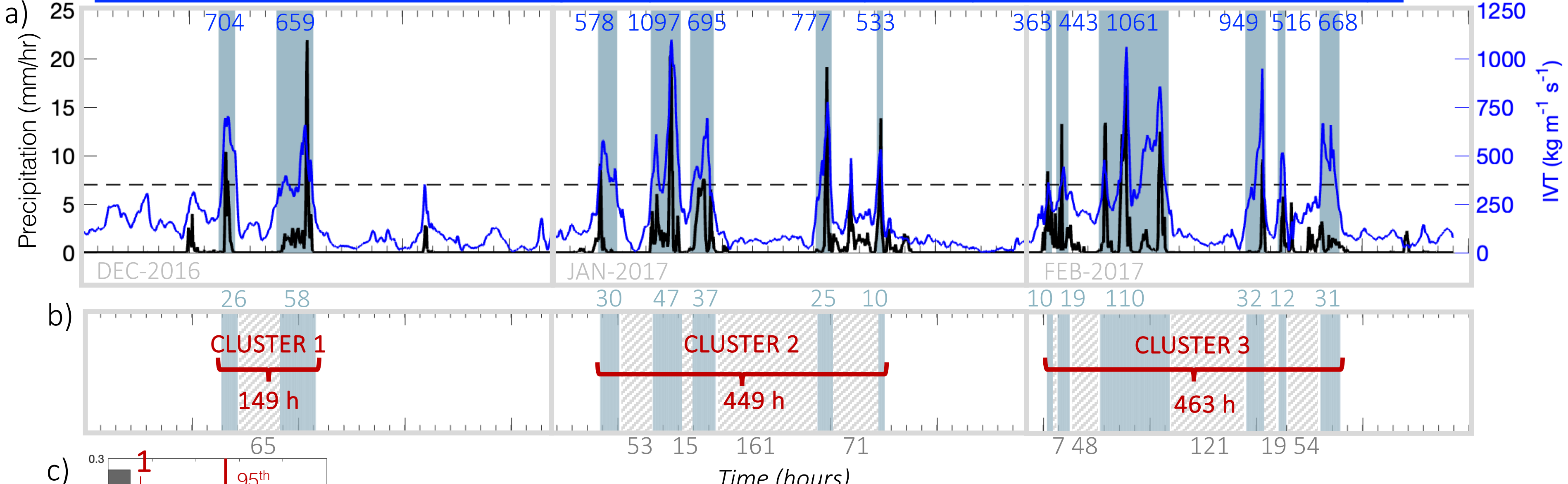
Significant Clustering Timescales

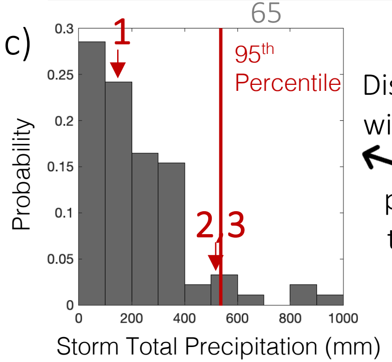
- *Maximum timescales with significant clustering*
- *Distinct North-South pattern with shorter-longer maximum timescales with significance*
- *Maxima (up to 50 days) in Northern California and across Sierra Nevada*
- *Minima (up to 20 days) across Oregon and Washington*

Maximum significant aggregation period



CASE STUDY: DJF 2017 Bodega Bay (BBY) Hourly Precipitation and AR Timesteps



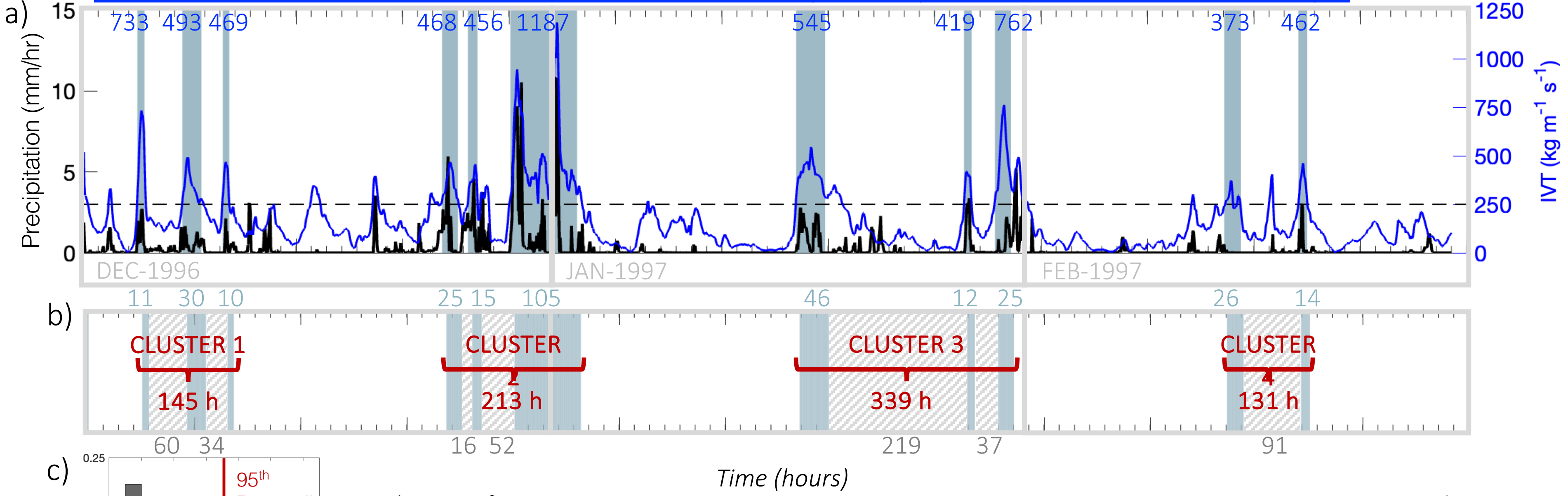


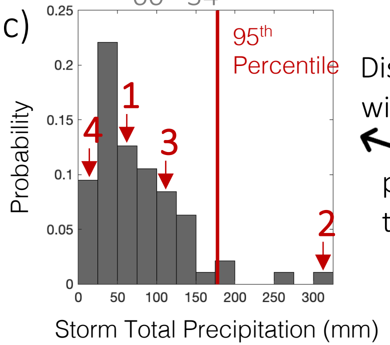
Distribution of wintertime AR cluster precipitation totals at BBY

Cluster #	Total Precipitation	AR Events	Duration
1	190.2 mm	2	6 days
2	512.7 mm	5	19 days
3	513.0 mm	6	19 days

** Clusters are identified by imposing criteria relating to the minimum gap between AR events, guided by the aggregation time scales that were found to be significant*

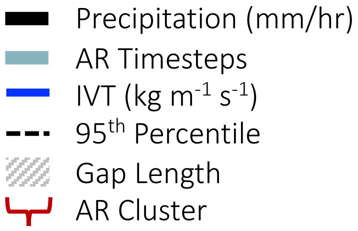
CASE STUDY: DJF 1997 Portland (PDX) Hourly Precipitation and AR Timesteps



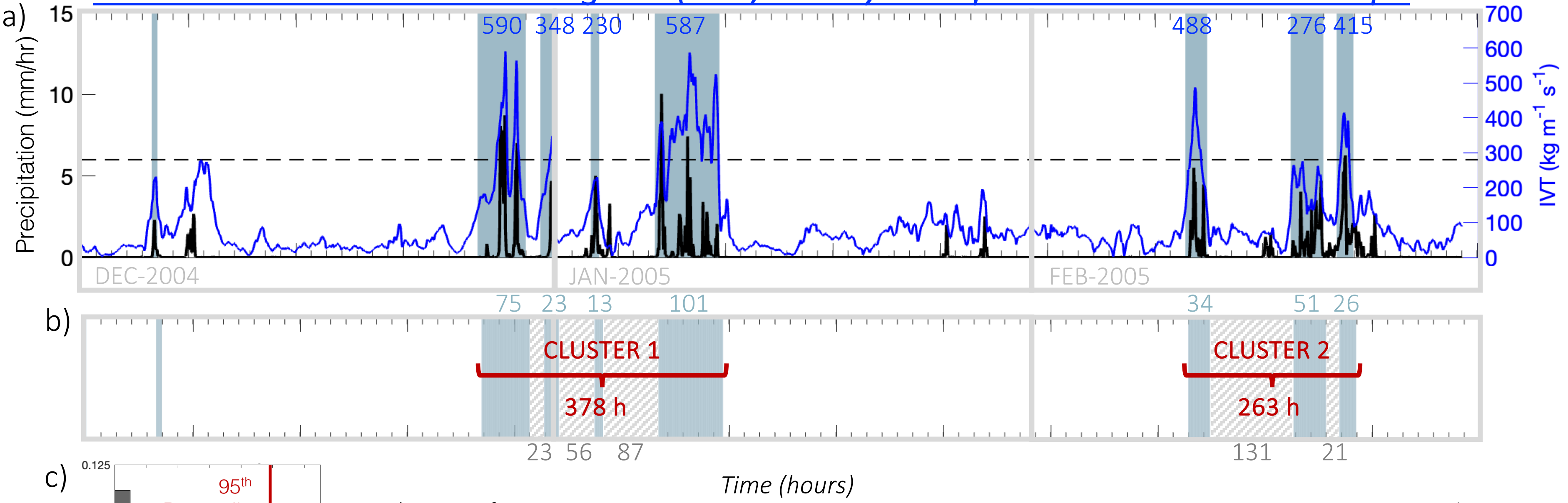


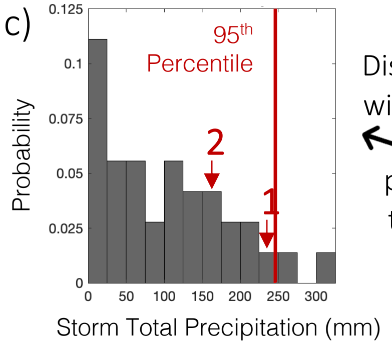
Distribution of wintertime AR cluster precipitation totals at PDX

Cluster #	Total Precipitation	AR Events	Duration
1	53.0 mm	3	6 days
2	308.3 mm	3	9 days
3	111.4 mm	3	14 days
4	14.2 mm	2	6 days



CASE STUDY: DJF 2005 Los Angeles (LAX) Hourly Precipitation and AR Timesteps





Distribution of wintertime AR cluster precipitation totals at LAX

Cluster #	Total Precipitation	AR Events	Duration
1	225.8 mm	4	16 days
2	158.1 mm	3	11 days

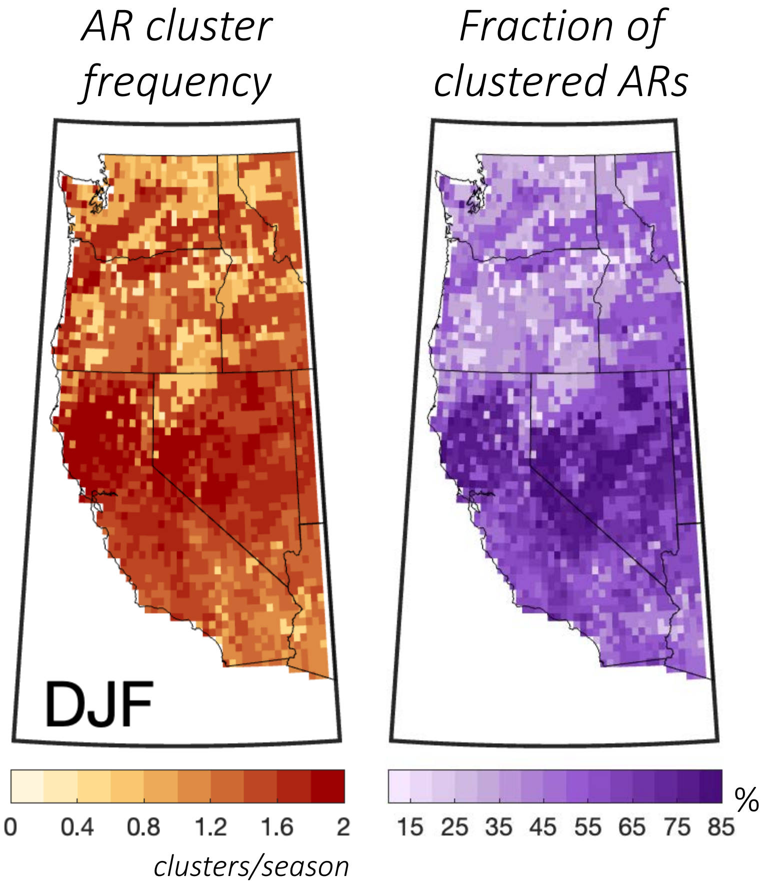
How often do AR clusters occur?

AR Cluster Frequency: *clusters per season recorded between 1979-2020*

- *Maxima (>2 per season) along the coast of Northern California south of Cape Mendocino*
- *Minima (<1 per season) across lower elevations of Washington and Oregon*
- *Negative North-South frequency gradient over California*

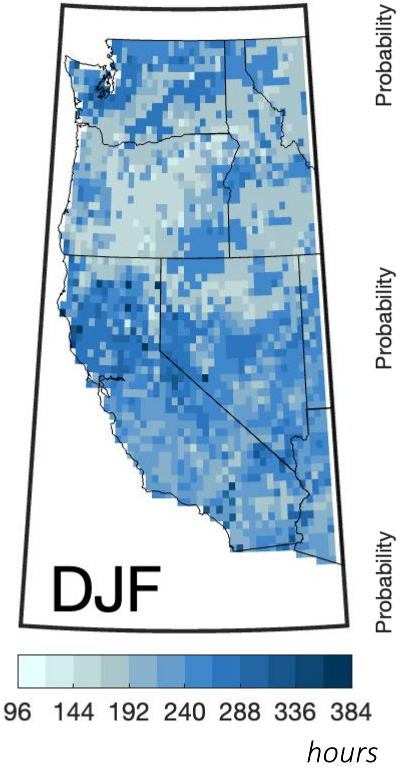
Fraction of Clustered ARs: *clustered AR events / total AR events*

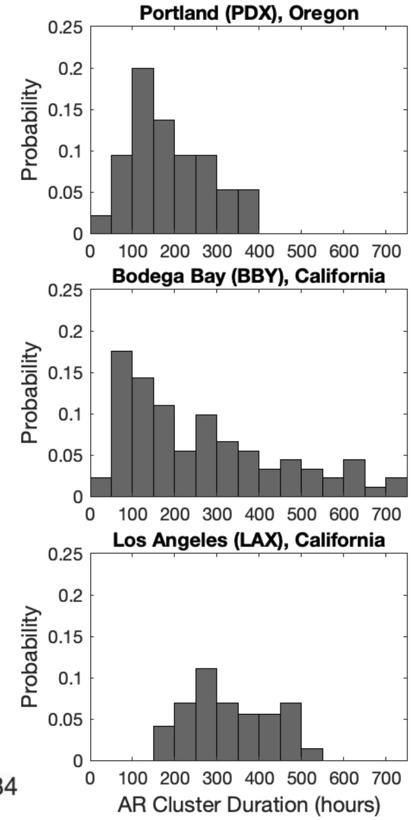
- *Positive relationship with the fraction of clustered ARs*
- *>85% of ARs along the coast of Northern California and Sierra Nevada occur as a part of a cluster*
- *Smaller proportions (20%) visible across the Northwest*



How long do AR clusters typically last?

Average AR cluster duration





***Average AR Cluster Duration**: average number of hours of AR cluster conditions (including gaps) at a given location*

- *Longest duration (>336 h) clusters found across Northern California and Transverse Ranges*
- *Broad minima (<192 h) across Central Oregon and inland*
- *Maximum significant clustering timescales influence but are not necessarily determinant of typical cluster duration*

__PDX__: range from days to just over 2wks, but most commonly 1wk
__BBY__: long right tail extending to over 4wks
__LAX__: relatively narrow with a higher degree of uniformity ranging 1-3wks

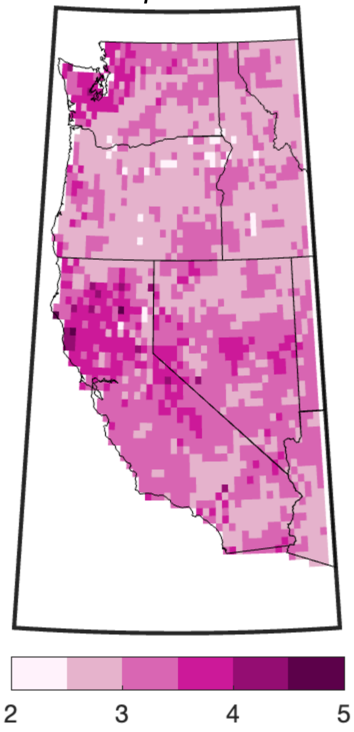
How many AR events occur within a cluster?

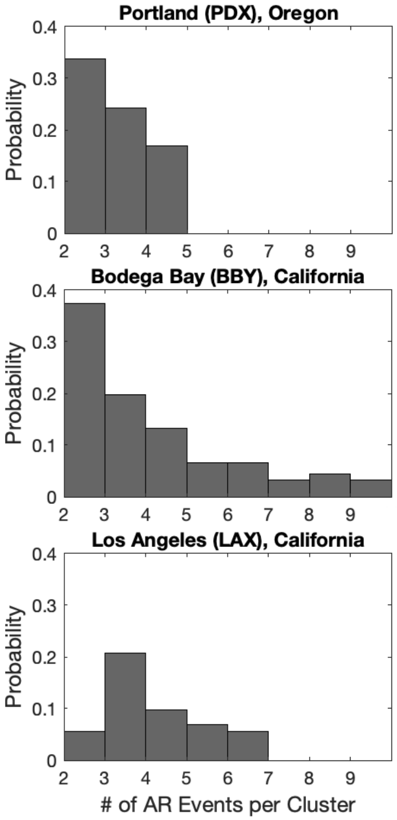
***Average AR Events per Cluster**: average number of individual AR events contributing to a clustering episode at a given location*

- *Longer (shorter) duration clusters tend to be comprised of a higher (lower) count of contributing AR events*
- *Maxima (5 AR events) found on the northern California Coast*
- *Broad minima (<3 AR events) found across central Oregon and Northwest interior as well as across portions of Southern California*

__PDX__: clusters are composed of between 2-4 ARs
__BBY__: larger spread with a long right-tail indicating clusters can contain up to 9 individual ARs
__LAX__: clusters range between 2-6 ARs, with 3-4 most common

Average AR events per cluster





AR Cluster Precipitation

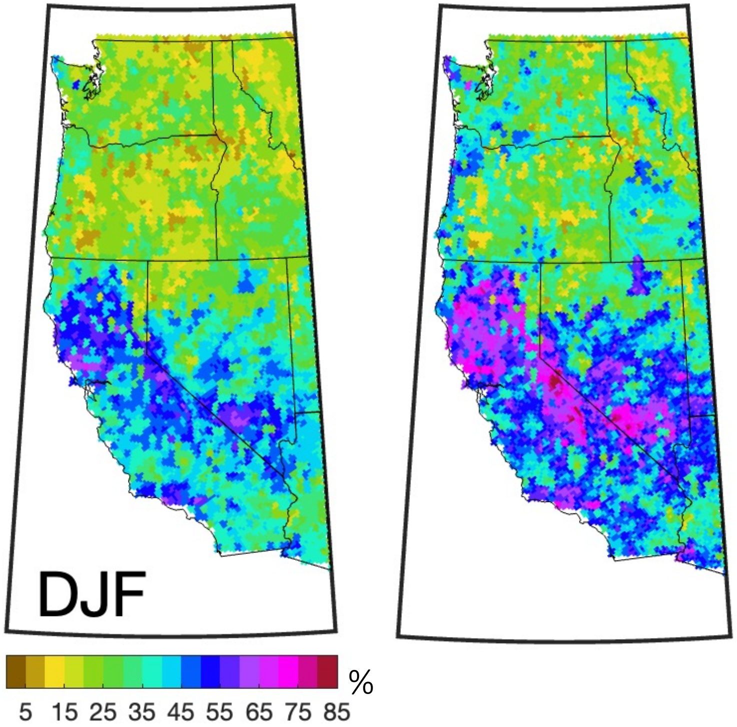
*What percentage of **precipitation** is associated with AR clusters?*

$$\frac{\textit{AR cluster precipitation}}{\textit{Total precipitation amount}}$$

- *Maxima (65%) across the Northern California Coast, Sierra Nevada, and Transverse Ranges*
- *Lower fractions (<35%) across the NW due to shorter significant aggregation periods → shorter-lived clusters → smaller proportion of total precipitation*

Fraction of AR cluster precipitation

Fraction of AR cluster extreme precipitation



*How often are AR clusters associated with **precipitation extremes**?*

$$\frac{\textit{AR cluster extreme precipitation co-occurrence}}{\textit{Total extreme precipitation occurrence}}$$

- *Stronger gradients and higher degree of spatial variability*
- *Maxima (85%) over the northern extent of the Sierra Nevada*
- *Across the NW, values reaching 50% coincide with regions of complex terrain with minima (5-25%) found across the interior*

**Extreme precipitation is defined as an hourly exceedance of the 95th percentile*

Conclusions & Future Direction

Conclusions

1. ARs are clustering at a rate significantly different from what would be expected by random chance across the Western US with distinct spatiotemporal patterns
2. Case study analysis highlights link between AR cluster occurrence and notably impactful ARs
3. AR clusters are most frequent across the northern Coast Range of CA and OR-WA Coast-Cascade Ranges
4. Frequency patterns are positively related to average cluster duration with longer-lived (≥ 2 weeks) clusters found across Northern CA and shorter-lived (≤ 1 week) clusters across portions of the Northwest interior
5. AR cluster-related precipitation coincides with some of the highest hourly totals and is largest (>65%) over Northern CA, Sierra Nevada, and Transverse Ranges

Future Direction

- Do other regions affected by ARs also exhibit clustering?
- What are the large-scale environments that favor AR clustering?
- How well do models represent AR cluster characteristics and associated precipitation?
- Are AR clusters projected to change with warming? If so, how? Implications?

Discussion

Implications for an improved process-based understanding of ARs and predictability

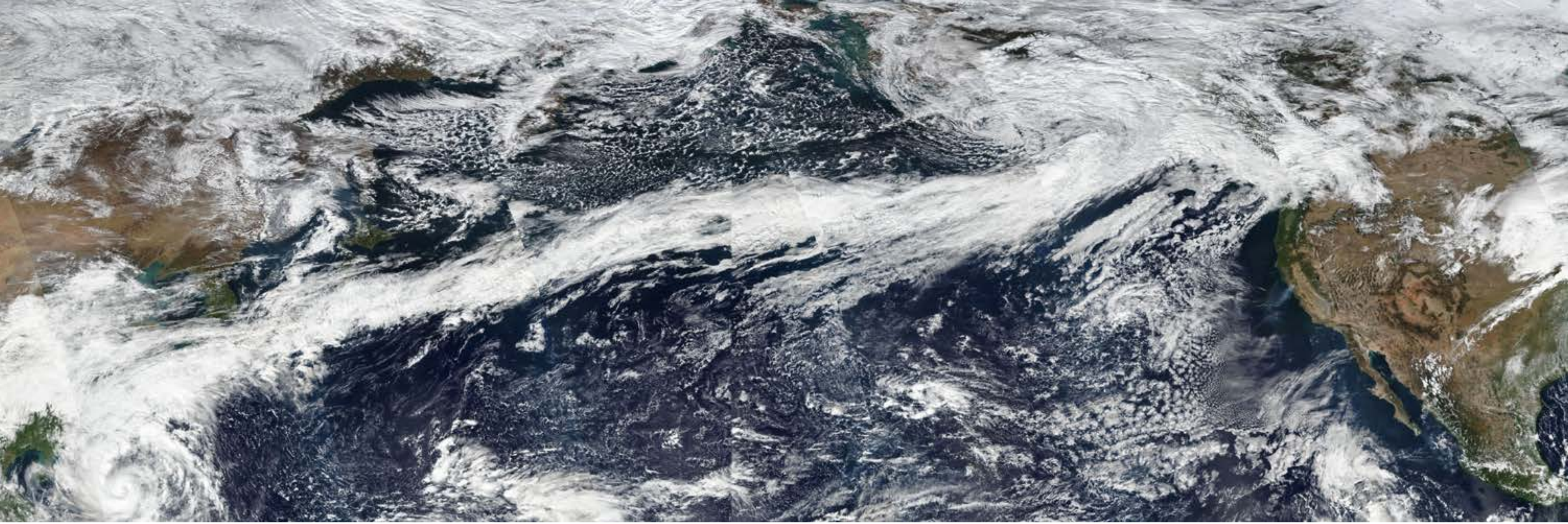
- Timescales identified where AR clustering occurs more frequently than expected by chance suggest dynamical mechanisms may favor their occurrence
- Improved understanding of AR duration → difficult to forecast at relevant spatiotemporal scales

To explore dynamical mechanisms and synoptic regimes through this lens can offer greater insight into the relevant scales, mechanisms, and potential predictability of these phenomena

Hypothesis:

- Dynamical mechanisms, such as Rossby wave breaking and North Pacific jet dynamics, which act on longer temporal and spatial scales than AR events, foster AR and cyclone development and modulate AR duration
- Modes of climate variability have been shown to influence Pacific AR activity and U.S. West Coast precipitation through modifications to midlatitude circulation patterns

Identification of predictors for increased AR activity and associated extreme precipitation has implications for statistical and/or dynamical modeling and hydrometeorological hazard situational awareness



Satellite image of continuous cloud line, ‘The Big Dark’, stretching across the Pacific Ocean. (VIIRS) October 14, 2017; Source: NASA

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Thank You! Questions?

Contact: eslinskey@g.ucla.edu

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