

# The Limits of the Deluge

## How Extreme Can Atmospheric Rivers Get?

**Matthew Koszuta**<sup>1</sup>, Luciana Cunha<sup>1</sup>, Caileen Yu<sup>1\*</sup>, Keith Mills<sup>2</sup>, Tony Janicek<sup>2</sup>, Jason Cordeira<sup>3</sup>, Xun Zou<sup>3</sup>, and Elçin Tan<sup>4</sup>

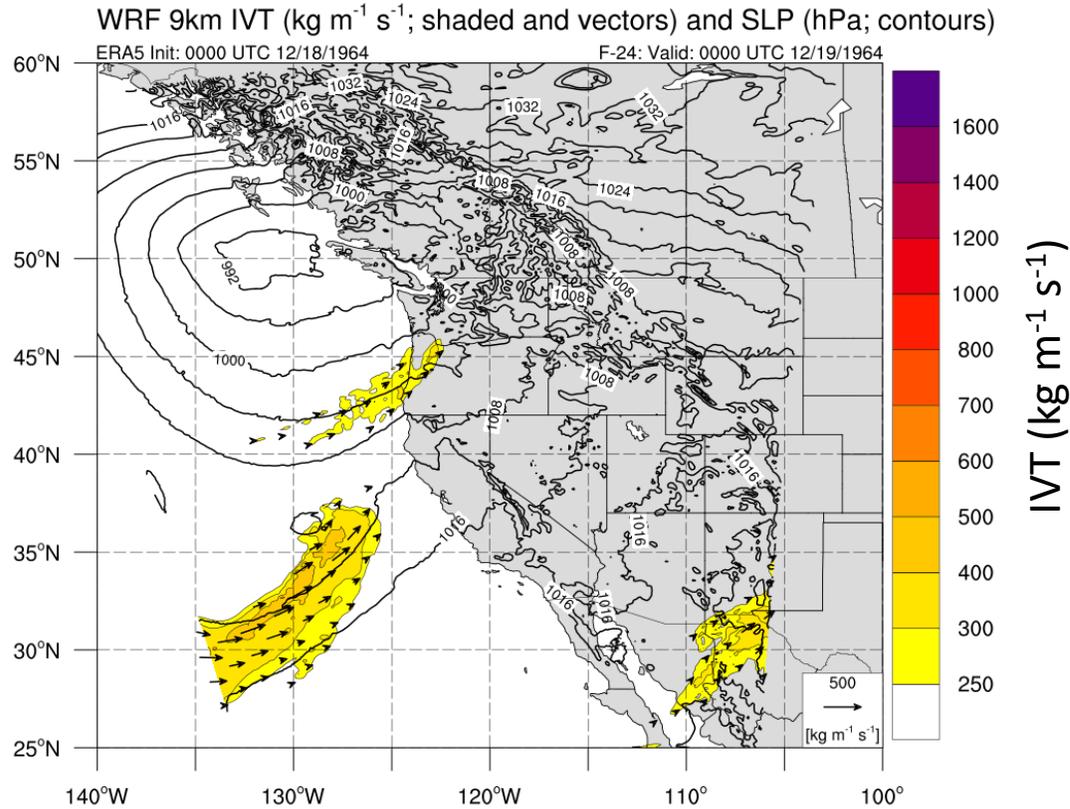
1. WEST Consultants
  2. Oregon Water Resources Department (OWRD)
  3. UCSD Center for Western Weather and Water Extremes (CW3E)
  4. İstanbul Teknik Üniversitesi
- \*now at U.S. Bureau of Reclamation (USBR)*

2021-10-21 19:00:32 UTC

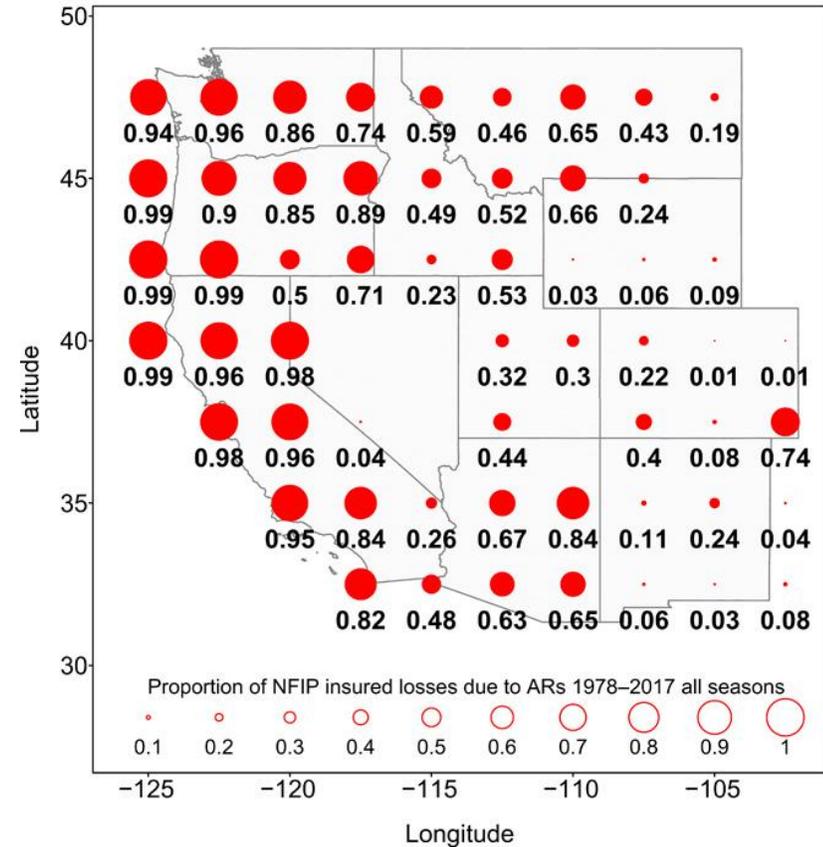


# Atmospheric Rivers (ARs)

**December 19-26, 1964**



Proportion of insured losses due to ARs



*Corringham et al. (2019)*

# What is Probable Maximum Precipitation (PMP)?

***Theoretically:*** “the greatest depth of precipitation for a certain duration meteorologically possible for a given size storm area at a specific time of year” (WMO, 2009)



# Designing for probable maximum flood (PMF)



***Precipitation  
(PMP)***



***Flooding  
(PMF)***

# PMP in US: Hydrometeorological Reports

## HMR-57

Published in 1994

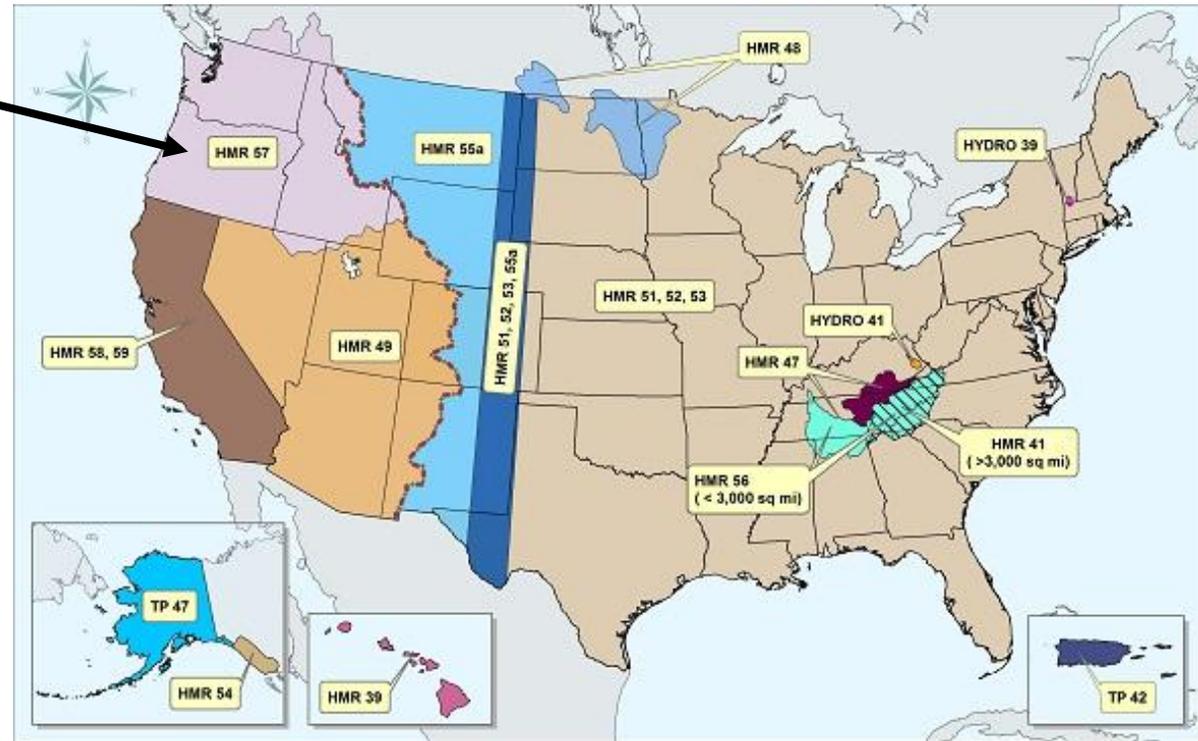
Data and assumptions made in HMRs are outdated—need to be updated

### Statewide PMP updates:

NE, CO, NM, WY, OH, AZ, VA,  
PA, MD, HI, NC, TX, and NJ

Site specific PMPs

## HMR: 1961-1999

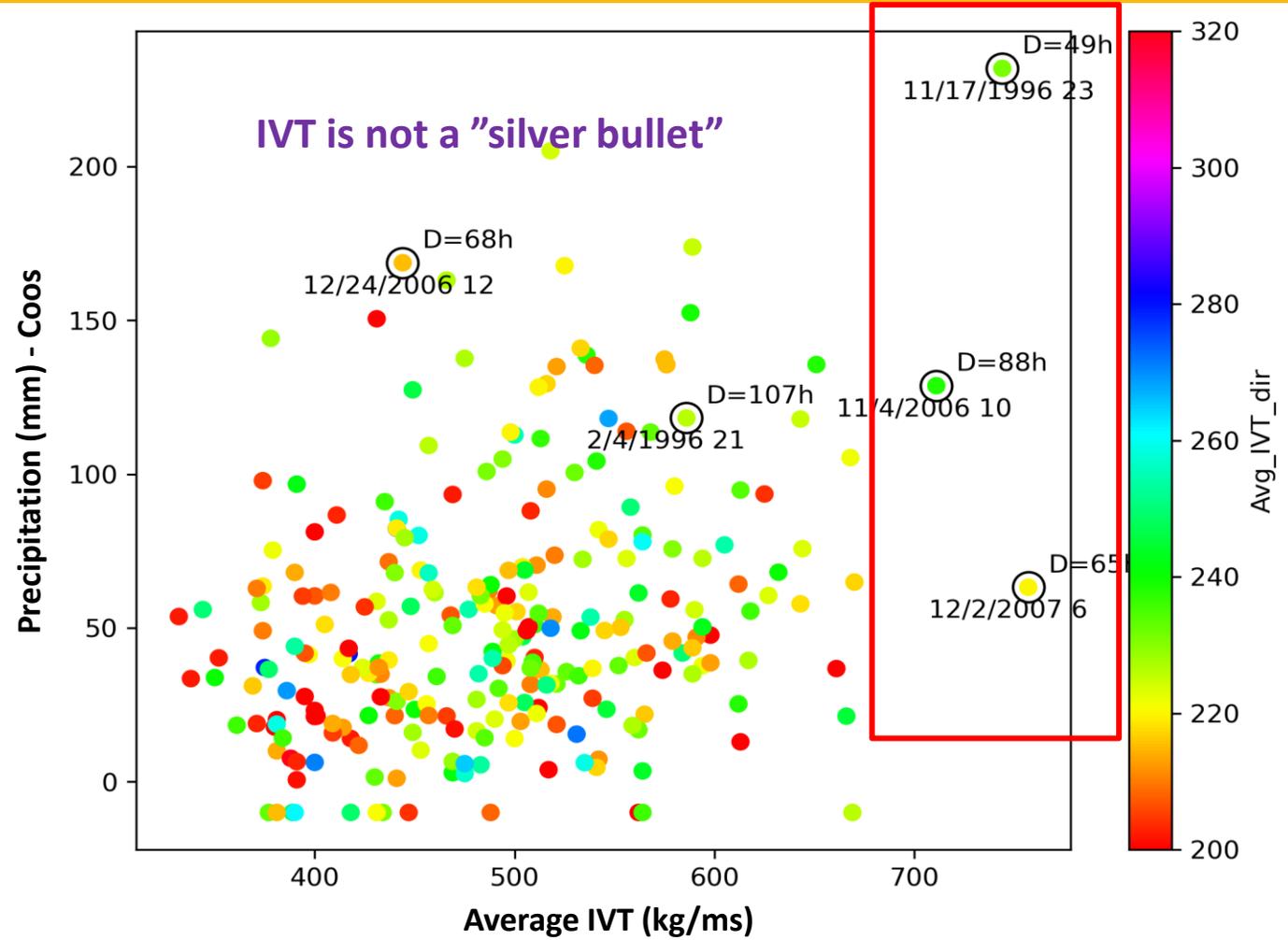
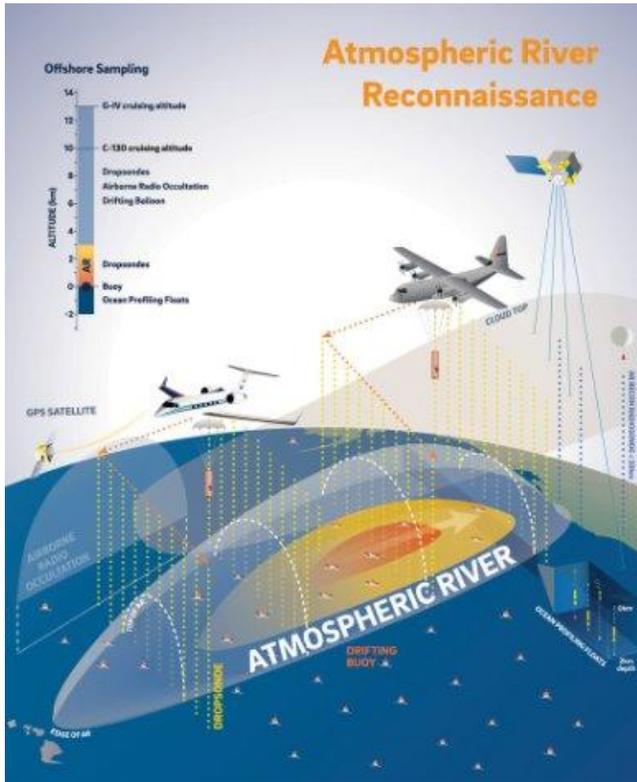


Source: National Weather Service

# What is the current understanding of extreme ARs?

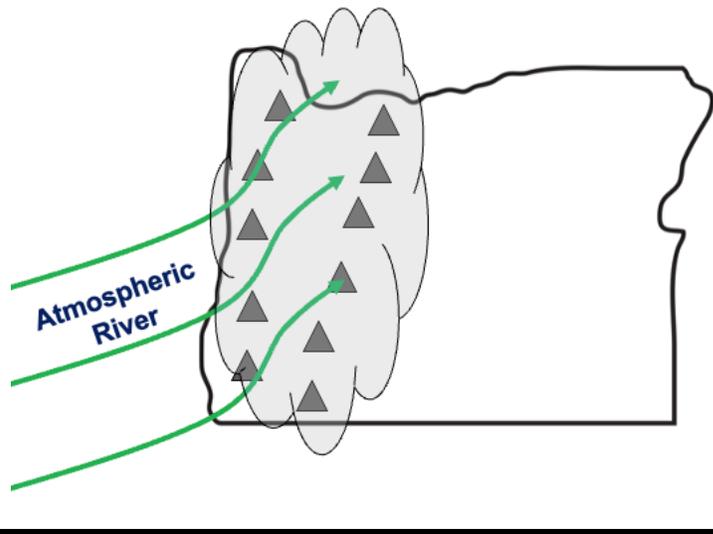


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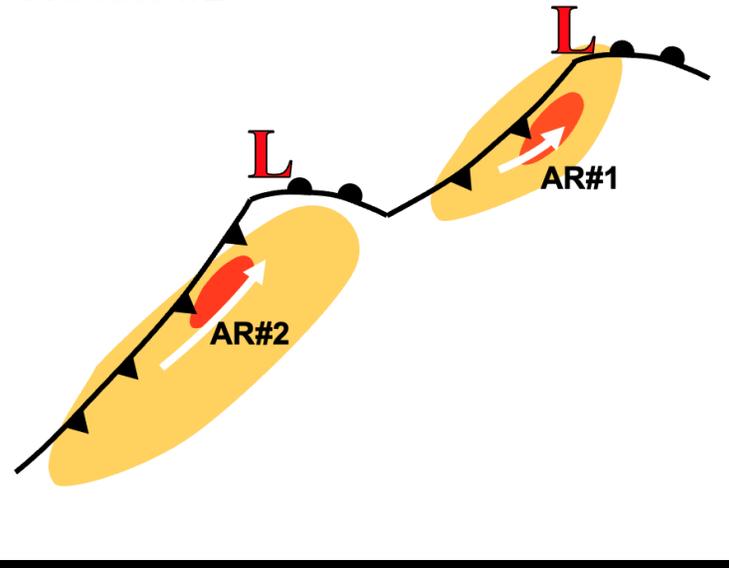
# What is the current understanding of extreme ARs?

Process #1



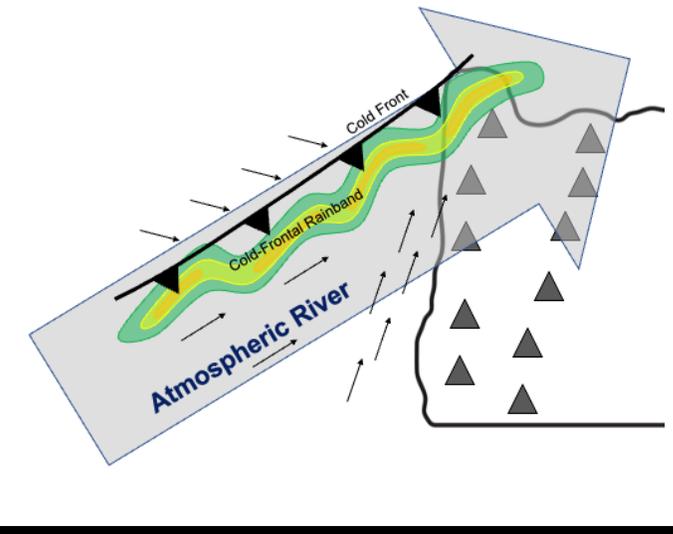
**Upslope/Orographic**

Process #2



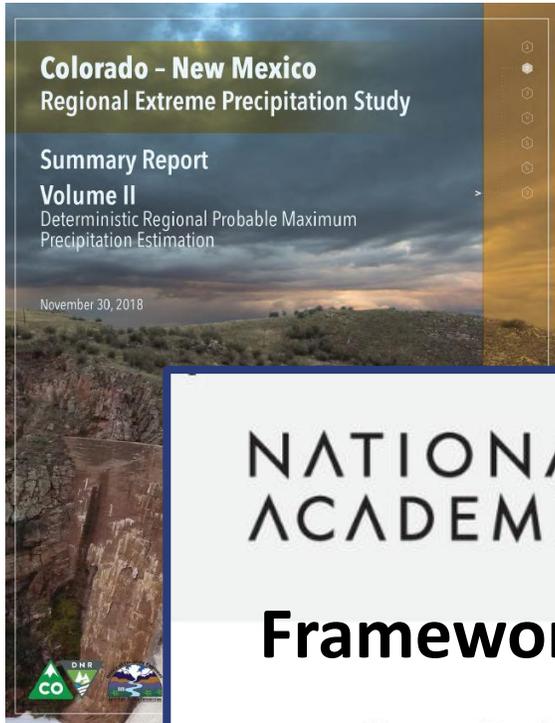
**Back-to-Back Storms**

Process #3



**Short-duration, high-intensity**

# Developing an AR-Based PMP



PMP based on  
methods


  
**Framework for the next 10-15 years of PMP**
  
 Modernizing Probable Maximum Precipitation Estimation



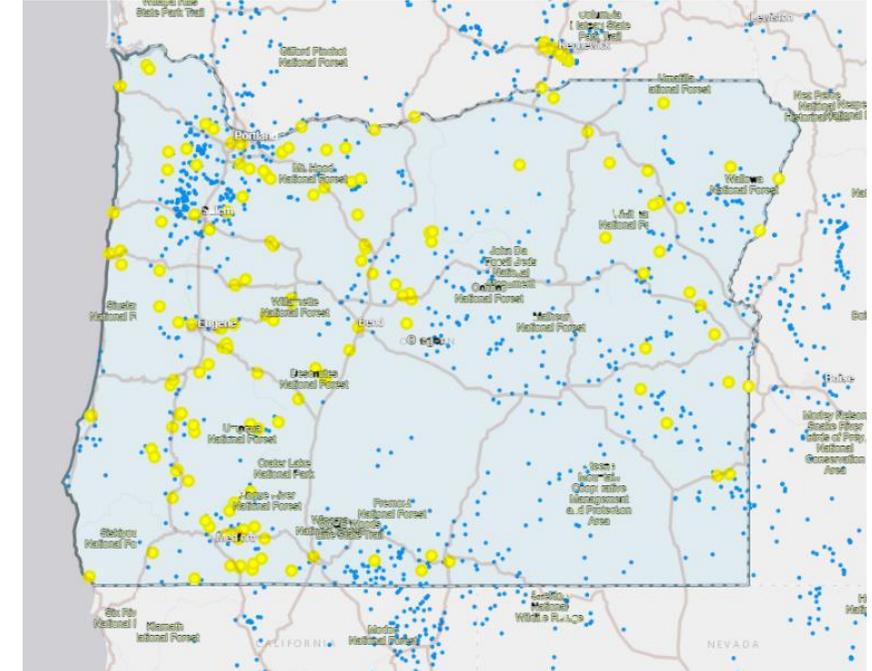
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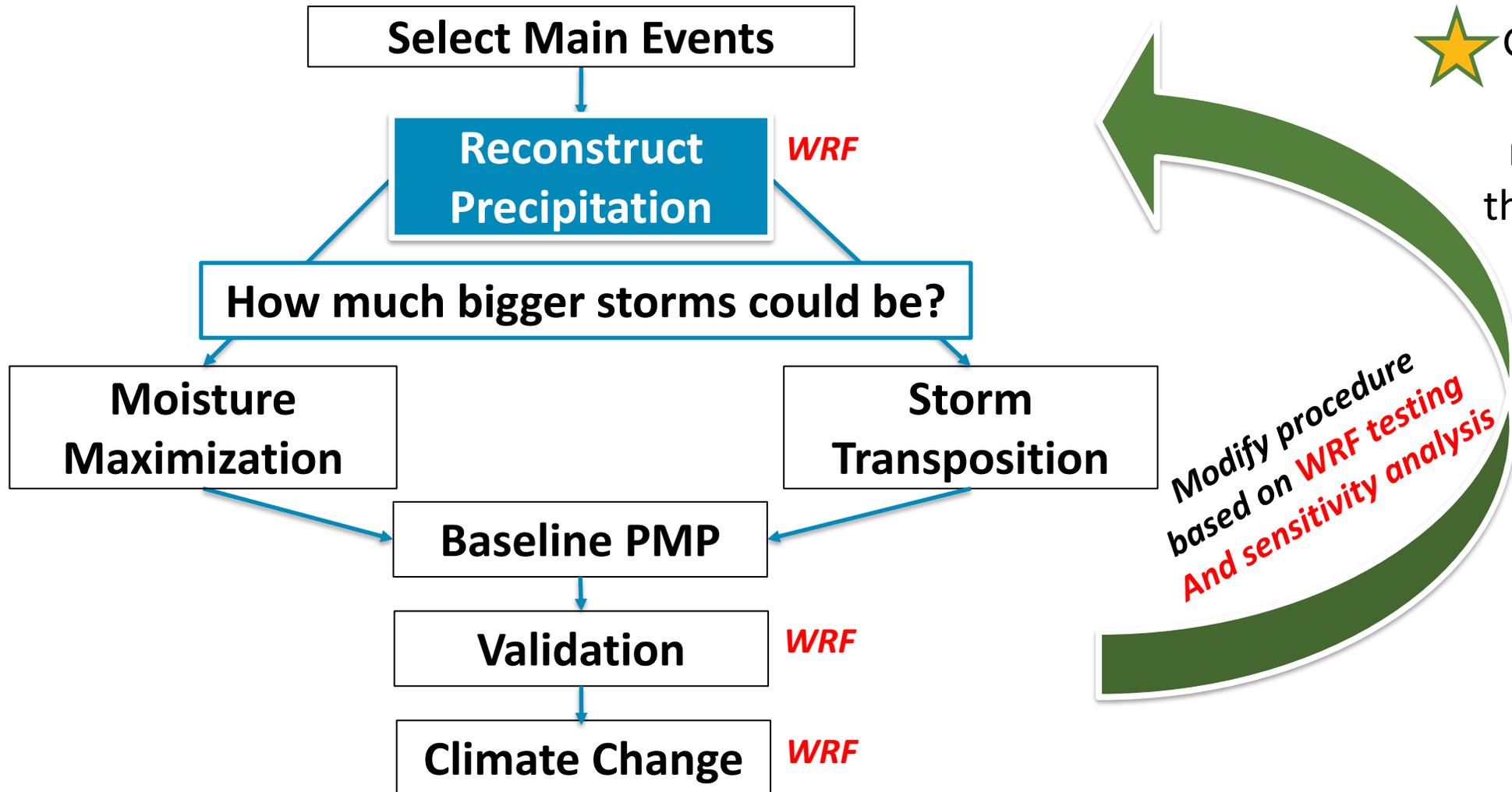
# Developing an AR-Based PMP for Oregon

Our study area (Oregon):

- > 700 State regulated dams (96 high-hazard)
- > 170 Federal regulated dams



# Project workflow to improve HMR PMP estimates



★ Gather feedback from a panel of external reviewers throughout the process to improve our methodologies

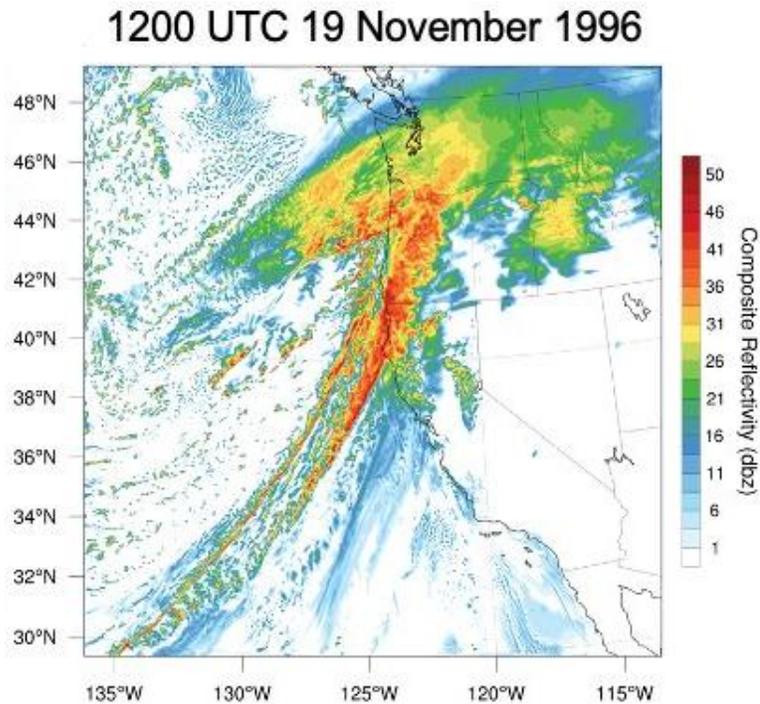
Modify procedure based on **WRF testing** And **sensitivity analysis**

# How are we approaching this problem?

## Numerical Weather Prediction (modelling)

- Using the Weather Research and Forecasting (WRF) model
- Mountain-resolving simulations with physically-driven processes

36 events identified and analyzed following improved HMR, 8 modelled in WRF (so far)



e.g., of West-WRF simulation of 1996 AR testcase



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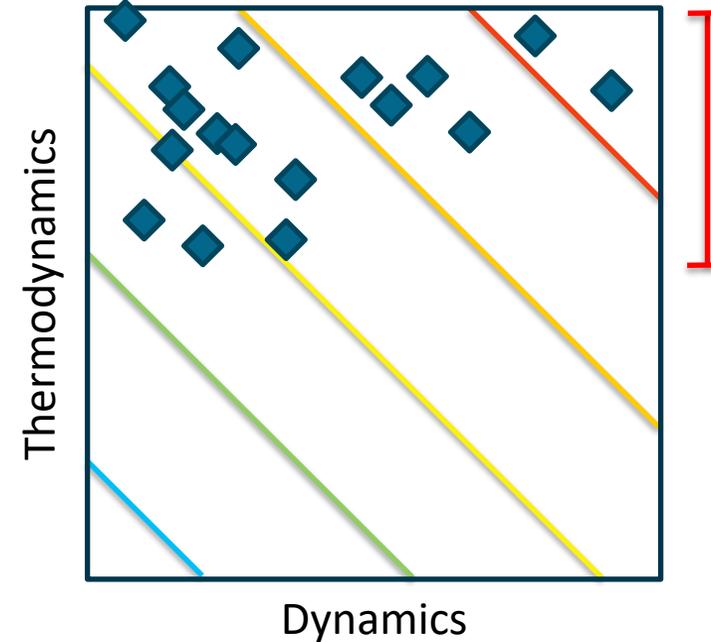
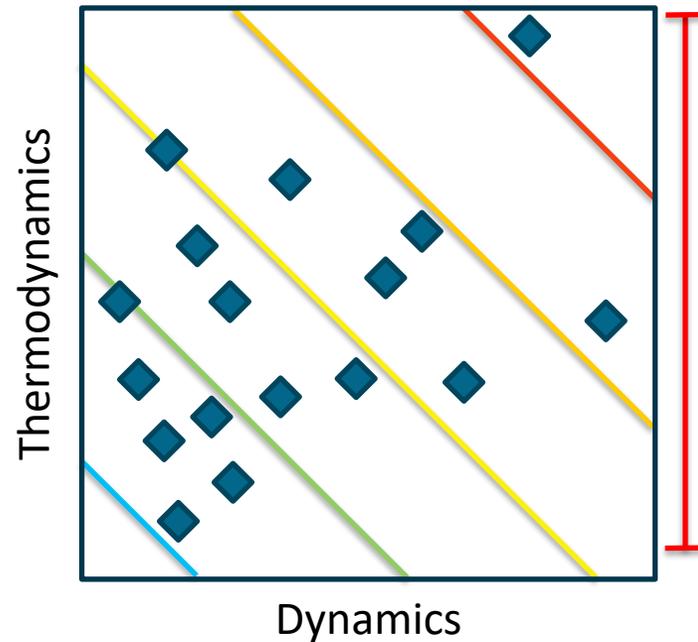
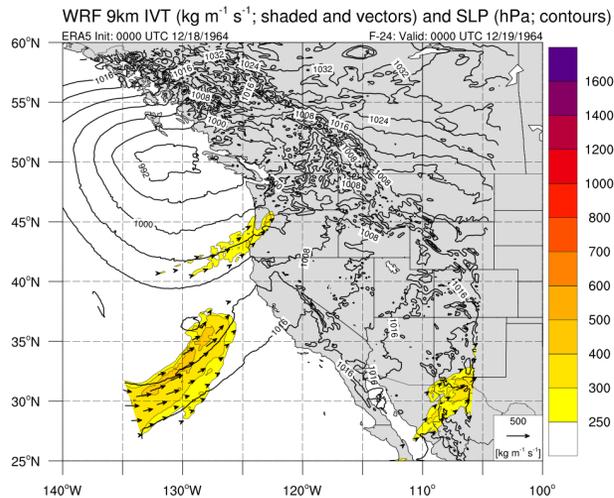
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# Are the ARs we consider maximized already?

Two factors: Dynamics and Thermodynamics

As air **temperature** ↑ so does **moisture** ↑

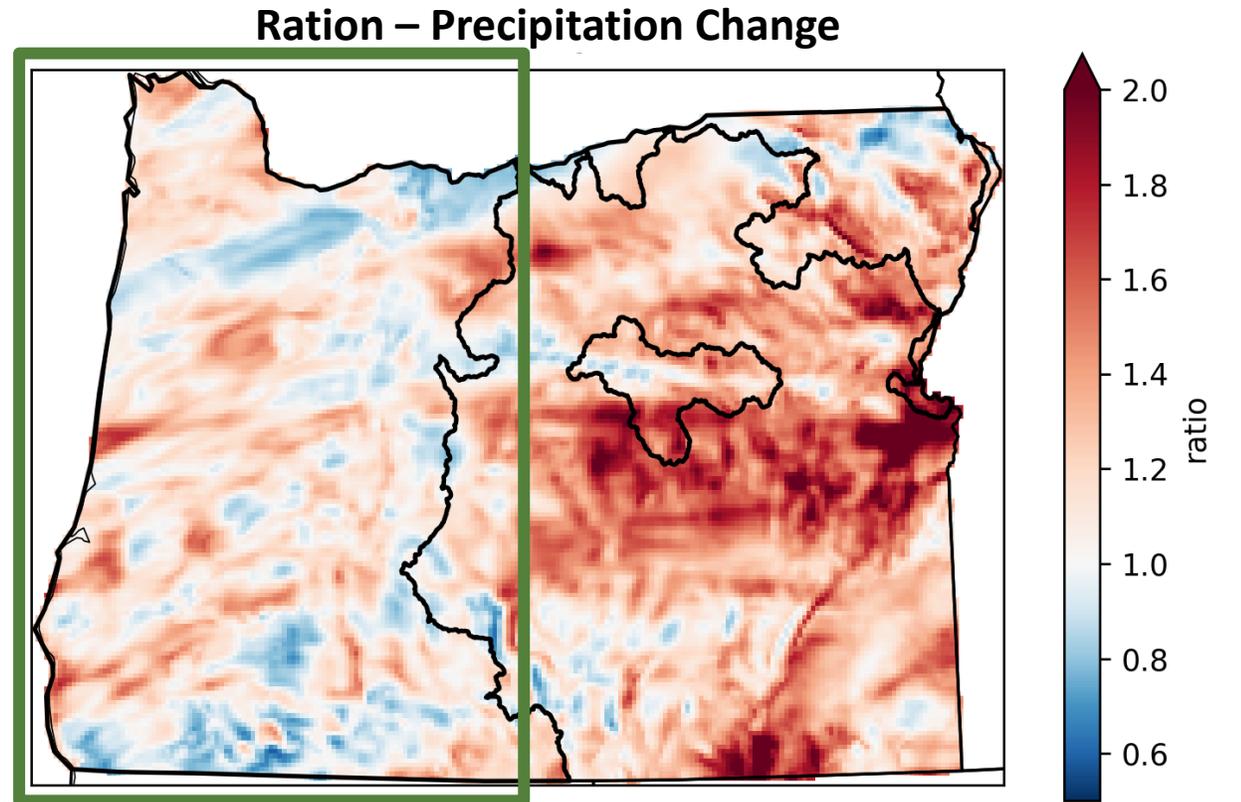
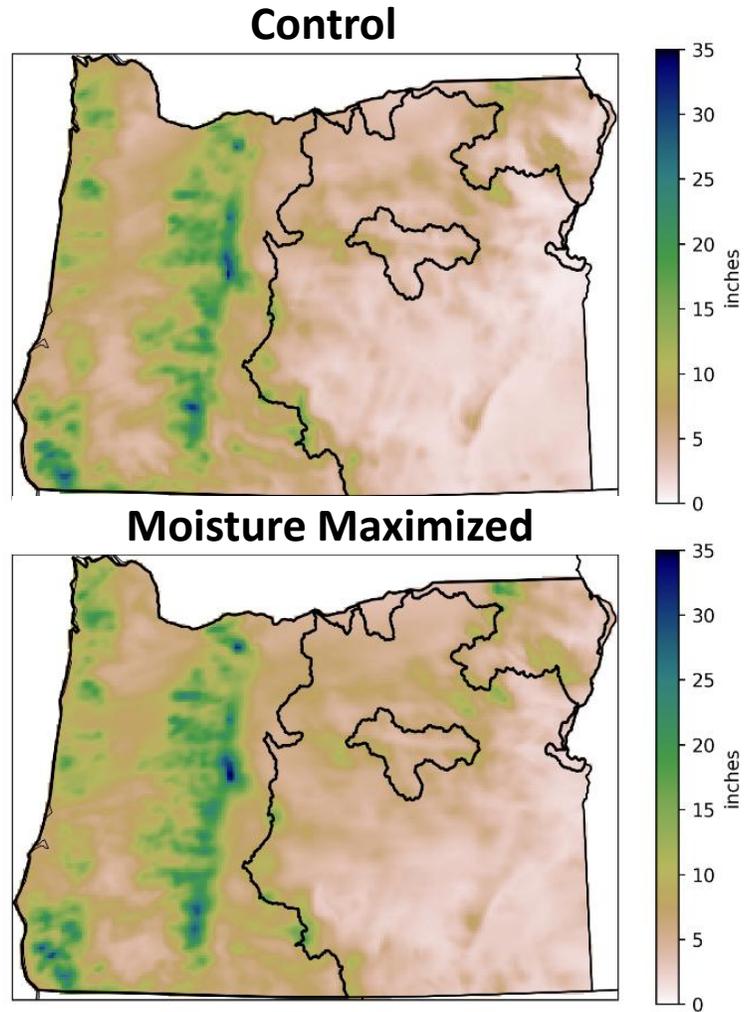
Moisture increases by ~12-26% in storms we modelled



Reduced opportunity  
for moisture  
maximization

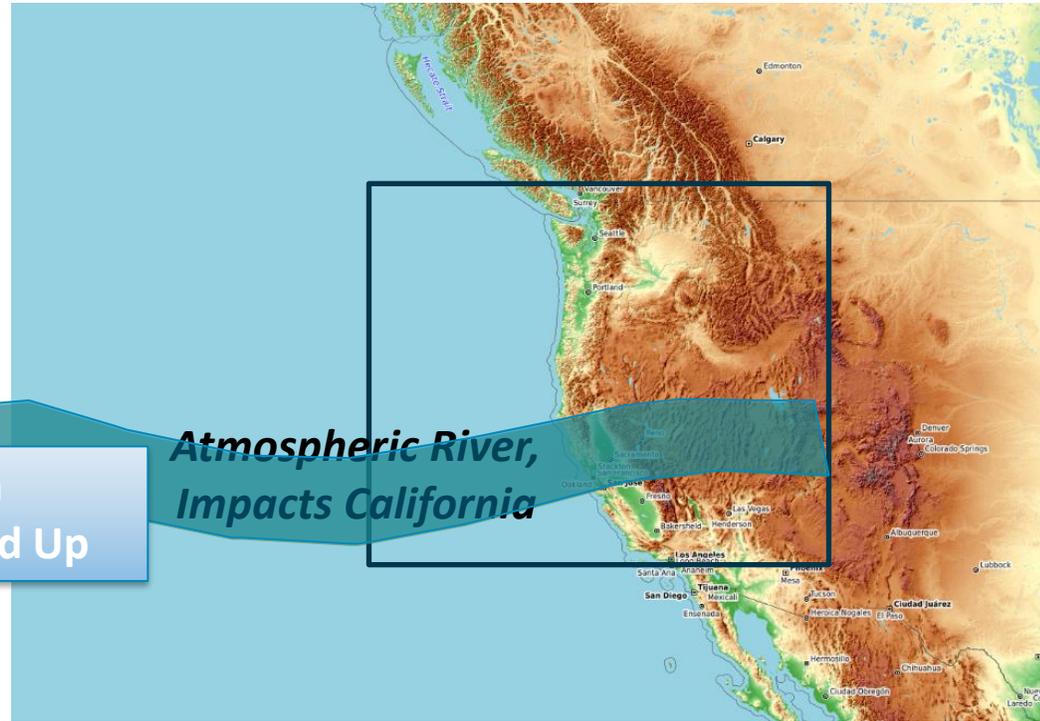
# Precipitation change when maximizing moisture

## 3-Day Max Precipitation



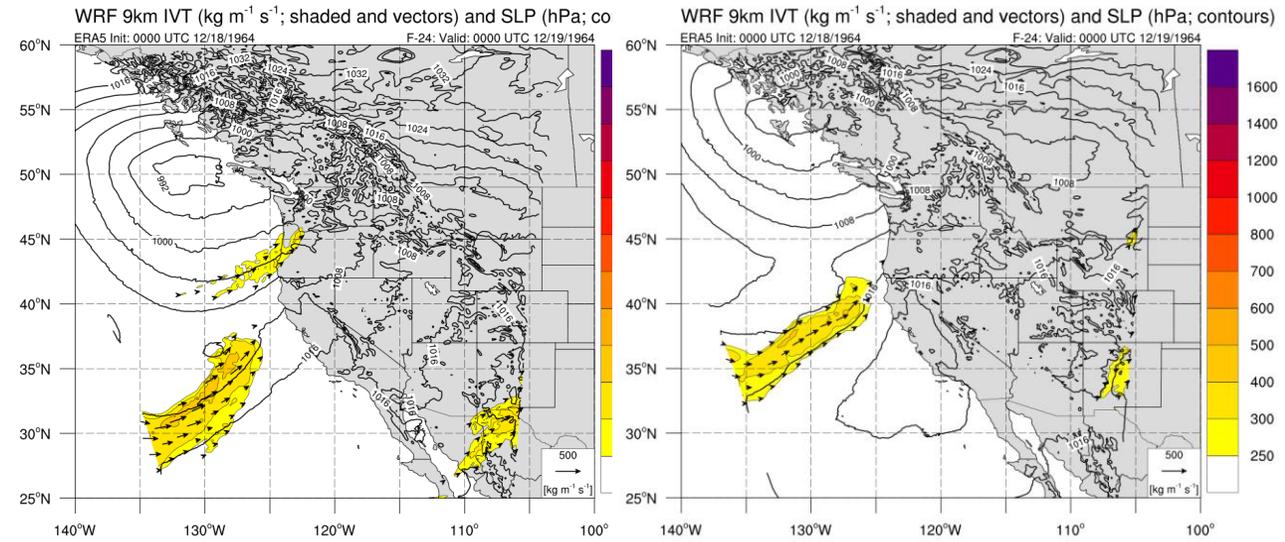
# Storm Transposition Schematic

## WRF Model Domain



## Control WRF

## Transposed 5°N



# Maximizing extreme ARs for Oregon

1. Maximize moisture
2. Transpose the storm

$\Delta T = 2.2^\circ C$

$\Delta T = 3.8^\circ C$

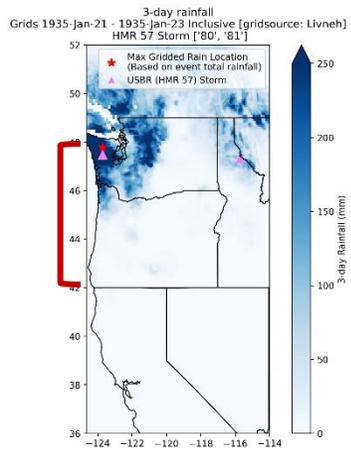
$\Delta T = 3.3^\circ C$

$\Delta T = 3.2^\circ C$

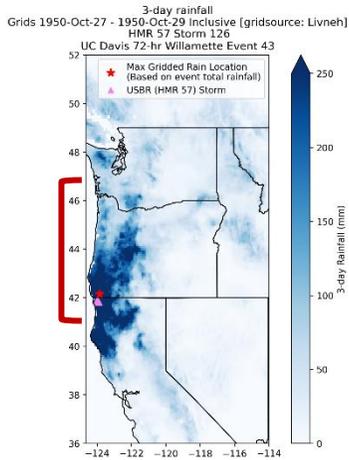
$\Delta T = 3.6^\circ C$

$\Delta T = 1.6^\circ C$

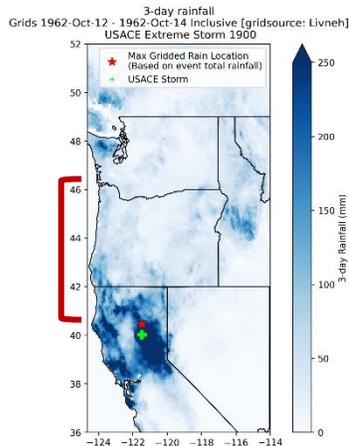
$\Delta T = 2.8^\circ C$



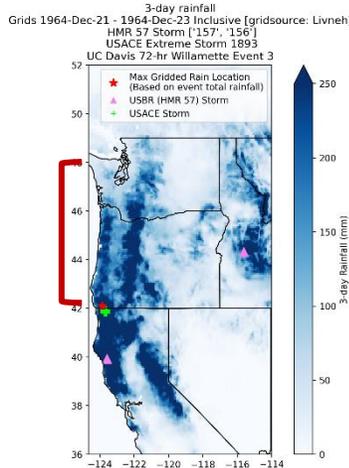
$1^\circ S - 6^\circ S$



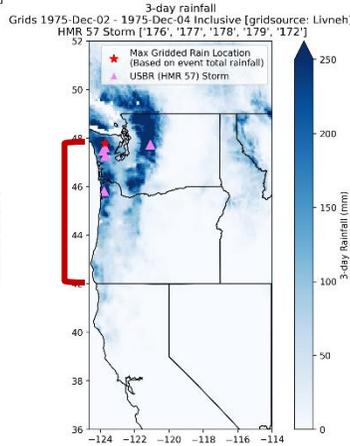
$1^\circ S - 5^\circ N$



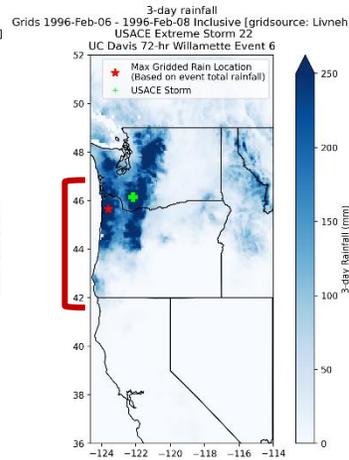
$1^\circ N - 6^\circ N$



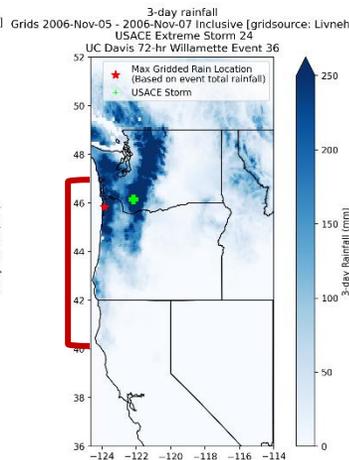
$1^\circ N - 6^\circ N$



$1^\circ S - 6^\circ S$



$4^\circ S - 1^\circ N$



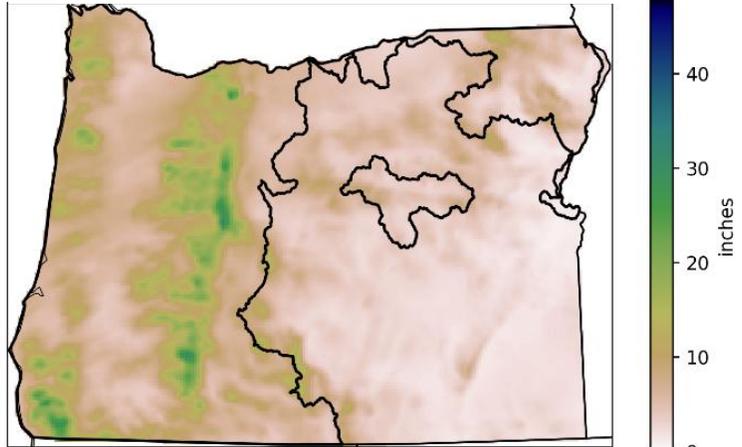
$6^\circ S - 1^\circ N$

1 storm not shown

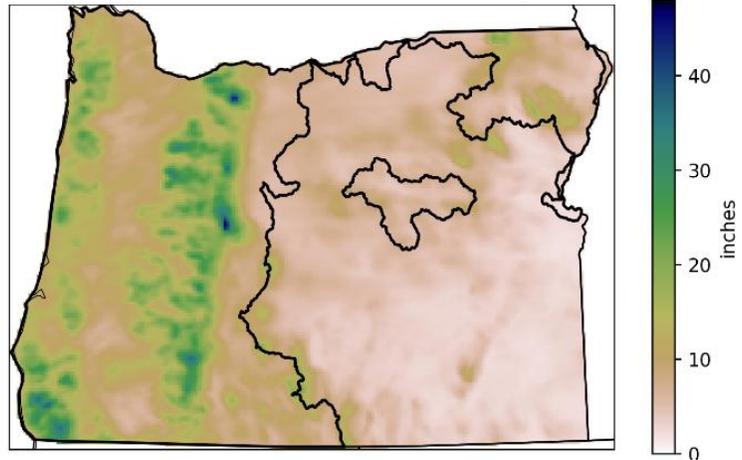
# Moisture Maximization and Storm Transposition

## 3-Day Max Precipitation

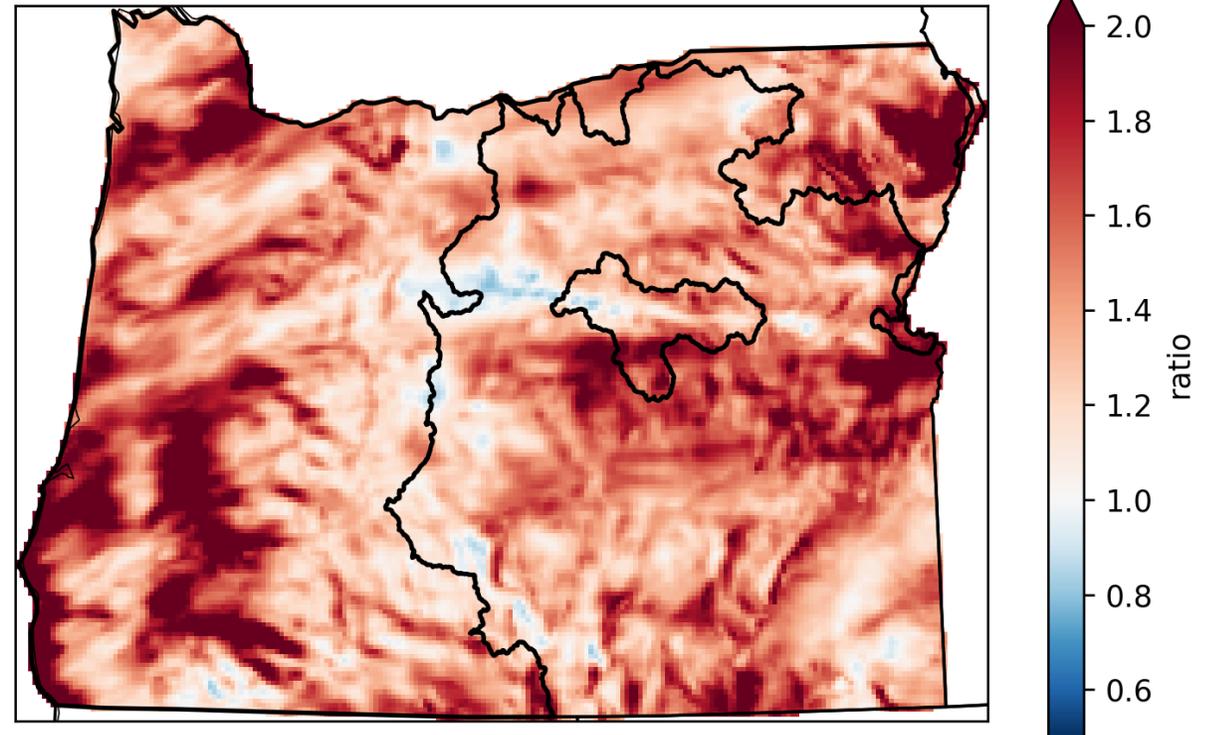
Control



Moisture Maximized & Transposed



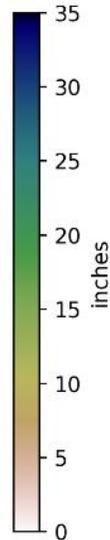
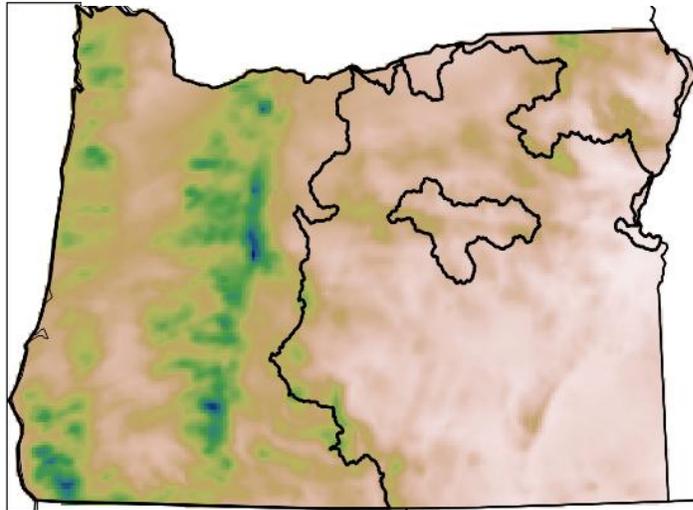
Ratio – Precipitation Change



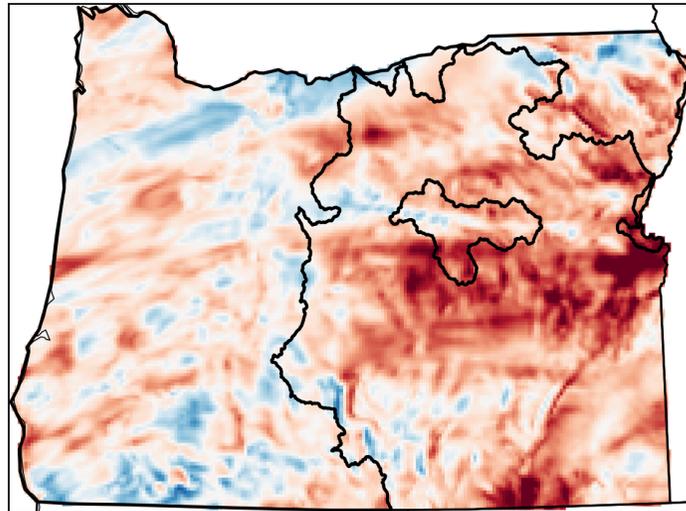
# Concluding Remarks

## 3-Day Max Precipitation

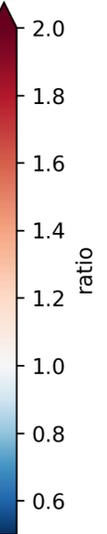
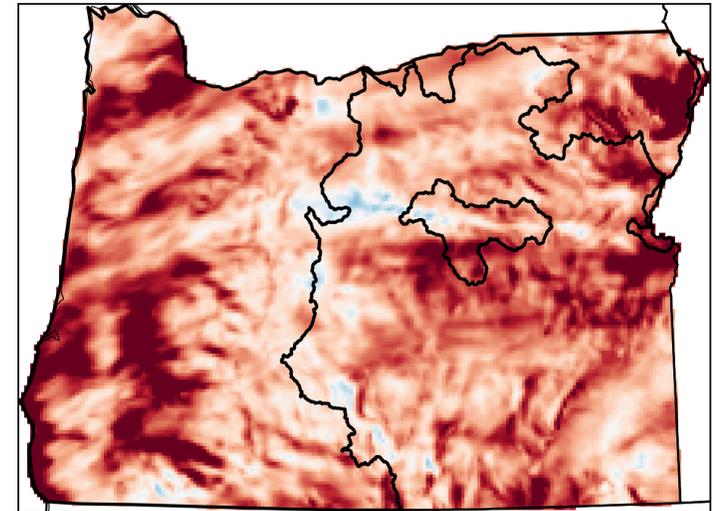
### Control



### Moisture Maximized



### Moisture Maximized & Transposed



# EXTRA SLIDES

# Model configuration—tested and implemented

## Tested

Option	Variants
Domain	Large domain, coast-aligned, and small domain
Vertical Resolution	100- vs. 45-levels
Nudging	Off, Grid-scale, or Spectral
Nesting	One-way, Two-way (3 variants)

Parameterizations not tested—used what has been used most frequently for the Pacific Northwest (e.g., West-WRF, WRF-UW operational forecasting, HRRR, etc.)

## Storm Reconstruction of Shortlist

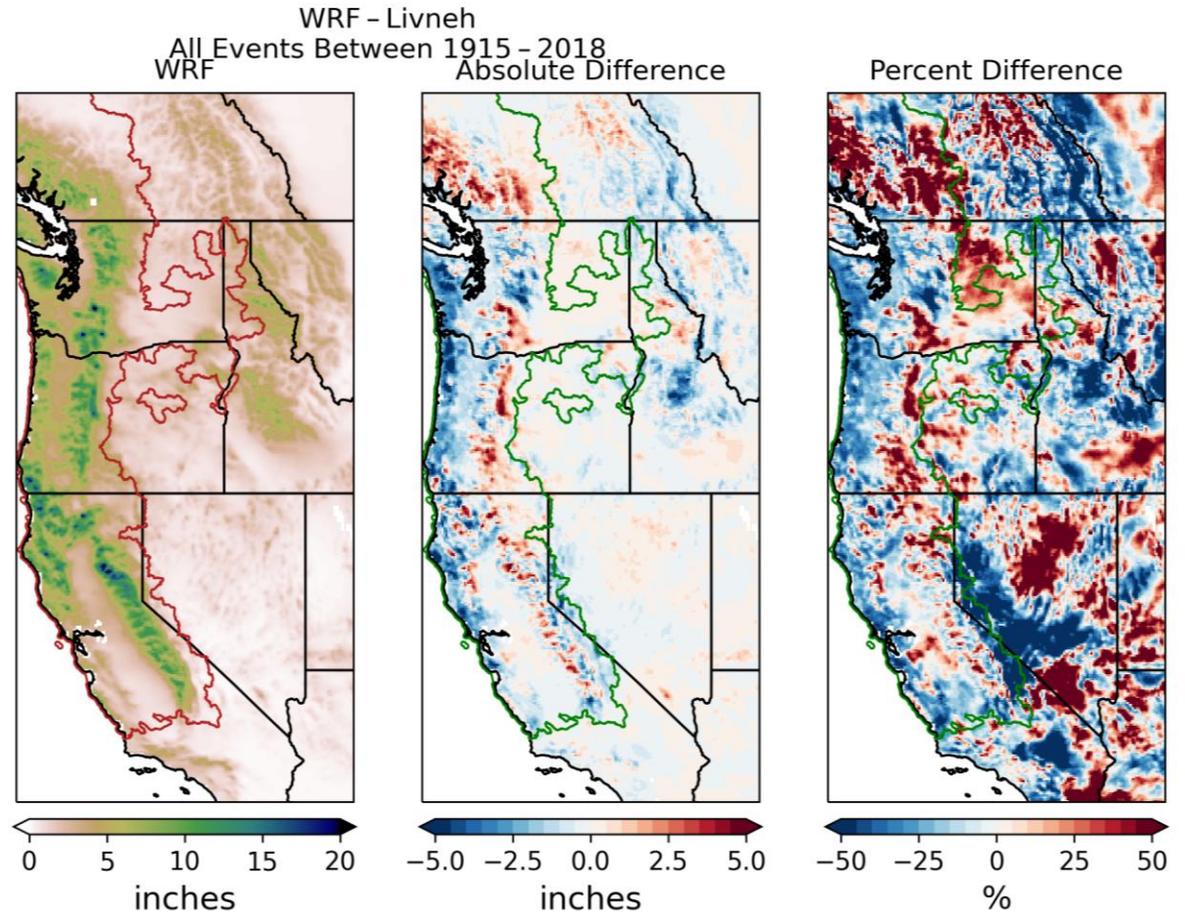
WRFv4.3.1	
Input data	ECMWF reanalysis data (ERA5)
Horizontal resolution	9 km / 3 km / 1 km
Vertical levels	100 / 45
Temporal Resolution	30min / 1h
Spin-up	24h
Microphysics	Thompson
PBL	YSU
Shortwave & Longwave	RRTMG
Land surface	Noah-MP
Surface layer	Monin-Obukhov Similarity
Cumulus	Grell-Freitas
Nudging	3-hrly Spectral (~1,000 km scale) Winds, Temperature, and Moisture
One-way Nesting	-

# Reconstruction of extreme ARs with WRF

## 36 storms modelled with WRF:

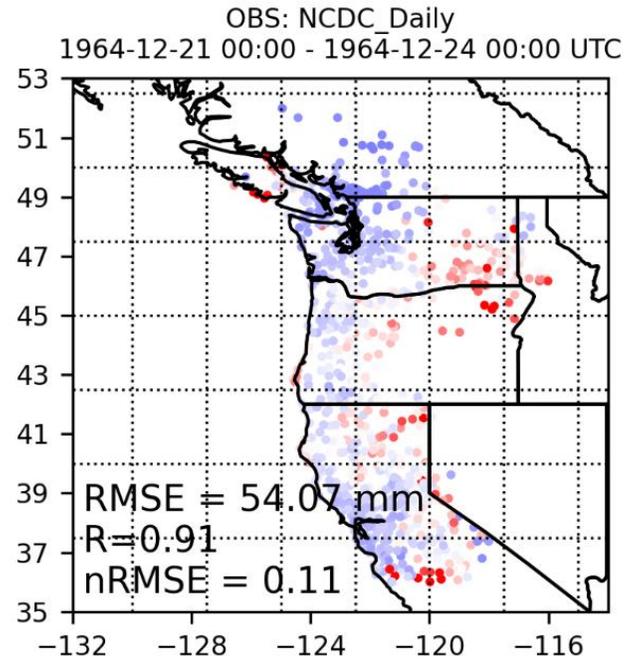
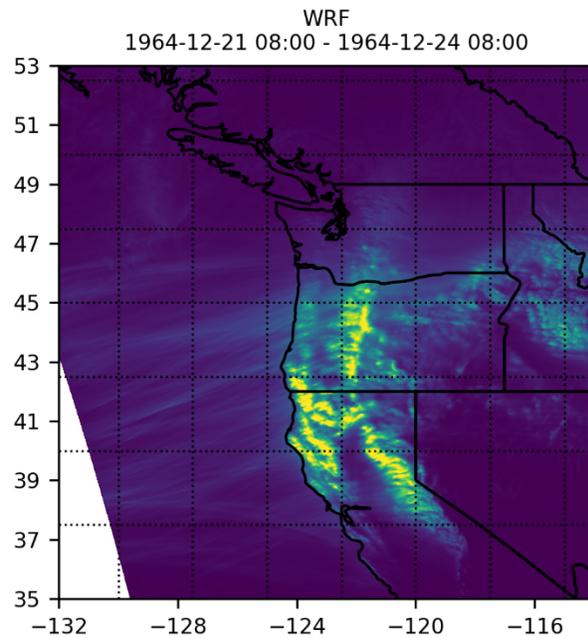
Total precipitation during the events in WRF has a dry bias along the coastal ranges relative to Livneh (Obs. Product) but a wet bias in the Oregon Cascades

Validation – focused on gauge rather than interpolated datasets

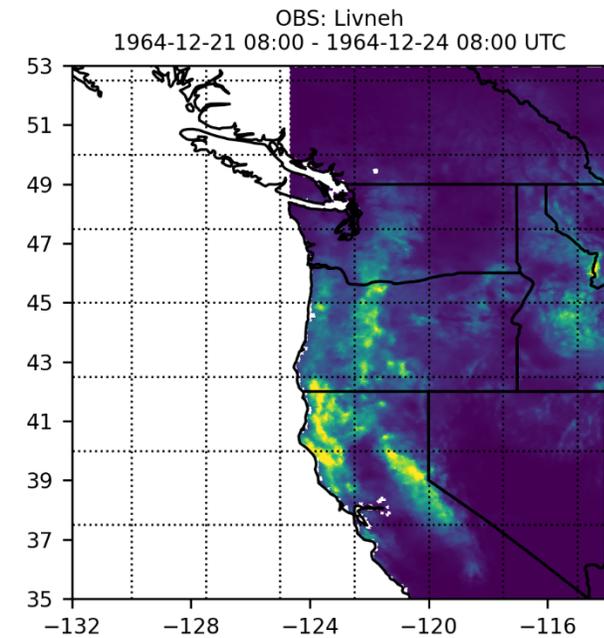


# December 1964 AR along CA/OR border

## 1964-12-18 Event: Maximum 72-hour Precip (mm)



%

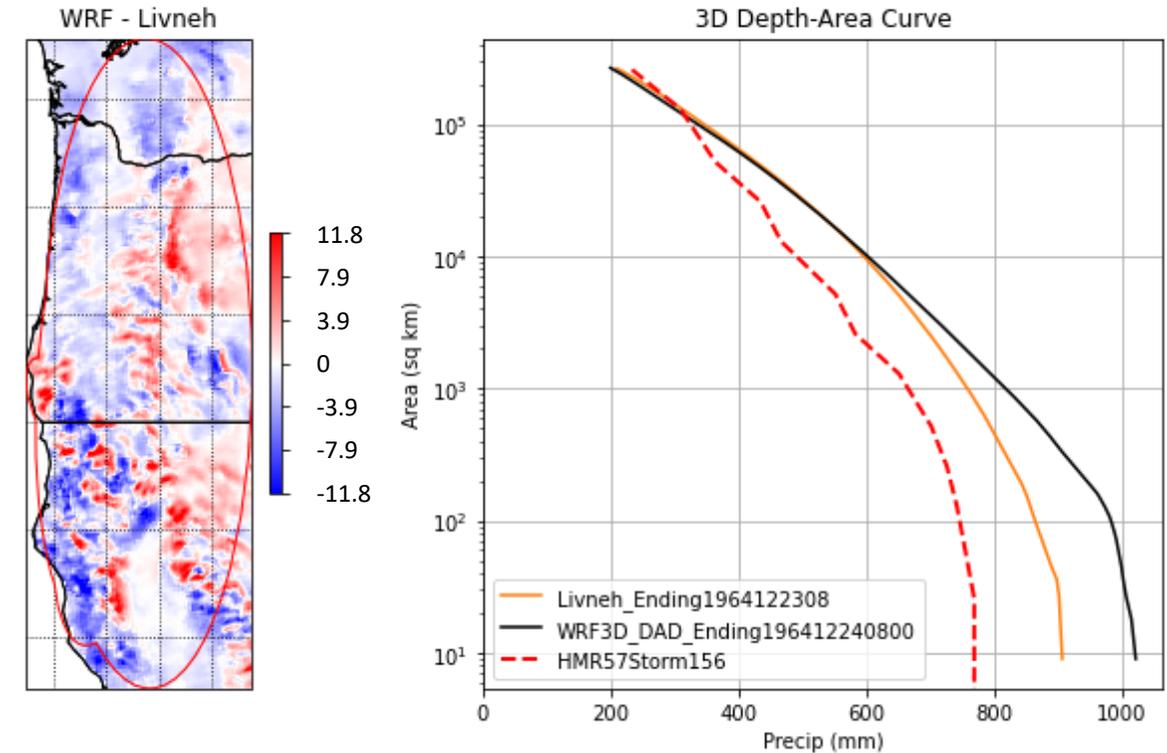


# December 1964 AR along CA/OR border

Precipitation in WRF penetrates more inland at the expense of lower coastal precipitation totals

Across the area of the storm, the depth-area curve for 3-day precipitation is higher in WRF than in the observations product (Livneh)

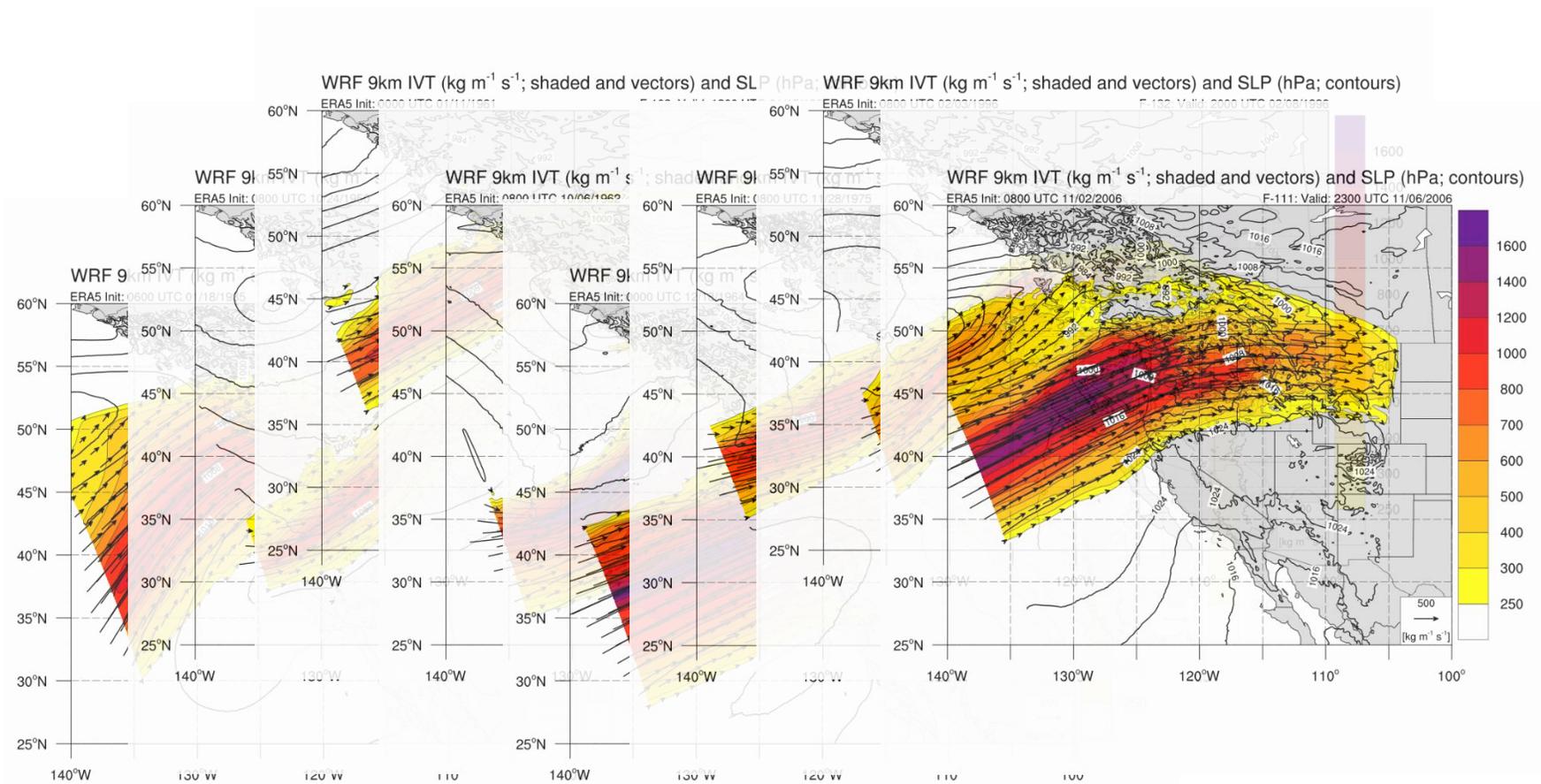
Max 27km<sup>2</sup> value 3D Depth-Area Curve



# Climatology of extreme ARs along the West Coast

Extreme ARs represent a diverse array of shapes, intensities, associated weather patterns, etc.

This subset represents 8 ARs that were identified as potential controlling storms of PMP in Oregon



# How has moisture maximization been done in WRF

Moisture modification methods:

1. Moisture *maximization* (RHM), original approach to moisture modification

2. Moisture *perturbation* (RHP):

1. Range of uniform increase to RH (e.g., 1.1x, 1.2x, etc.)
2. RH perturbation based on climatological ratios of water vapor

Avoids supersaturation and uses an IVT envelope (e.g., >250 kg/m/s)

3. Moisture scaling by climatological temperature

