Center for Western Weather and Water Extremes
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Survey of Atmospheric River, Precipitation Science, and Prediction

Jason Cordeira, F. Martin Ralph, Luca Delle Monache, Anna Wilson

Center for Western Weather and Water Extremes

UCSD Scripps Institution of Oceanography

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Tuesday, 7 January 2025
WPC PEAR-WWE Seminar Series

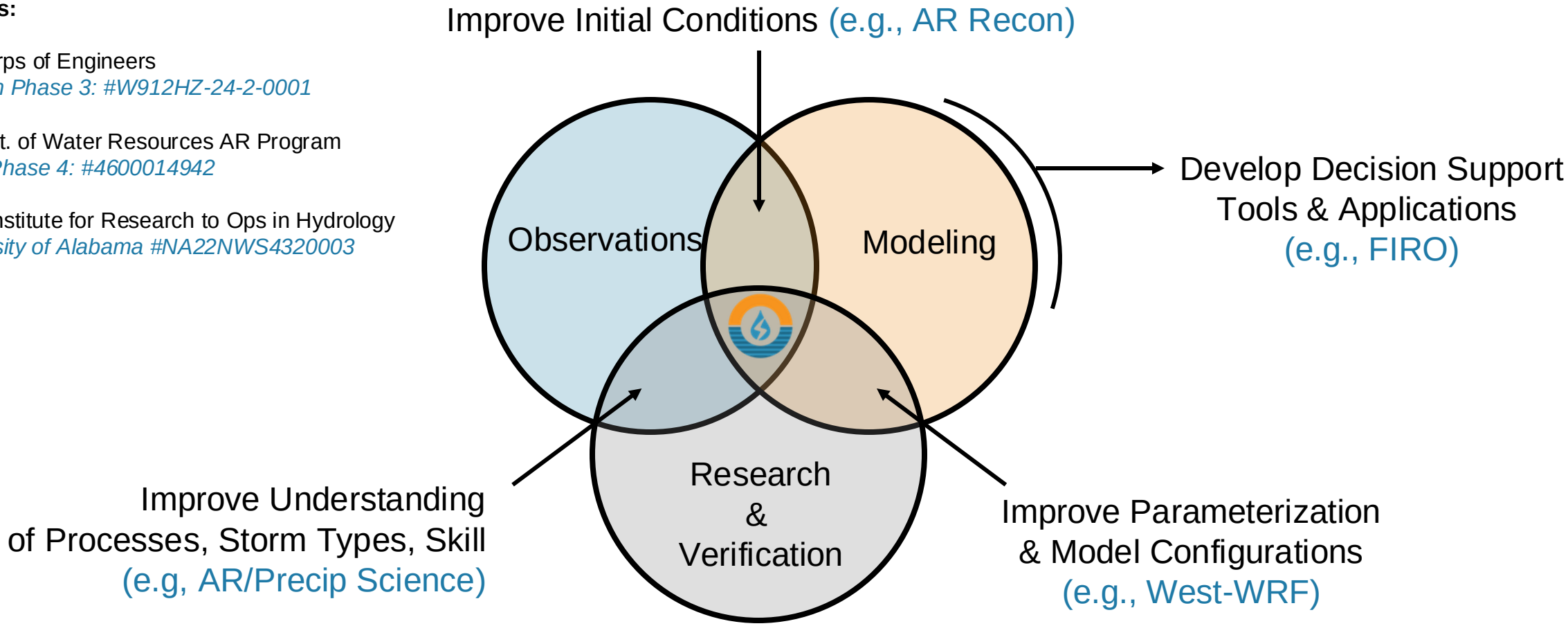
Improving QPF by focusing on Landfalling ARs across the Western U.S.

Key Sponsors:

U.S. Army Corps of Engineers
FIRO Program Phase 3: #W912HZ-24-2-0001

California Dept. of Water Resources AR Program
AR Program Phase 4: #4600014942

Cooperative Institute for Research to Ops in Hydrology
NOAA/University of Alabama #NA22NWS4320003



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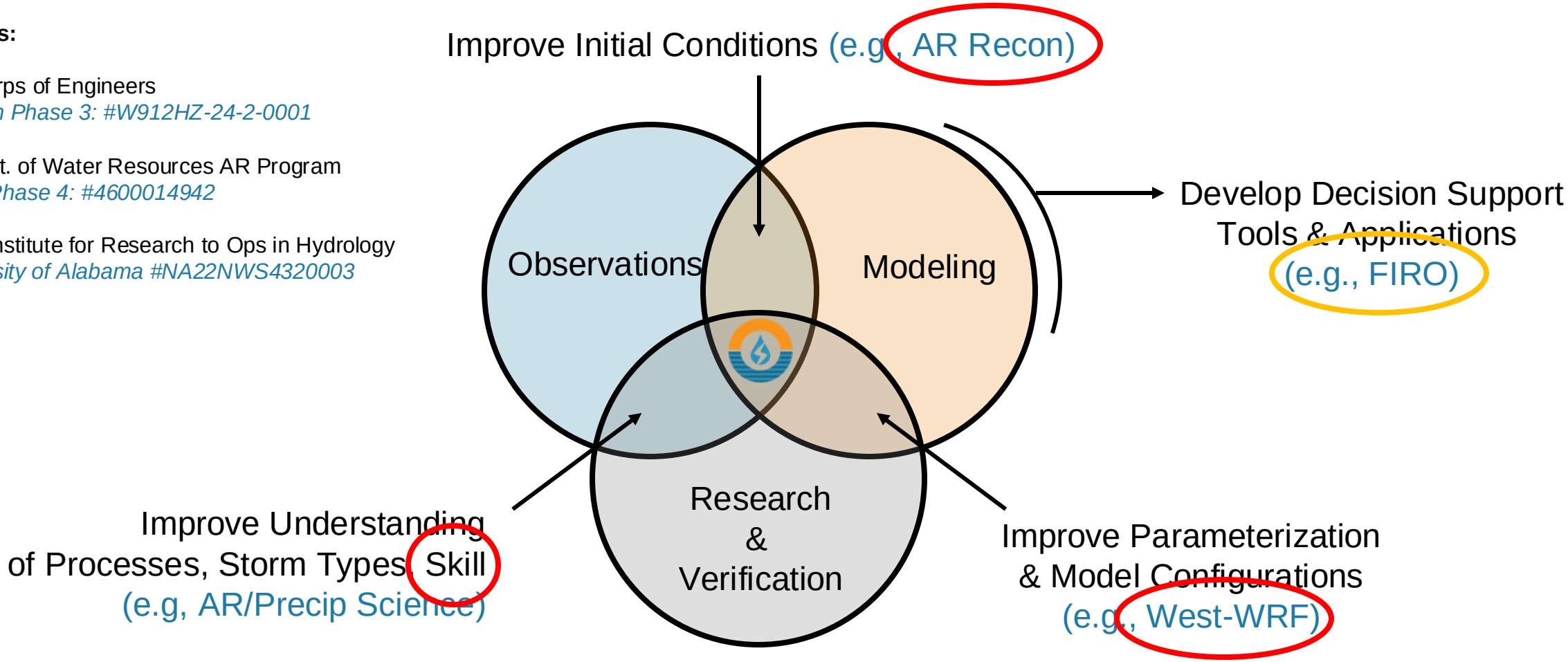
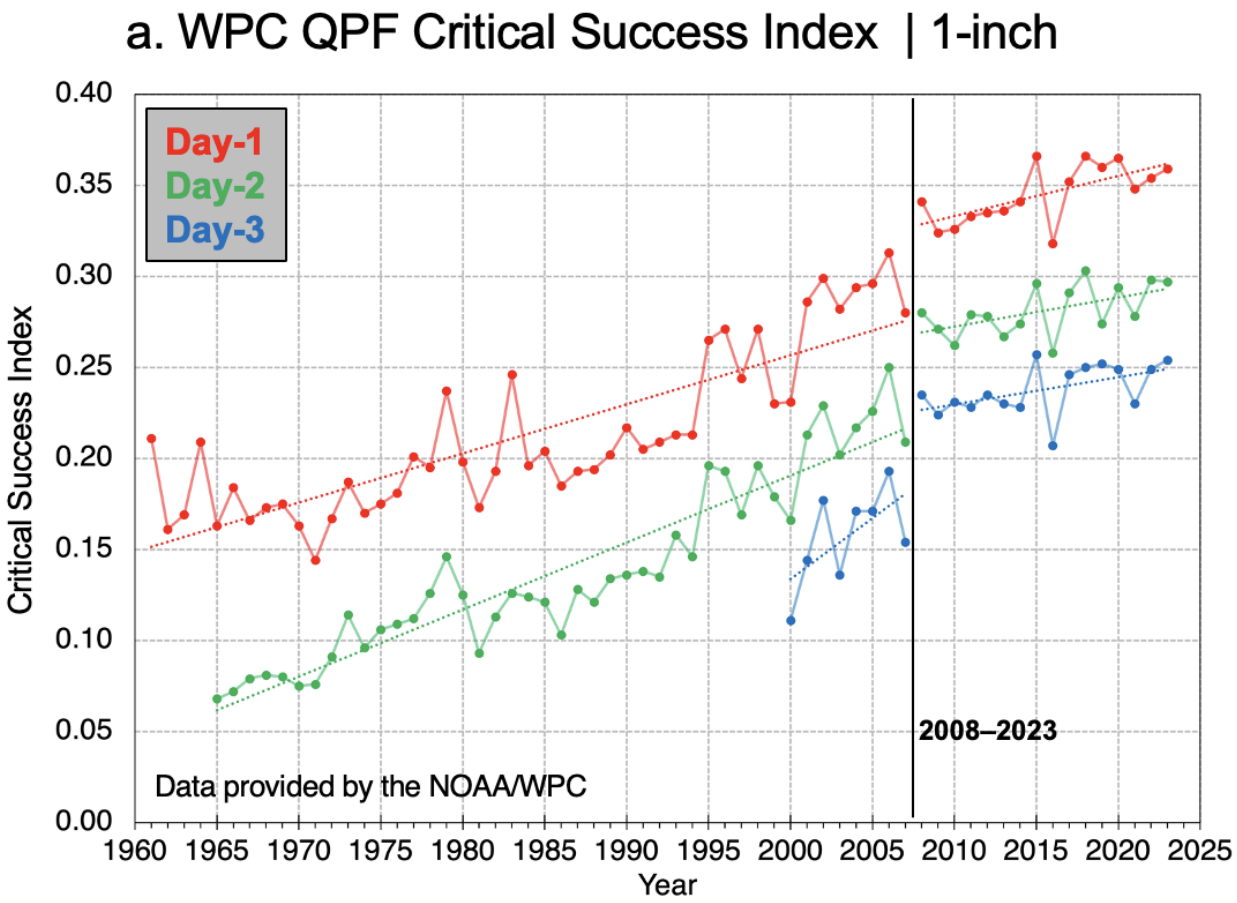
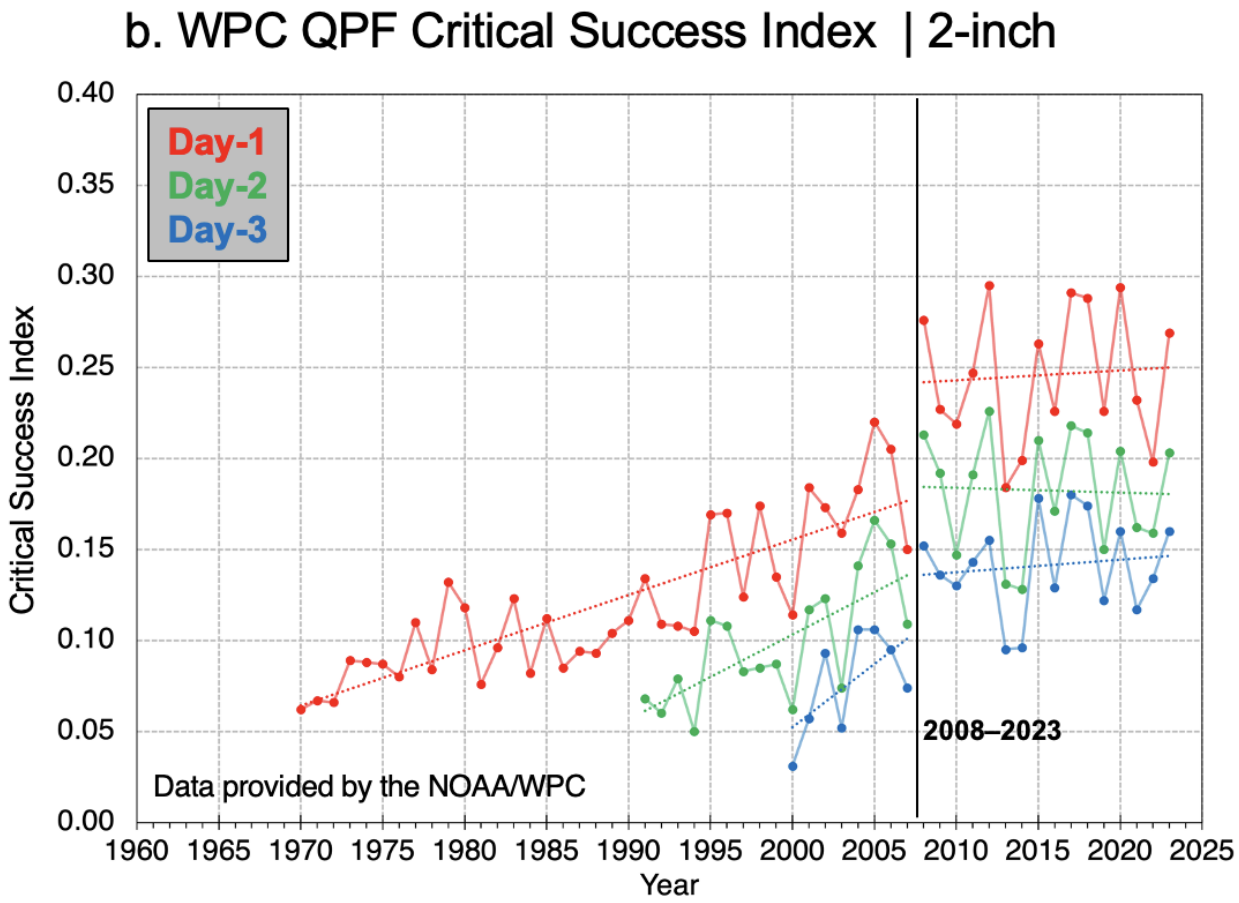


Motivation: National QPF Skill by the Weather Prediction Center

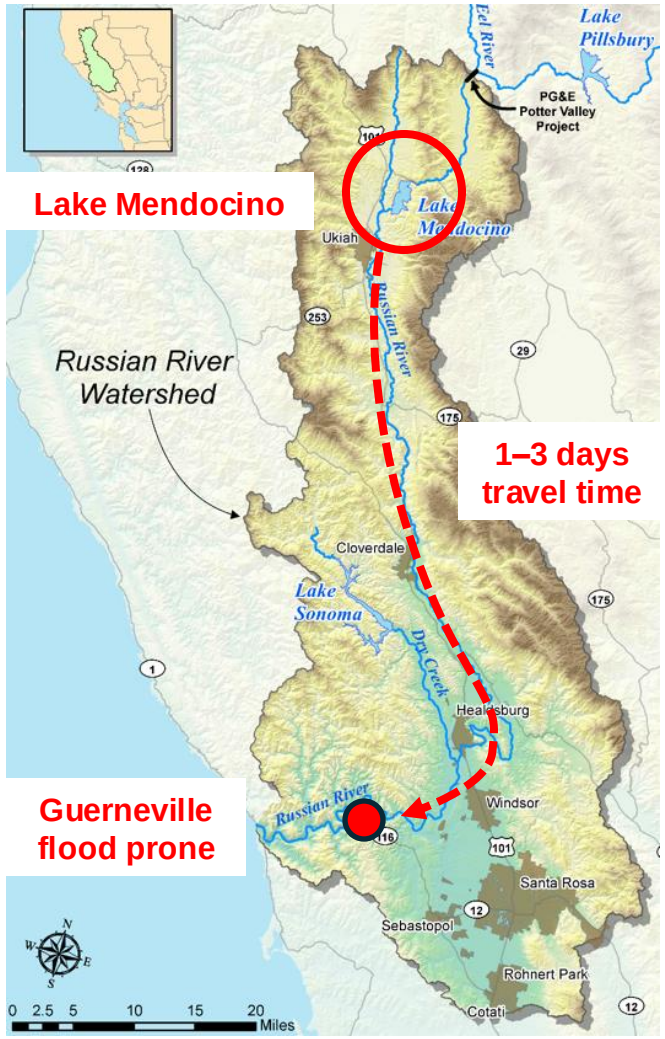


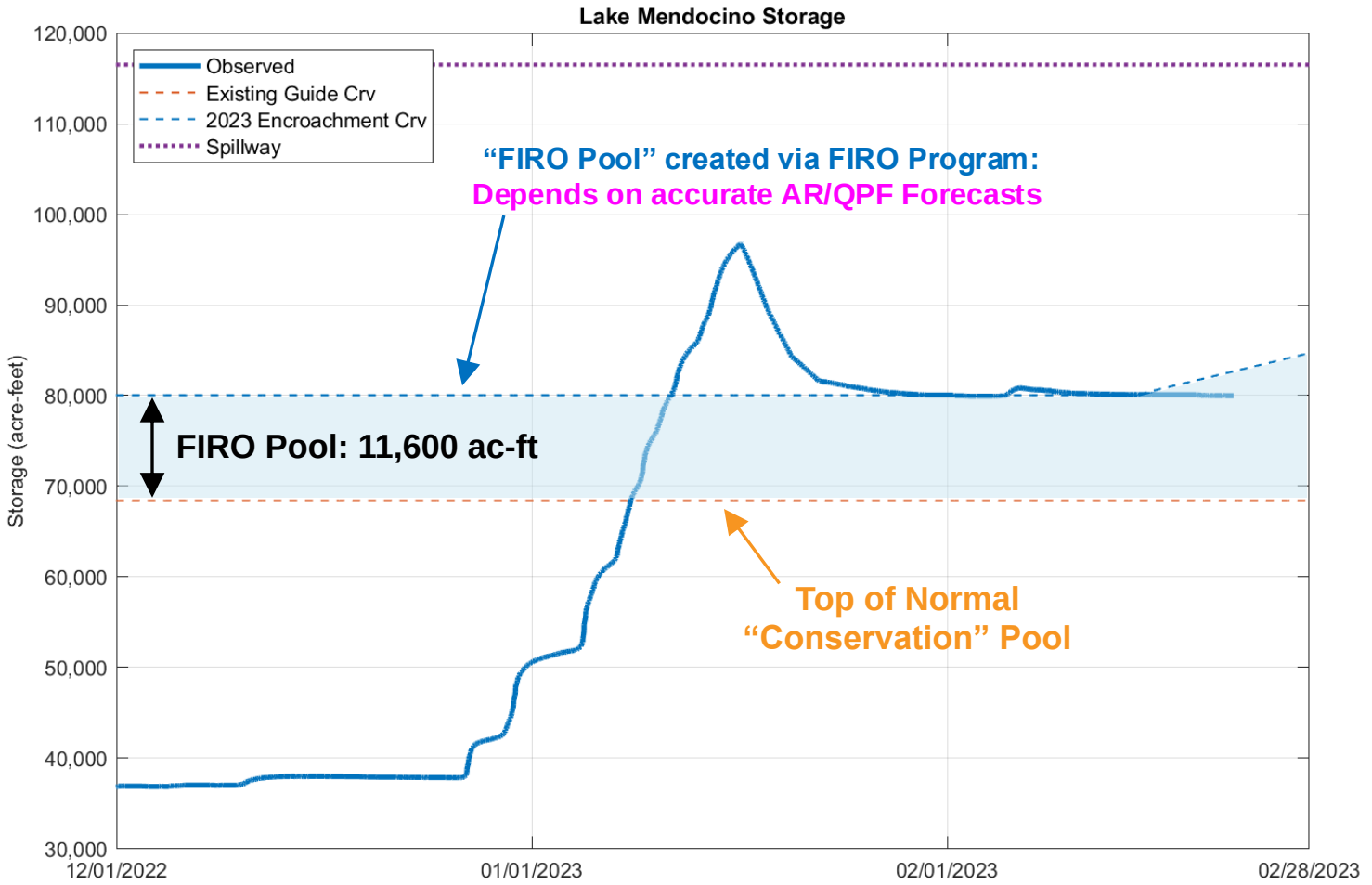


U.S. National QPF skill has been steadily improving, although the rate of increase has slowed during the last 10–20 years

Cordeira et al. (2024; submitted)

Application: Forecast Informed Reservoir Operations (FIRO)

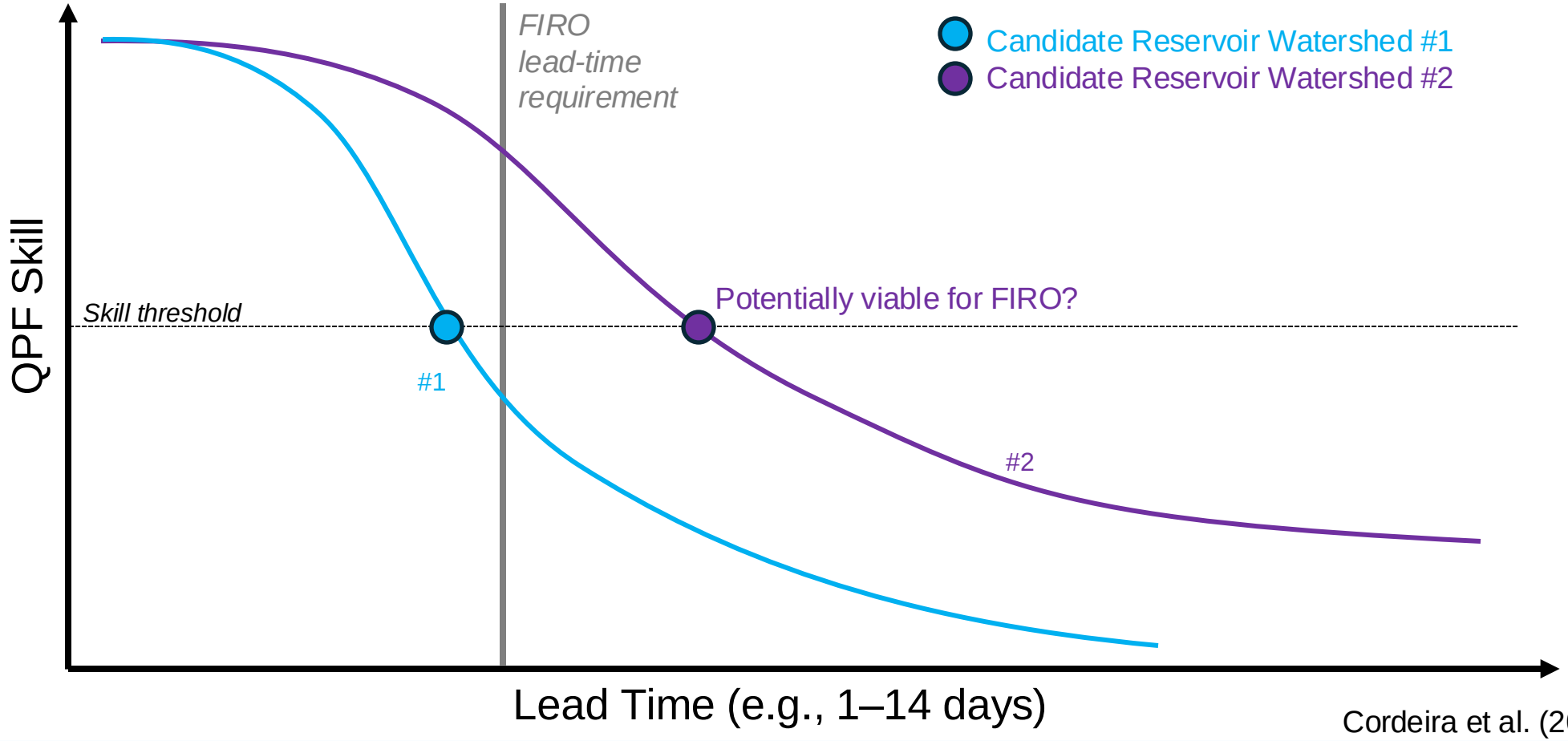




FIRO allowed retention of an extra 11,600 acre-feet at Lake Mendocino after the onslaught of ARs during Dec 2022–Jan 2023; FIRO requires skillful AR/QPF forecasts.

Application: Leveraging enhanced skill to screen for FIRO viability

CW3E is leading FIRO efforts with USACE to screen for viability across the U.S.
Viability is influenced by **whether skill is high enough** at a given **FIRO lead-time requirement**.



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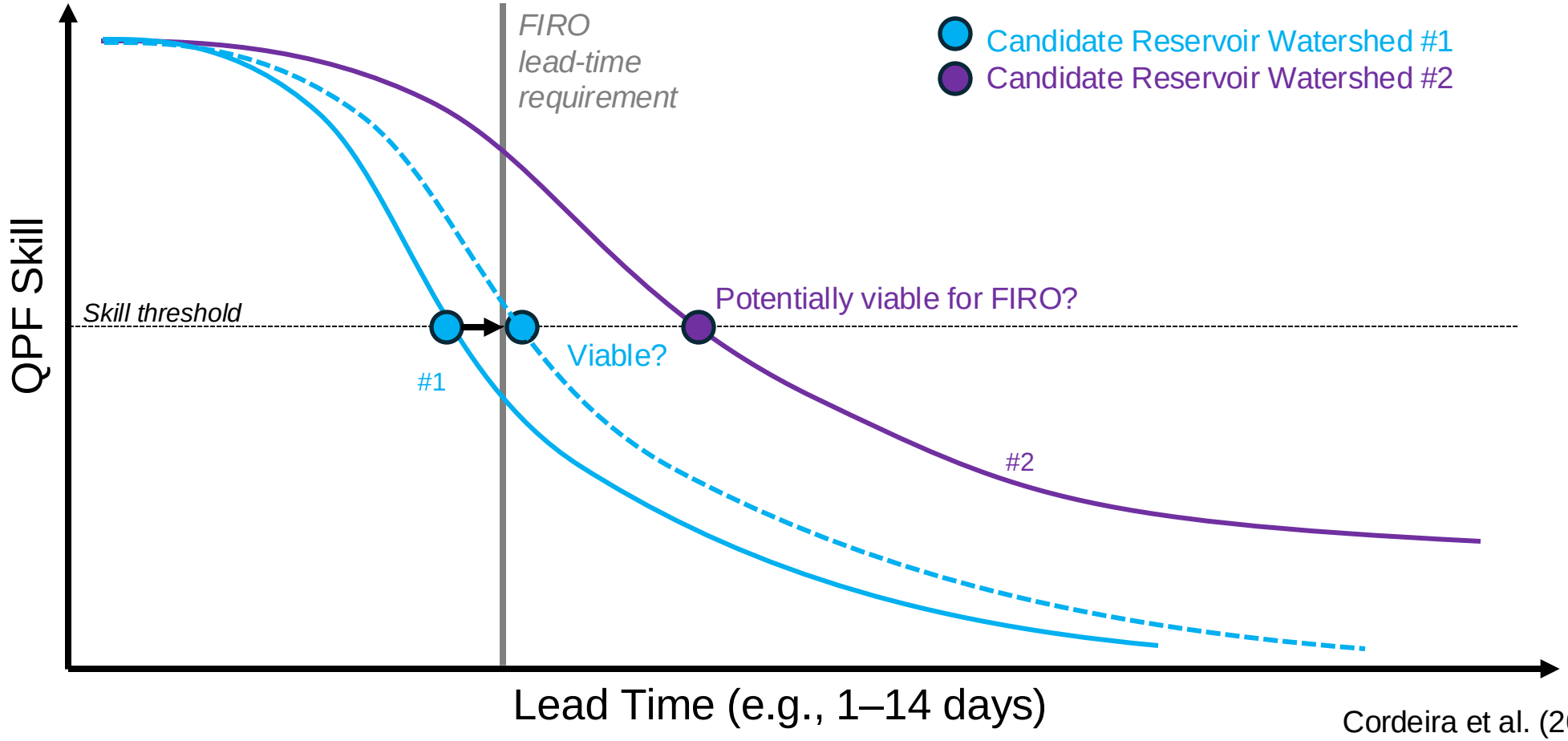

Cordeira et al. (2024; submitted)


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What is QPF skill?
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National QPF Skill: Design

Precipitation Forecast Data
GEFS-Reforecast
2000–2019 | Daily to 10 days
0.25-degree lat/lon gridded data

Precipitation Estimate Data
Oregon State PRISM
2000–2019 | Daily
4-km gridded data

→

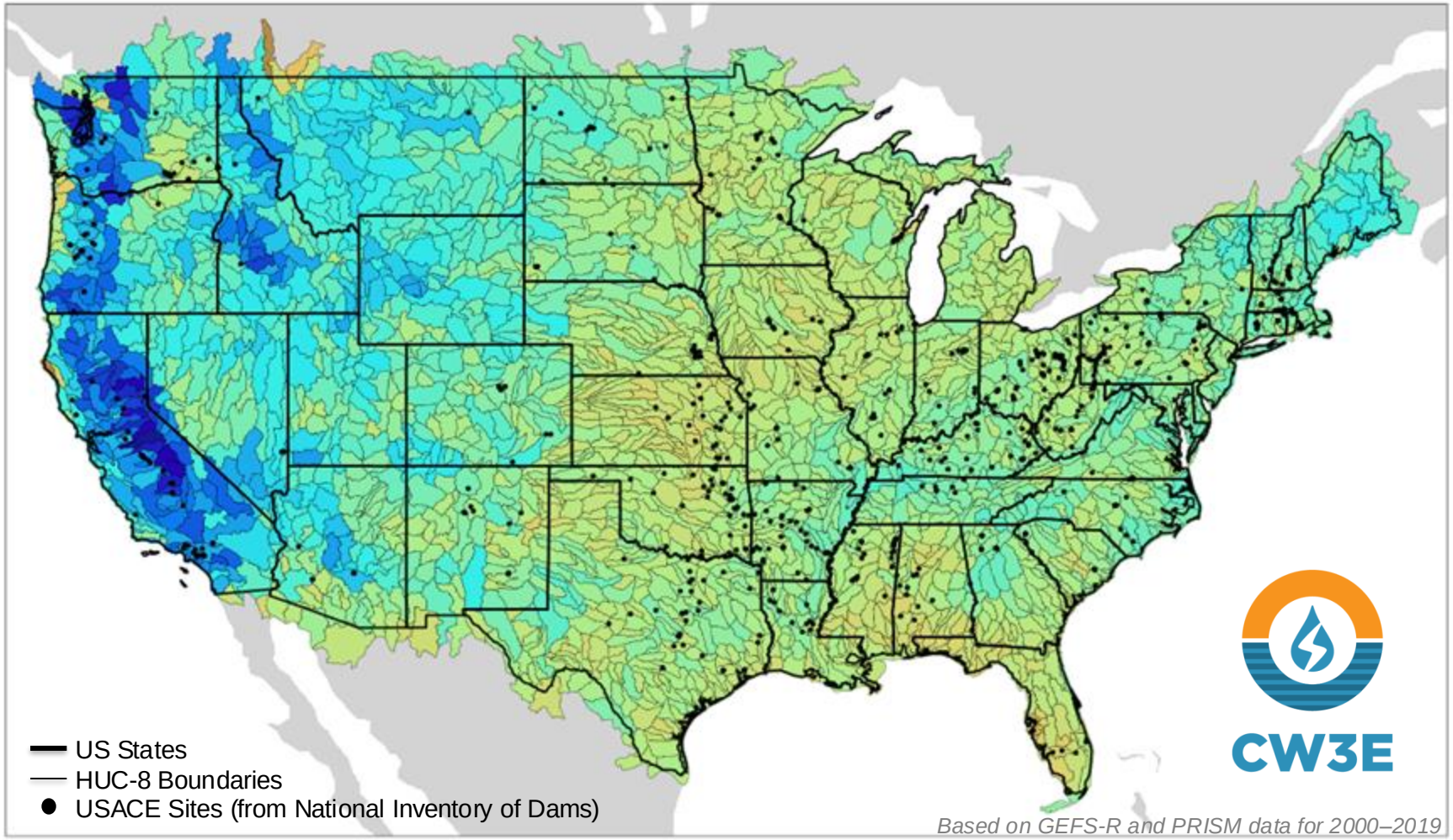
Regions of Interest
CONUS HUC-8 Watersheds
Mean Areal Precipitation

→

Skill Metric
Critical Success Index:
Threshold based
(i.e., Top-5% of wet days)

Context: CSI measures a combination of:
(1) When the model was right about an event
(2) When the model was wrong about an event
(3) When the model missed an event

Nationwide QPF Skill (CSI) | Top-5% | Days-1–3



Day-1 [F12–F84] Critical Success Index

0.000 0.050 0.100 0.150 0.200 0.250 0.300 0.350 0.400 0.450 0.500 0.550 0.600 0.650 0.700 0.750

Key Results:

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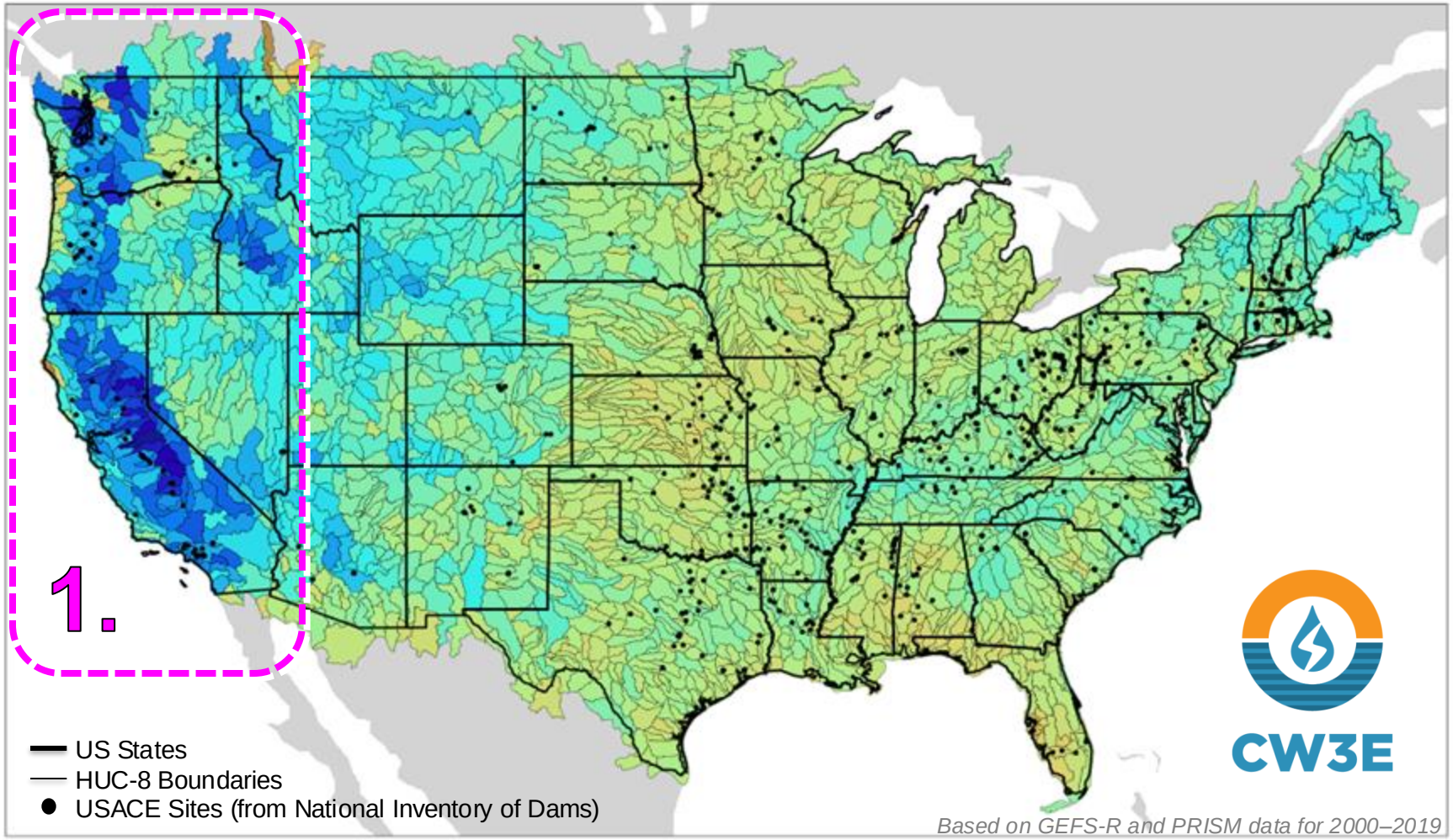

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Key Results:

1. Highest skill over West anchored by terrain and atmospheric rivers (ARs).

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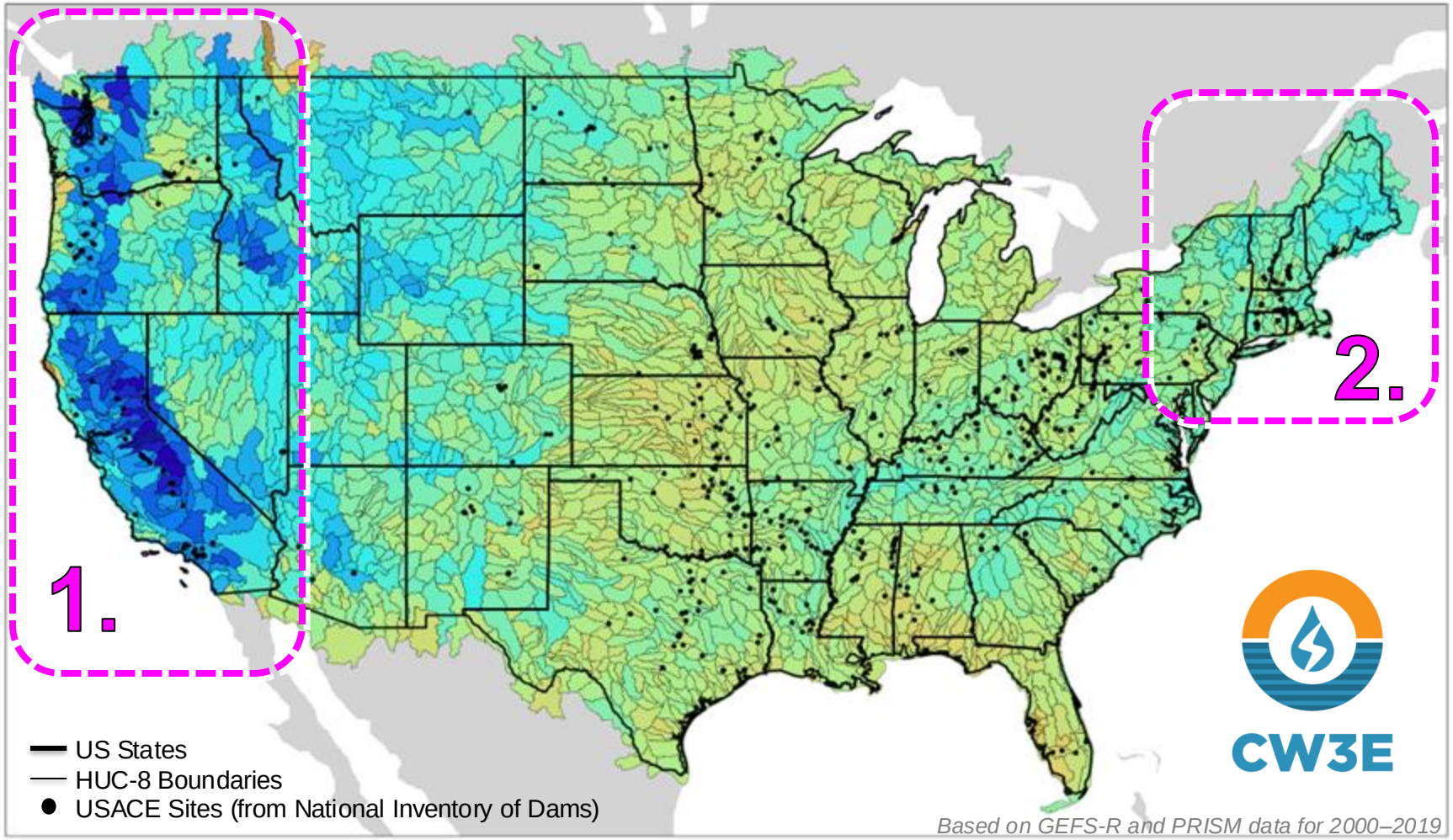

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2. Higher skill also over New England and Mid-Atlantic influenced by ARs and Nor'easters.

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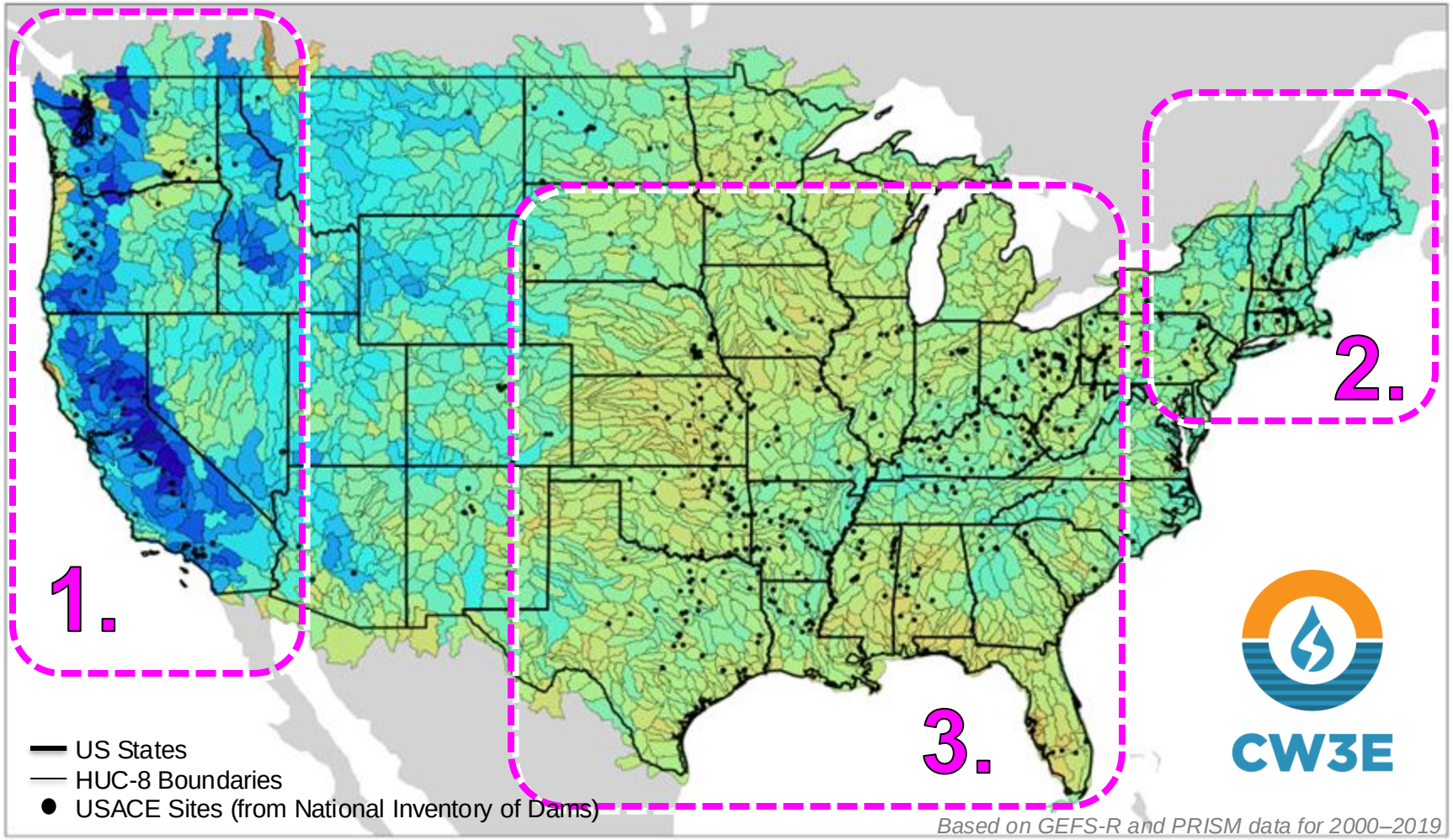

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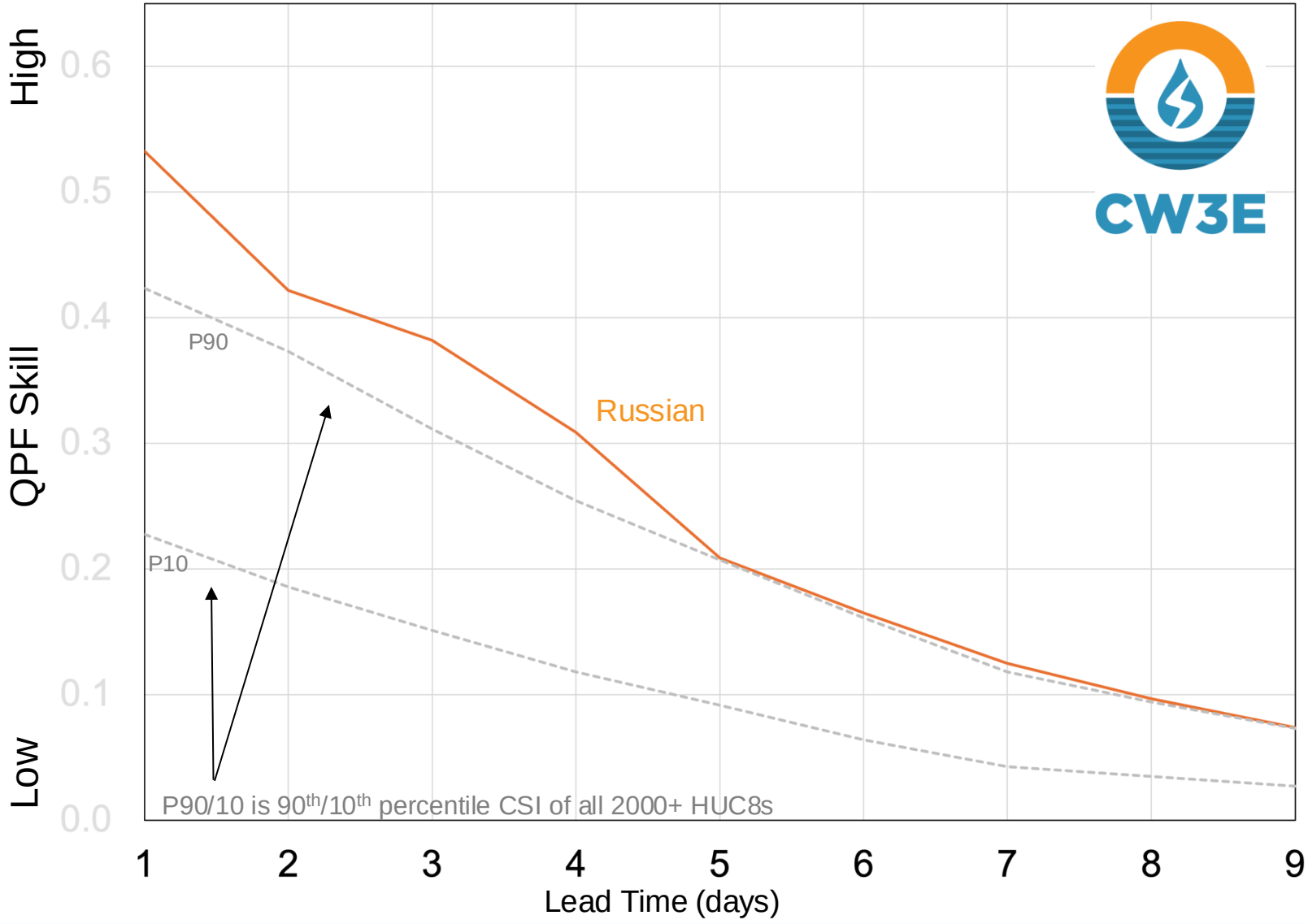
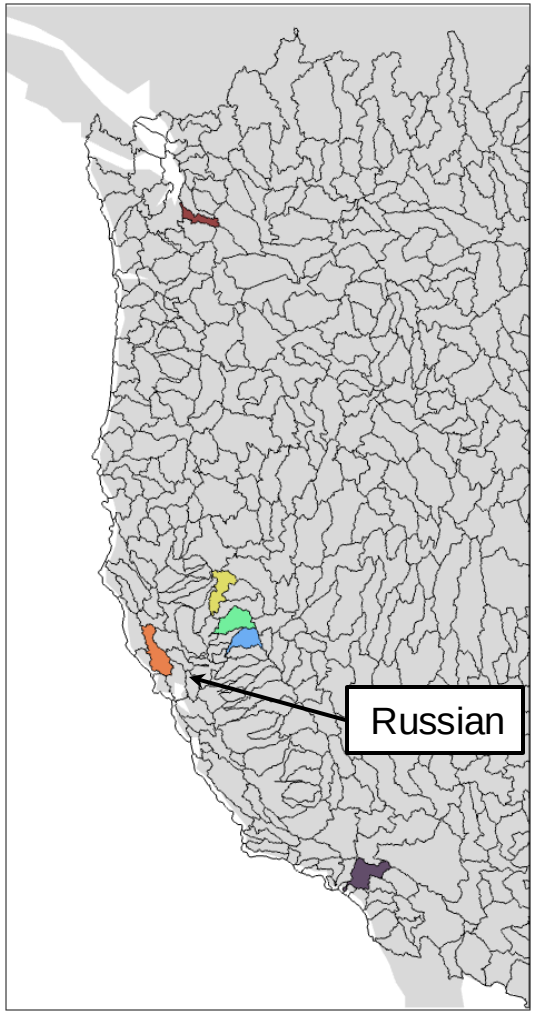
Key Results:

1. Highest skill over West anchored by terrain and atmospheric rivers (ARs).
2. Higher skill also over New England and Mid-Atlantic influenced by ARs and Nor'easters.
3. Lower skill over Central and Southeast influenced by convection and tropical processes (with some exceptions; e.g., along the Appalachians).

FIRO HUC-8 QPF Skill (CSI) | Top-5% | Days 1–9





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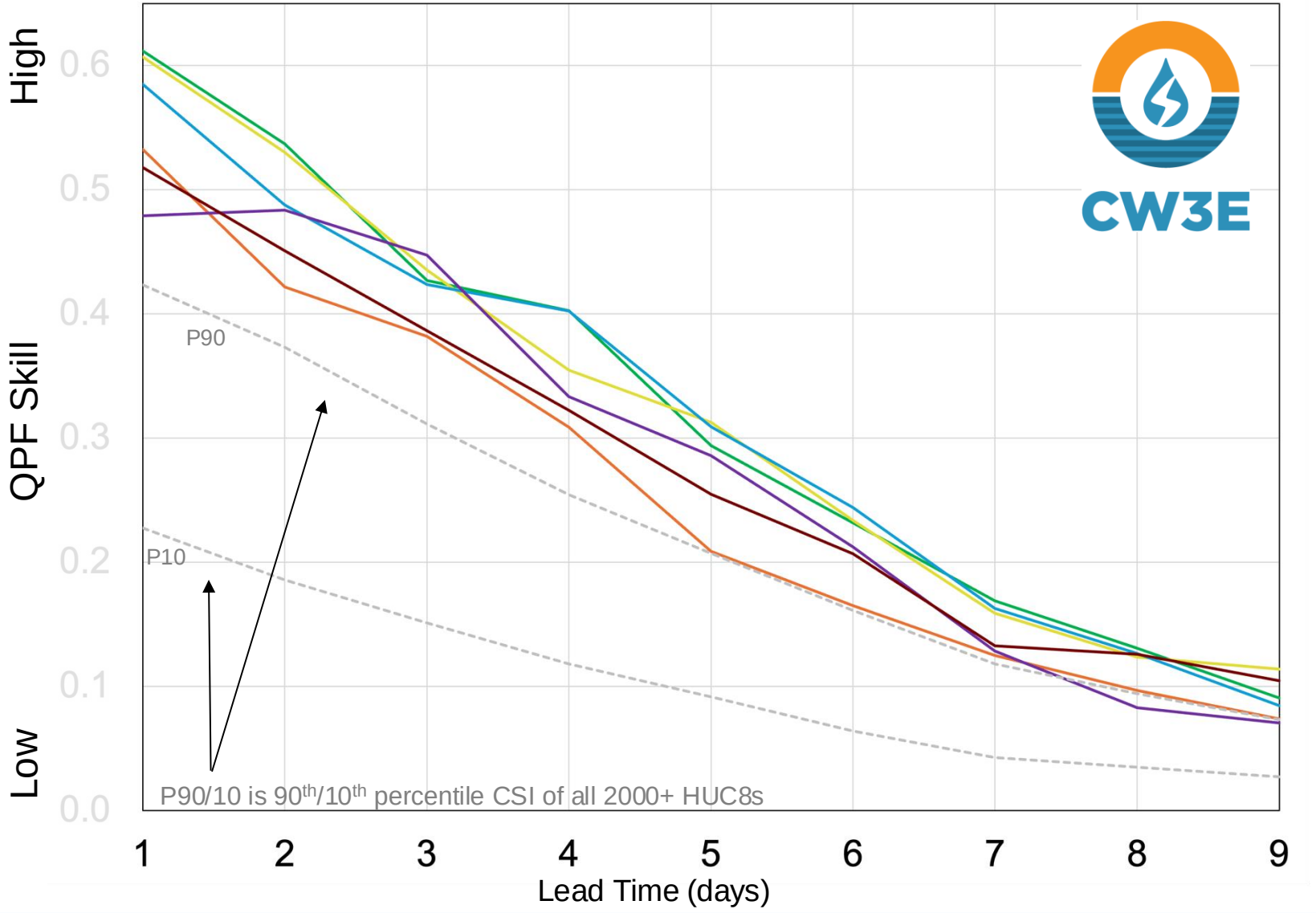
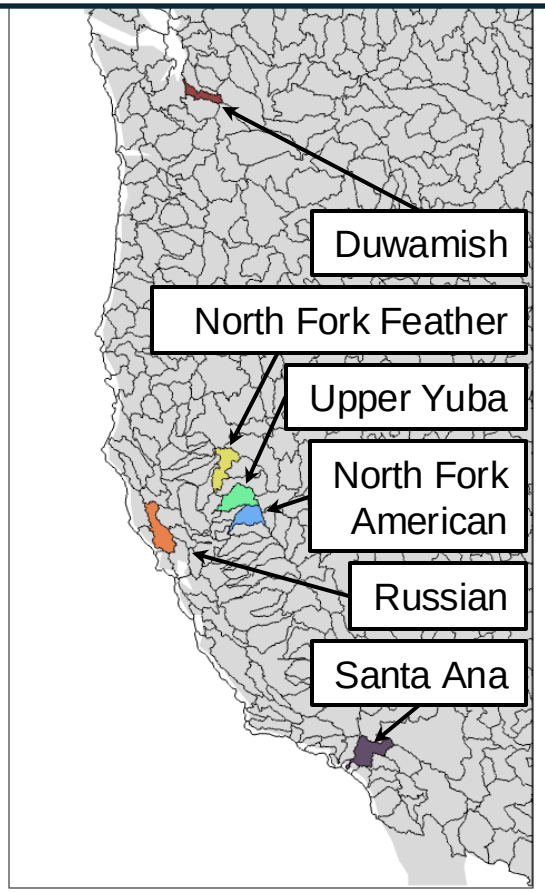


Current “FIRO HUC-8” watersheds contain skill in the top-10% nationally



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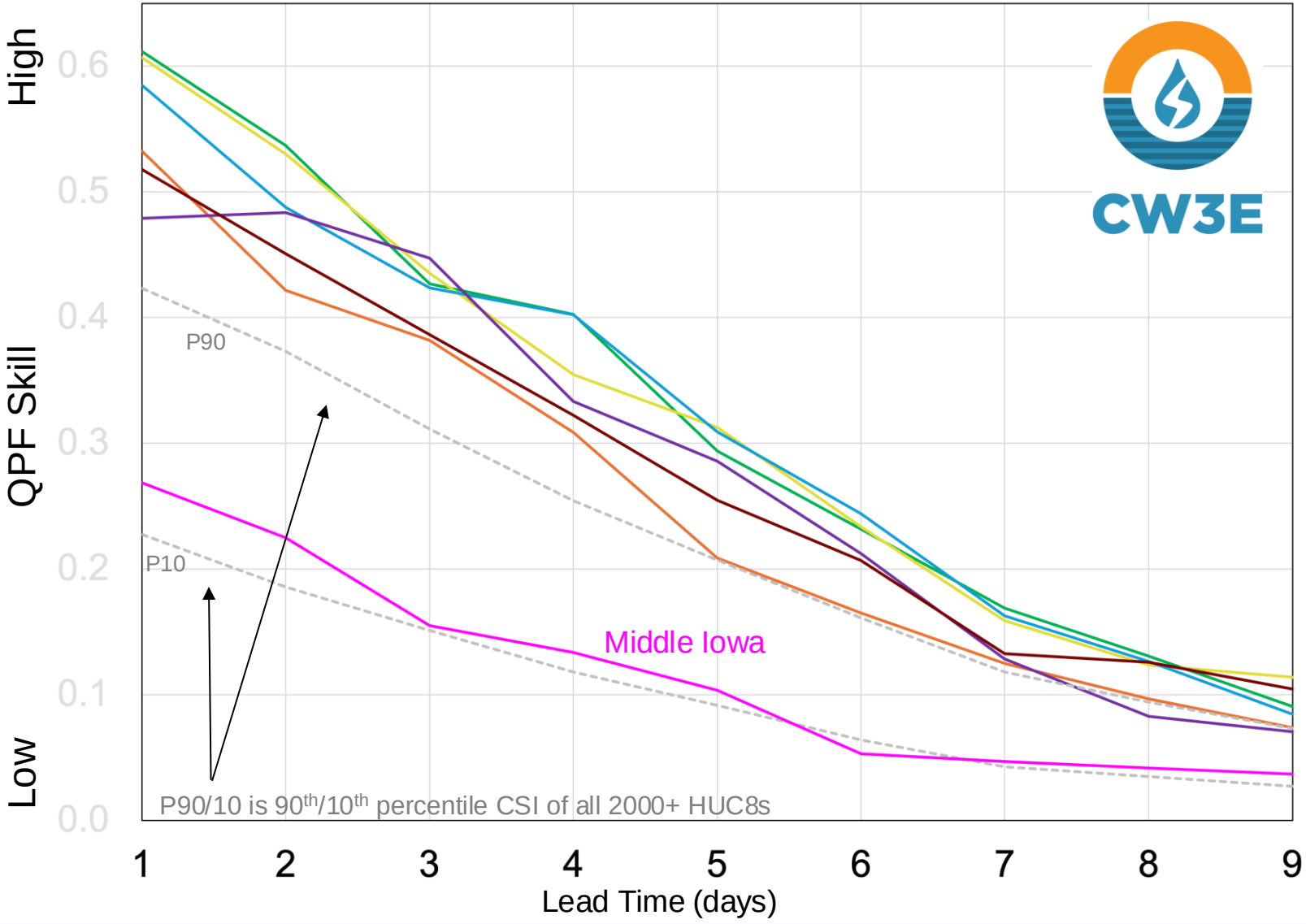

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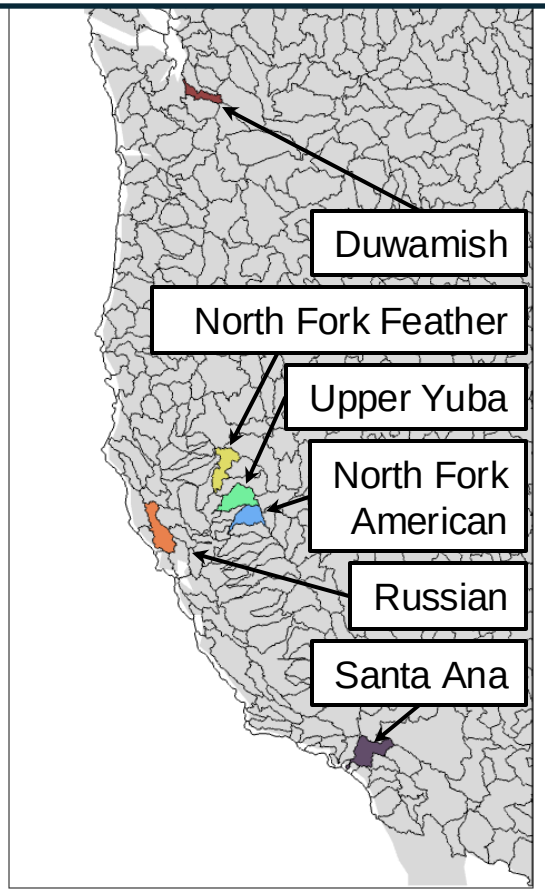

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Now that we know the (relative) skill, how can we improve it?

Improving QPF by focusing on Landfalling ARs across the Western U.S.

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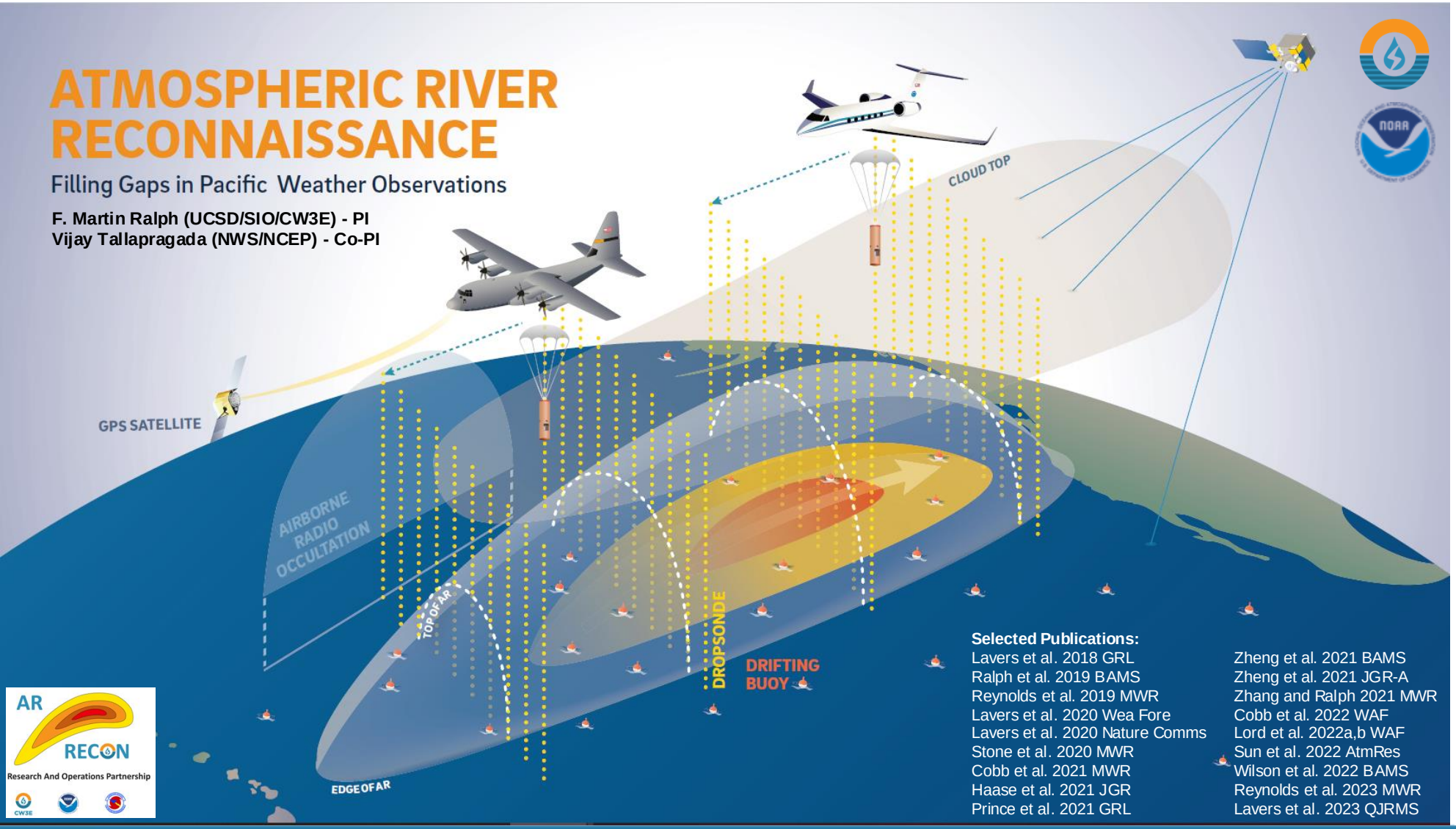
AR Recon: Targeting ARs to improve QPF skill



Selected Publications:

Lavers et al. 2018 GRL
Ralph et al. 2019 BAMS
Reynolds et al. 2019 MWR
Lavers et al. 2020 Wea Fore
Lavers et al. 2020 Nature Comms
Stone et al. 2020 MWR
Cobb et al. 2021 MWR
Haase et al. 2021 JGR
Prince et al. 2021 GRL
Zheng et al. 2021 BAMS
Zheng et al. 2021 JGR-A
Zhang and Ralph 2021 MWR
Cobb et al. 2022 WAF
Lord et al. 2022a,b WAF
Sun et al. 2022 AtmRes
Wilson et al. 2022 BAMS
Reynolds et al. 2023 MWR
Lavers et al. 2023 QJRMS

Research and Operations Partnership (RAOP)
PI: Marty Ralph (UCSD)
Co-PI: Vijay Tallapragada (NCEP)

Integrated within National Winter Season Operations Plan

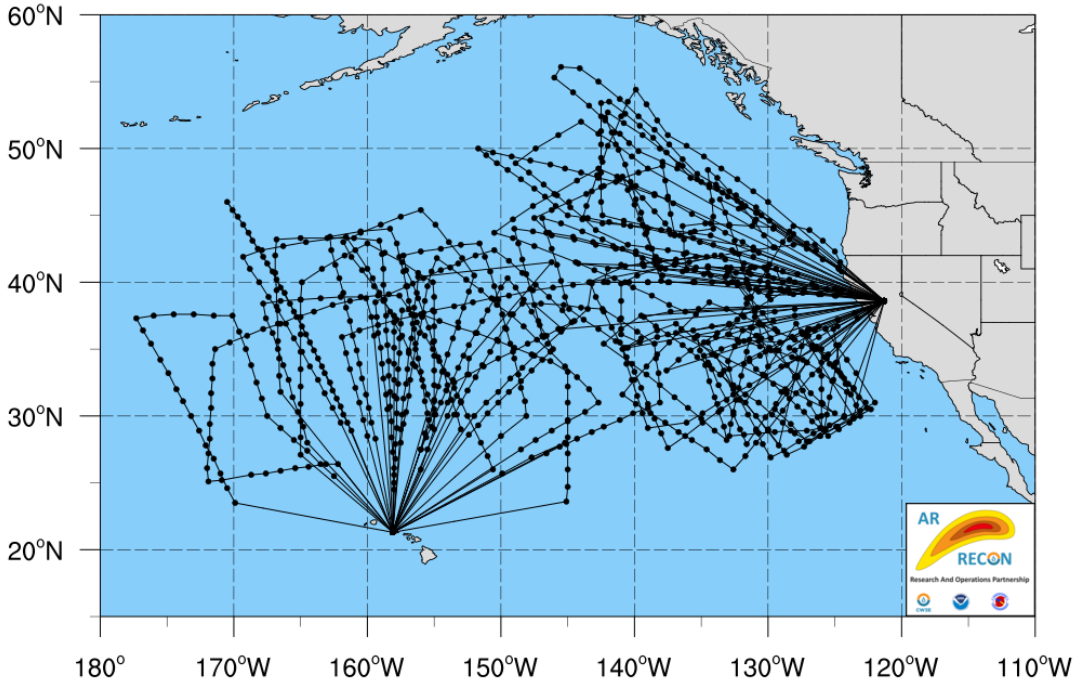
Involves NOAA G-IV and USAF Reserve 53rd Hurricane Hunter aircraft based in Hawaii, Western U.S., and Guam

Primary instrumentation: dropsondes, drifting buoys, airborne radio occultation, ground-based complements.

Goal enhance observations the AR and its environment, including regions of model uncertainty/sensitivity to improve QPF prediction across the Western U.S. and beyond

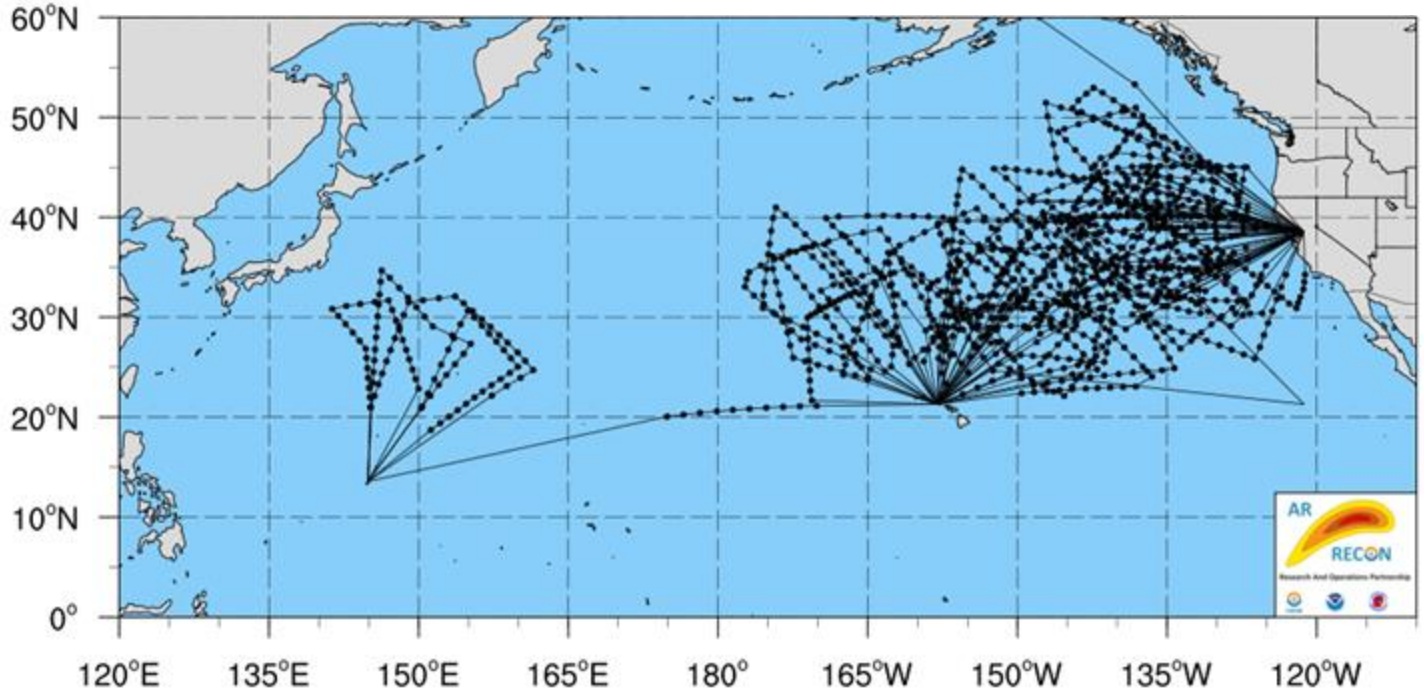
AR Recon: Targeting ARs, Essential Structures, and Sensitivity

AR Recon WY2023: 3 Nov 2022 – 13 Mar 2023



39 IOPs; 1228 dropsondes

AR Recon WY2024: 15 Nov 2023 – 29 Feb 2024



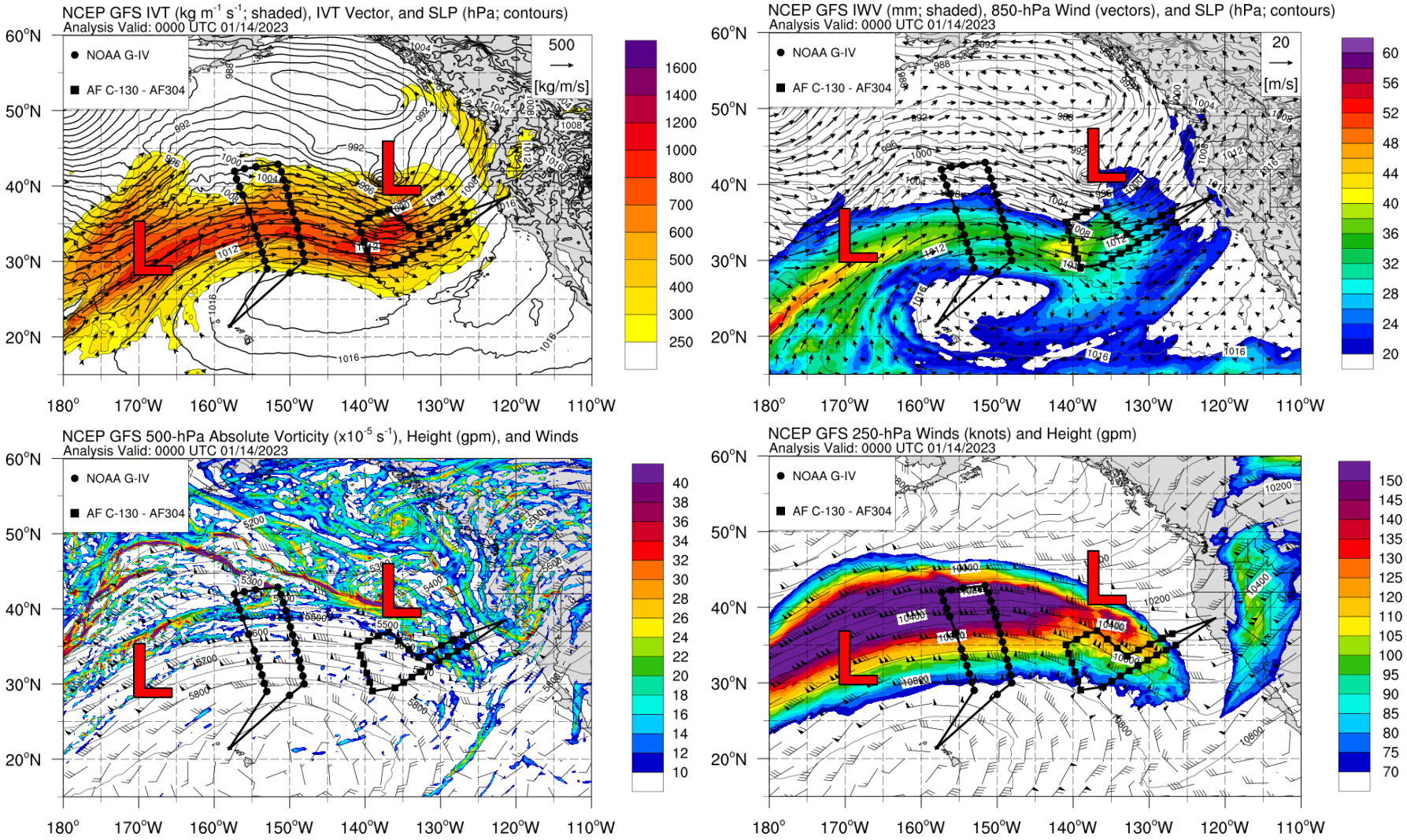
40 IOPs; 1475 dropsondes

How do we determine where to fly and where to drop?

- Fundamental physics knowledge → "Essential Atmospheric Structures"
- Model sensitivity diagnostics → Adjoint model sensitivity (NRL), Ensemble sensitivity (U Albany, NCEP)
- Logistical considerations with close coordination between flight directors, including 53rd on-site

Images courtesy Brian Kawzenuk (CW3E)

AR Recon: Example of from 14 January 2023 (IOP-14)



Top Left:
SLP with IVT

Top Right:
IWV, 850-hPa Wind and SLP

Bottom Left:
500-hPa Abs. Vorticity, Geo. Height, and Winds

Bottom Right:
250-hPa Wind and Geo. Height

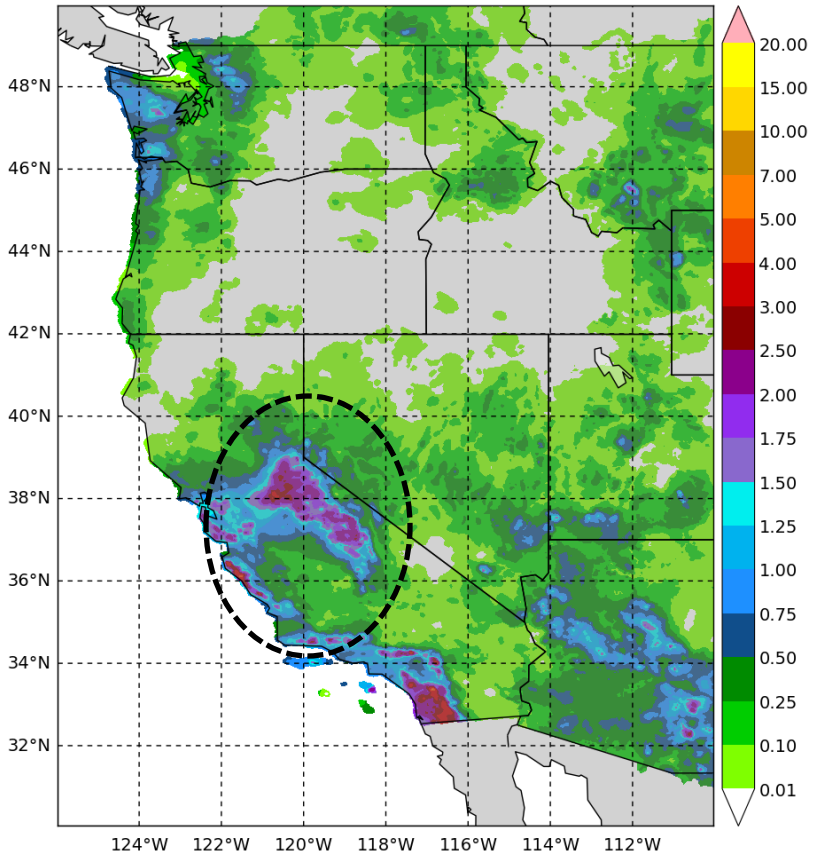
Hawaii Track: NOAA G-IV

CA Track: 53rd AF C130

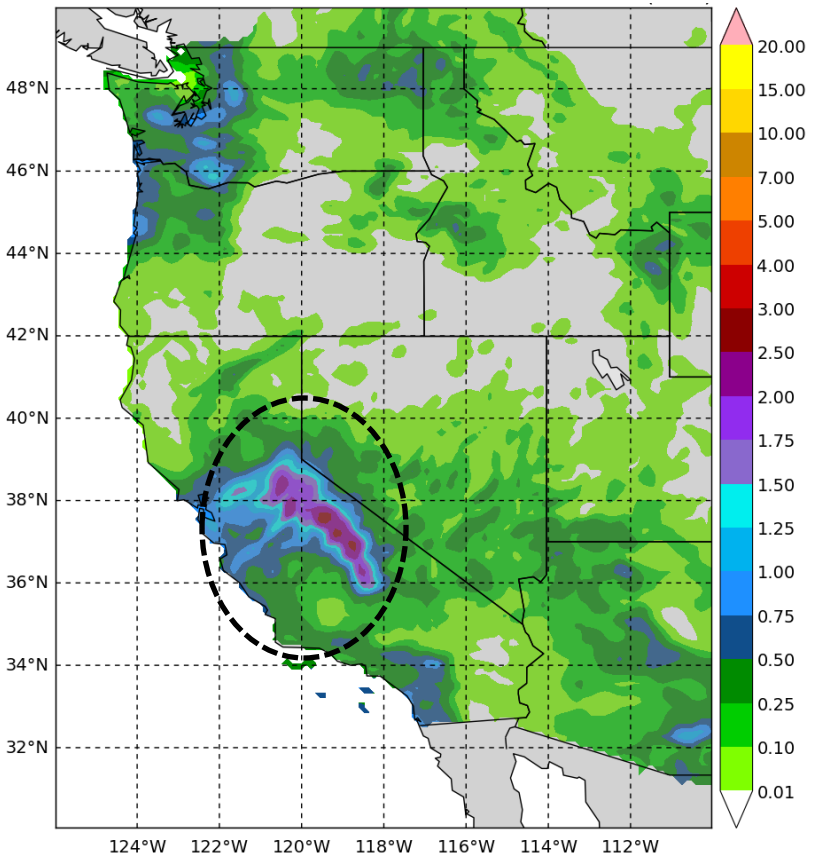
Images courtesy Brian Kawzenuk (CW3E)

AR Recon: Example of from 14 January 2023 (IOP-14)

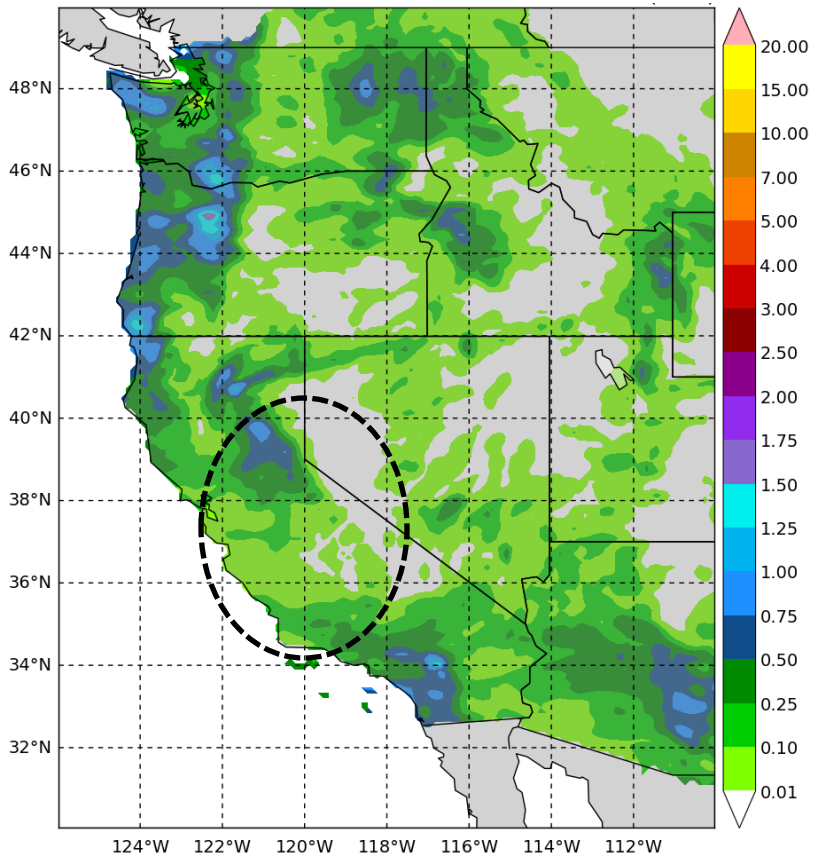
24-h QPE valid 00Z 17 January 2023



GFSv16 24-h QPF WITH DROPS



GFSv16 24-h QPF WITHOUT DROPS



GFS model forecast with assimilated dropsondes is more skillful than model assimilated without dropsondes

Images courtesy Xingren Wu and Vijay Tallapragada (NCEP)

AR Recon: Improved QPF Skill during 2022–2023

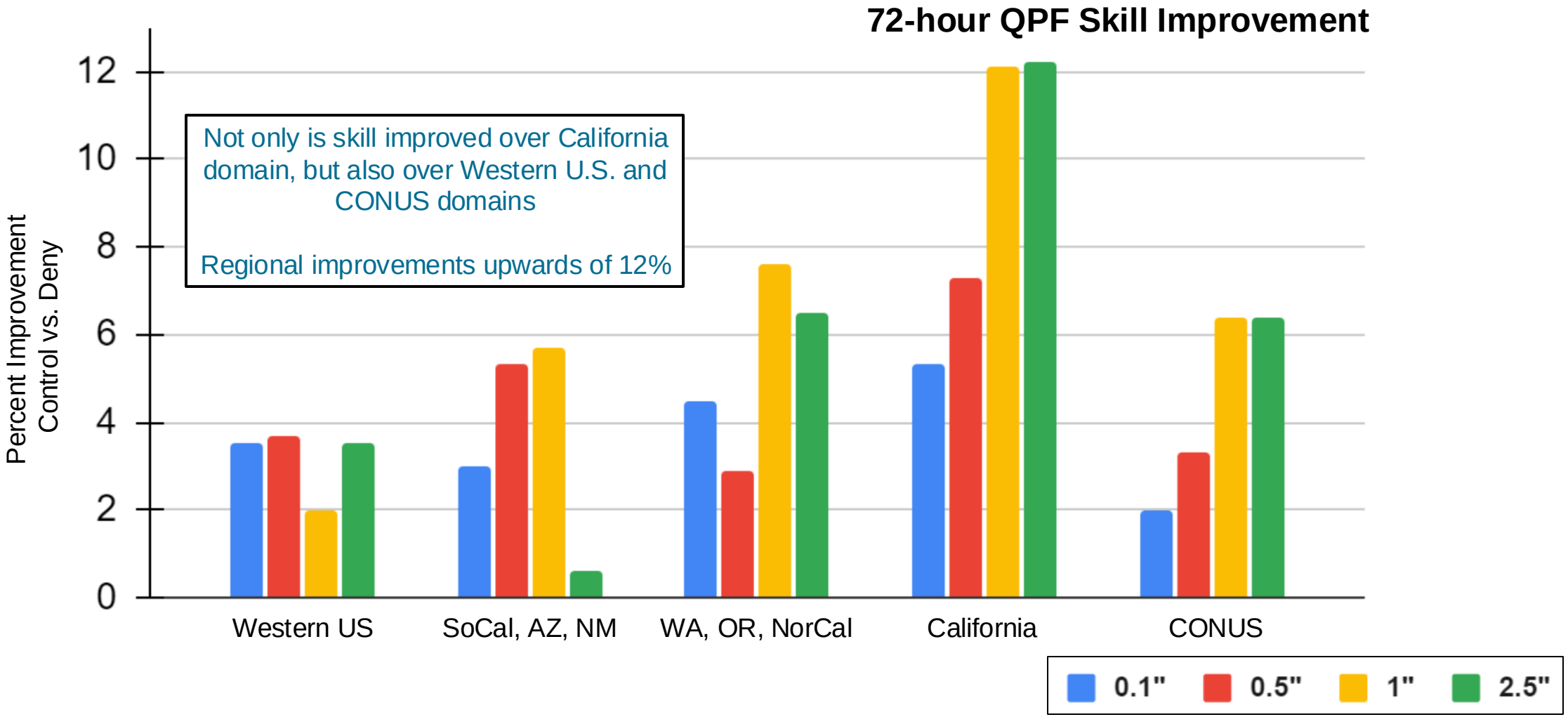


Image adapted from Vijay Tallapragada (NCEP)

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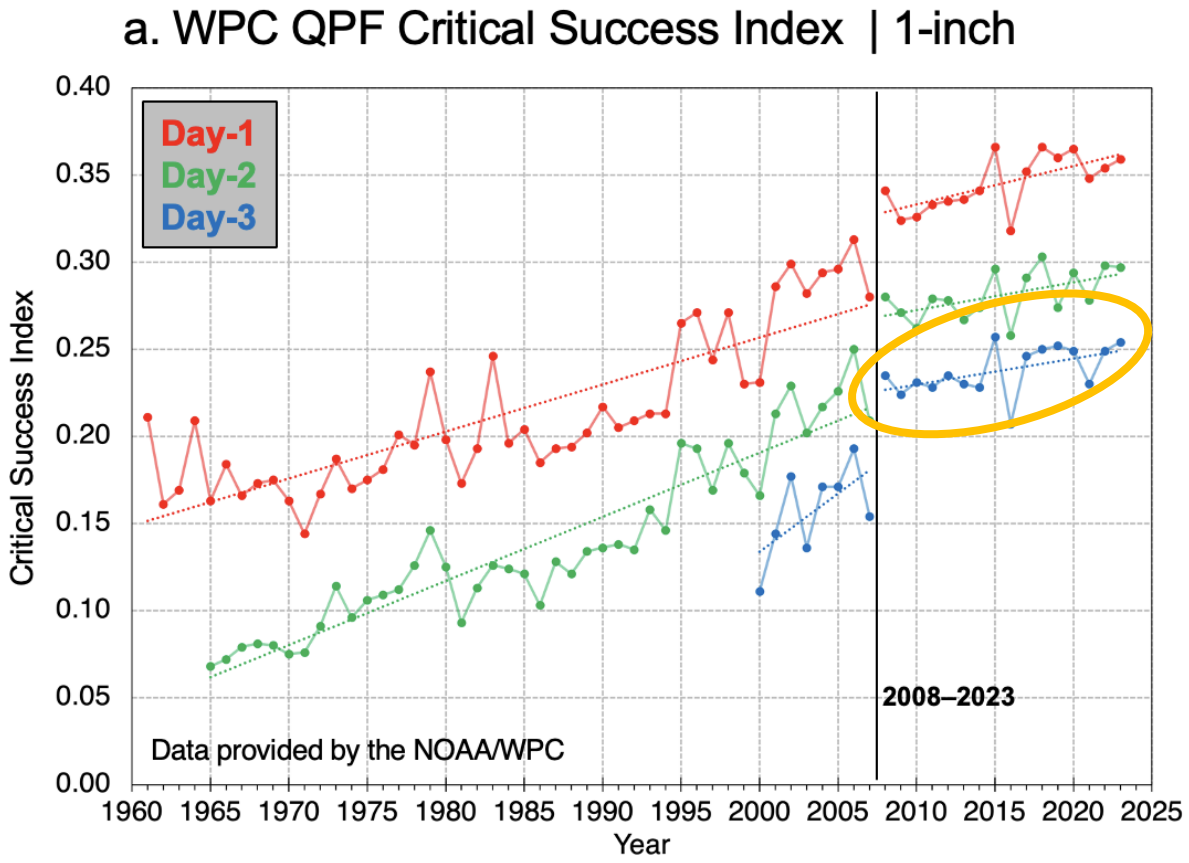

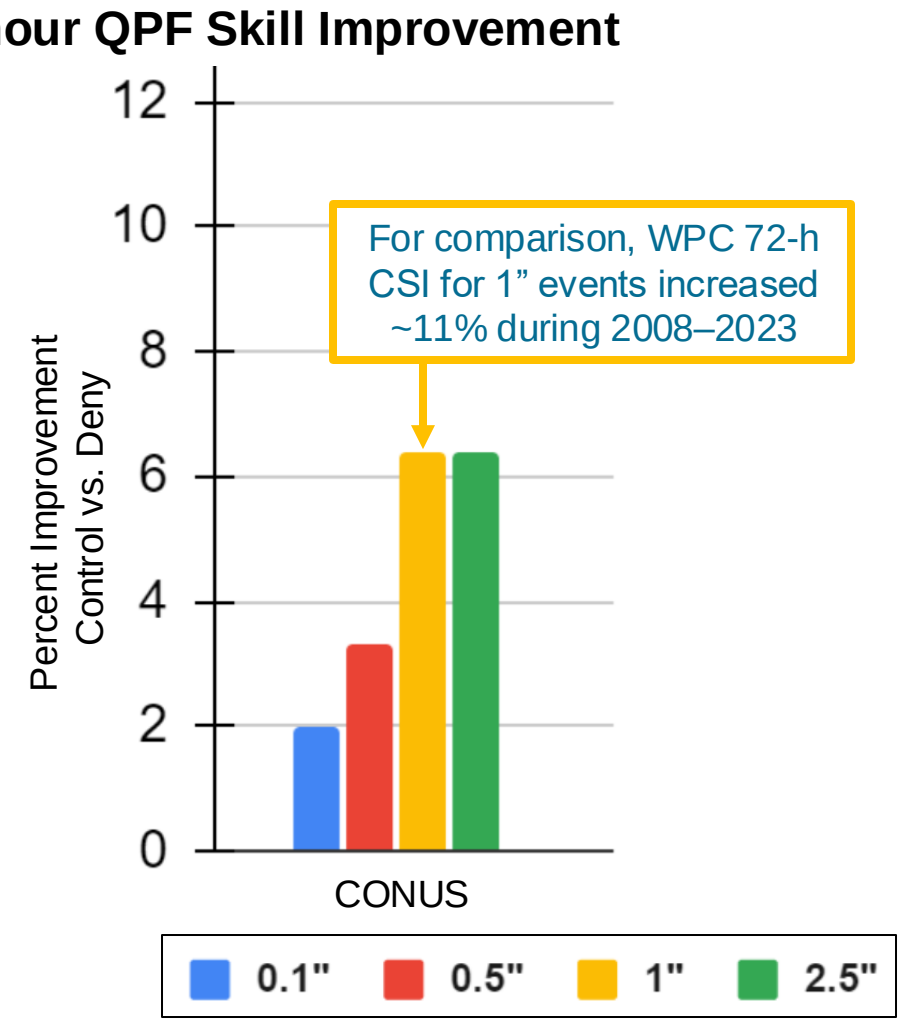

Image adapted from Vijay Tallapragada (NCEP)


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Now that we know the (relative) skill, how can we improve it?
Model Development
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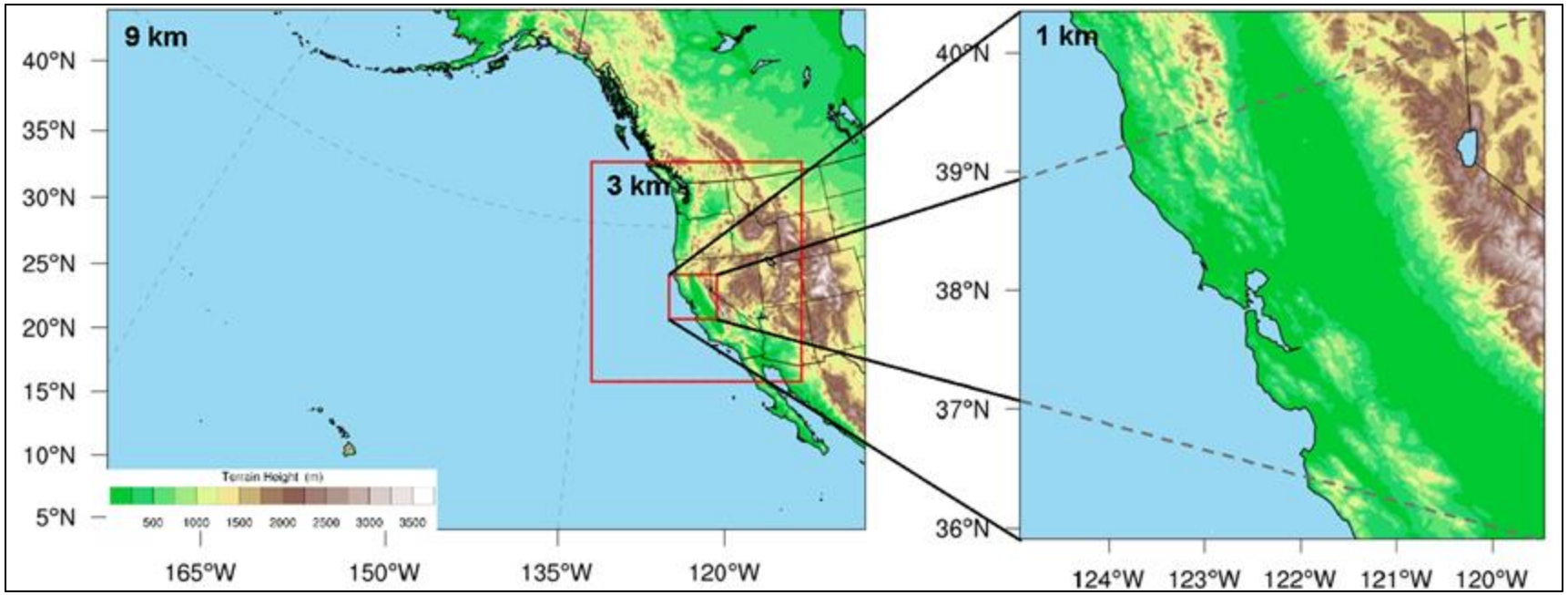
Model Development: West WRF

Forcing	Model type	WRF	Vertical	Horizontal	Temporal
GFS	Deterministic	4.4.1	100 levels	9/3/1 km	00/12Z
ECMWF	Deterministic	4.4.1	100 levels	9/3/1 km	00/12Z
GFS (frozen)	Deterministic	4.1.2	60 levels	9/3 km	00/12Z
GEFS+EPS	200 Ensemble	4.4.1	60 levels	9 km	00Z

Model Res	Lead Time
1 km	3 days
3 km	5 days
9 km (det.)	10 days
9 km (ens.)	7 days



200-member ensemble design:

- 82 IC/BCs from 31 GEFS members and 51 ECMWF EPS members
- 200 SKEB perturbations (Stochastic Kinetic Energy Backscatter)
- 100 distinct physics config. from 4 boundary layer, 5 microphysics, and 5 convection schemes

West-WRF: Martin et al. (2017)
Ensemble:
Delle Monache et al. (2024, in prep)

Model Development: West WRF

Objectives:

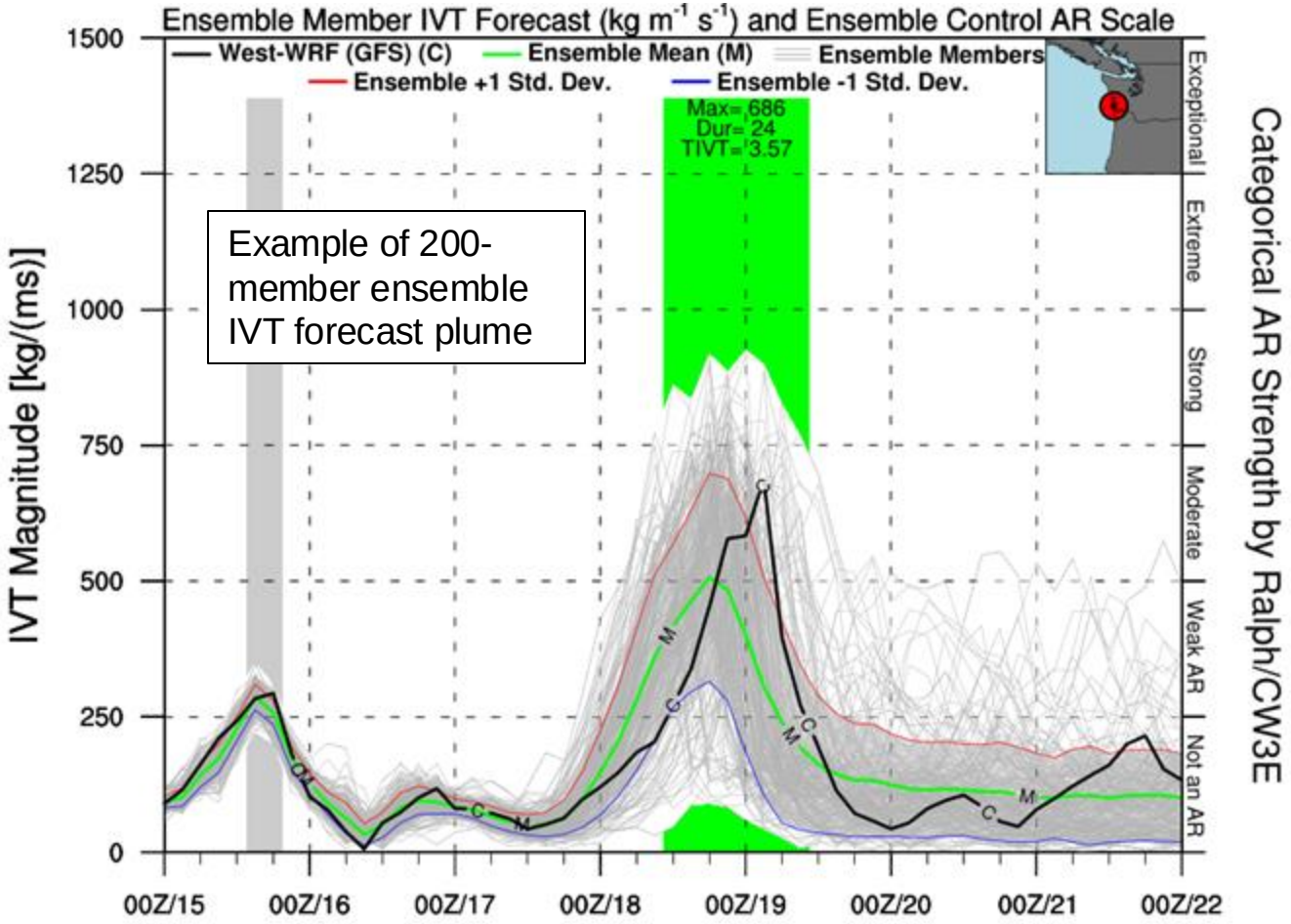
1. Increase skill of predicting timing and magnitude of extreme QPF events associated with ARS

2. Enhance statistical sampling of key sources of forecast uncertainty (e.g., initial/boundary conditions, physics)

3. Improve overall quality of probabilistic predictions

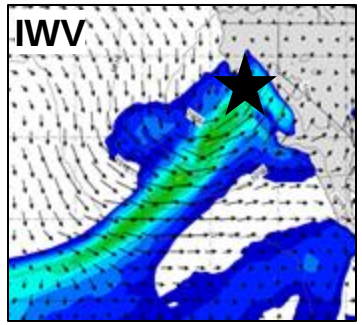
Available in near-real time ~t+12 h
https://cw3e.ucsd.edu/west-wrf_ensemble/

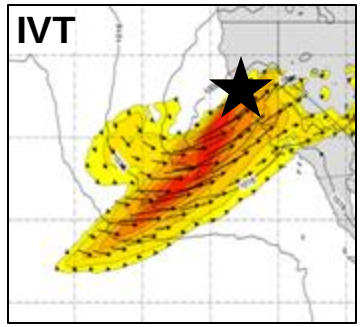
West-WRF Ensemble Initialized: 00Z 15 Dec 2021

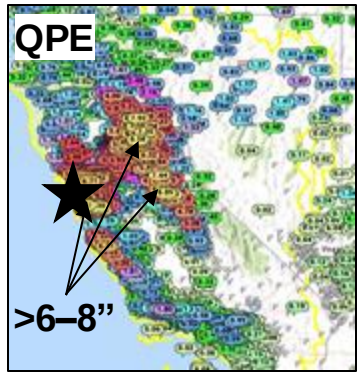


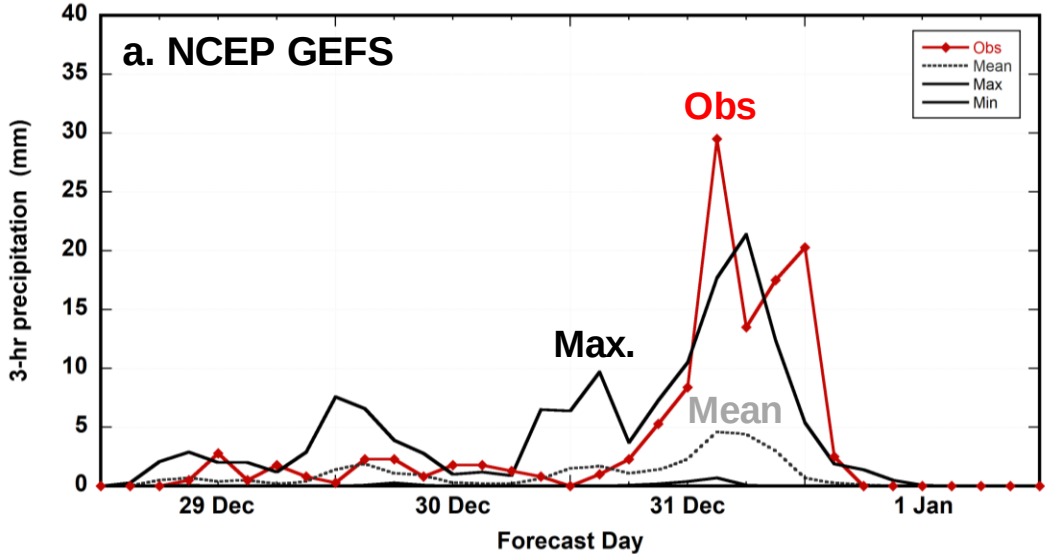
Model Development: WRF QPF/QPE analysis for 31 Dec 2022, San Francisco

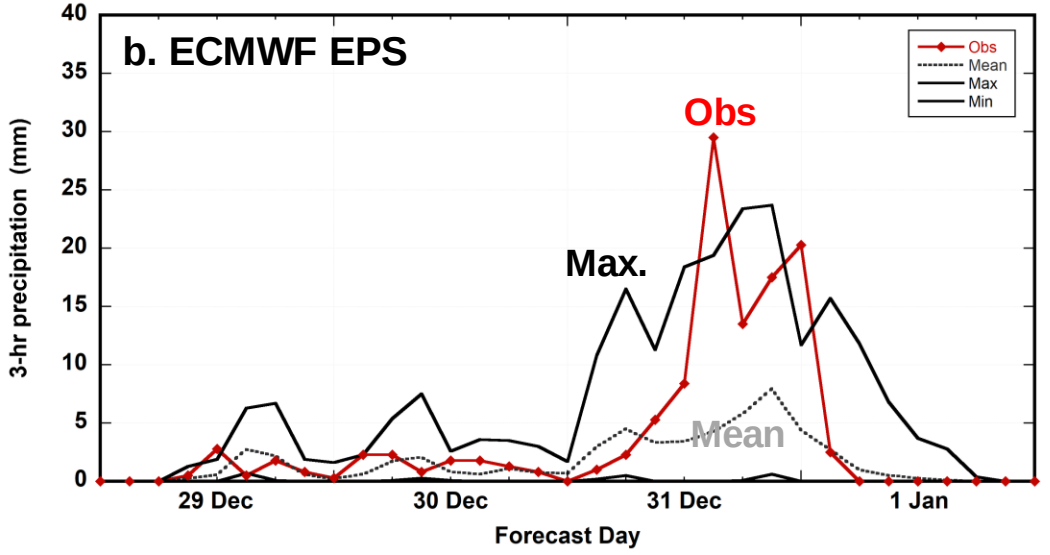
18Z/31 Dec 2022

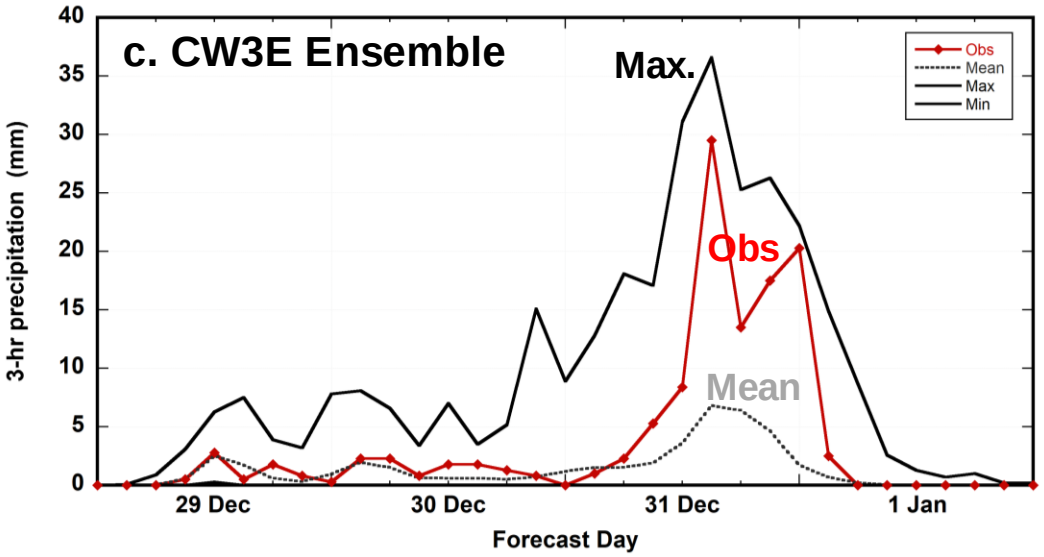










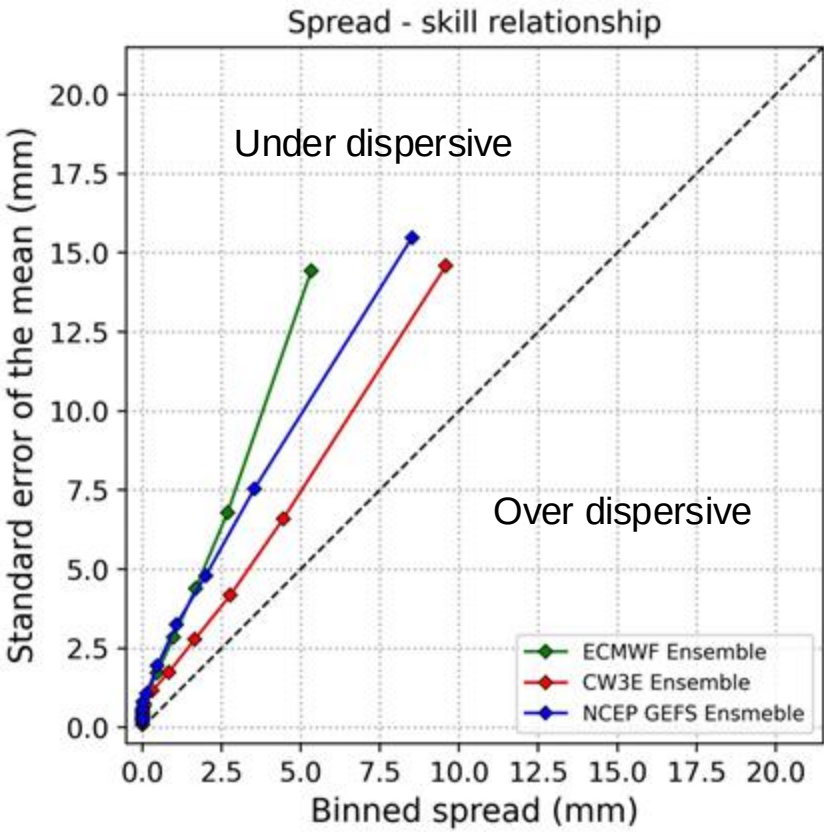


- GEFS/EPS spread failed to capture heaviest precip rates on 31 Dec 2022 during landfalling AR
- West-WRF generated considerably more ensemble spread during period of highest rain rates; captured all precip observations
- West-WRF ensemble provided value by better capturing likelihood of extreme precip

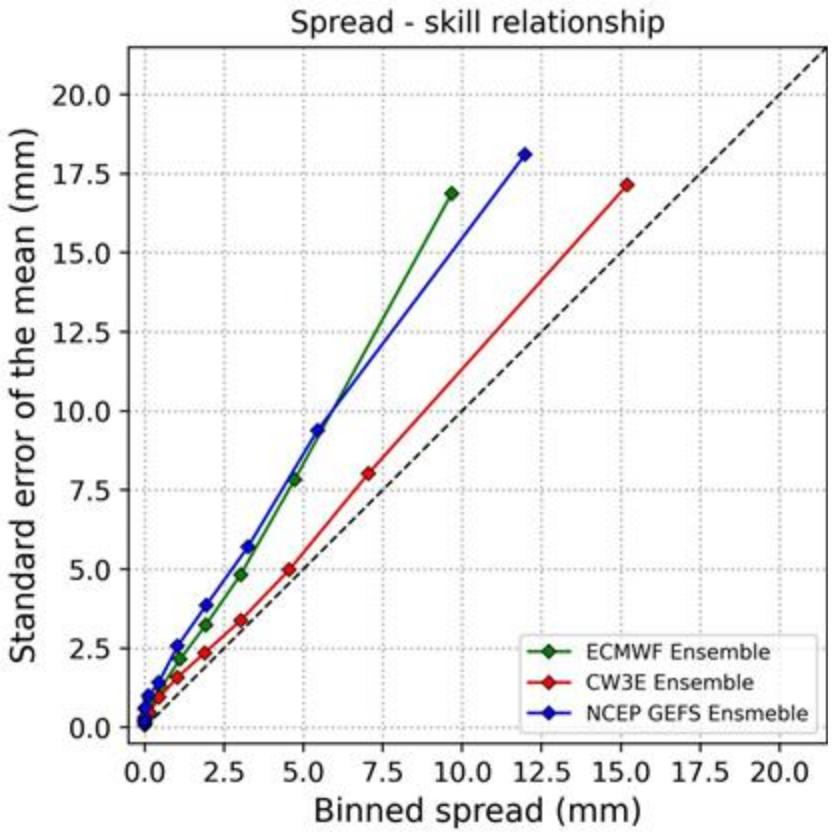
Delle Monache et al. (2024, in prep)

Model Development: WRF QPF skill analysis for WY22 and WY 23, Western US

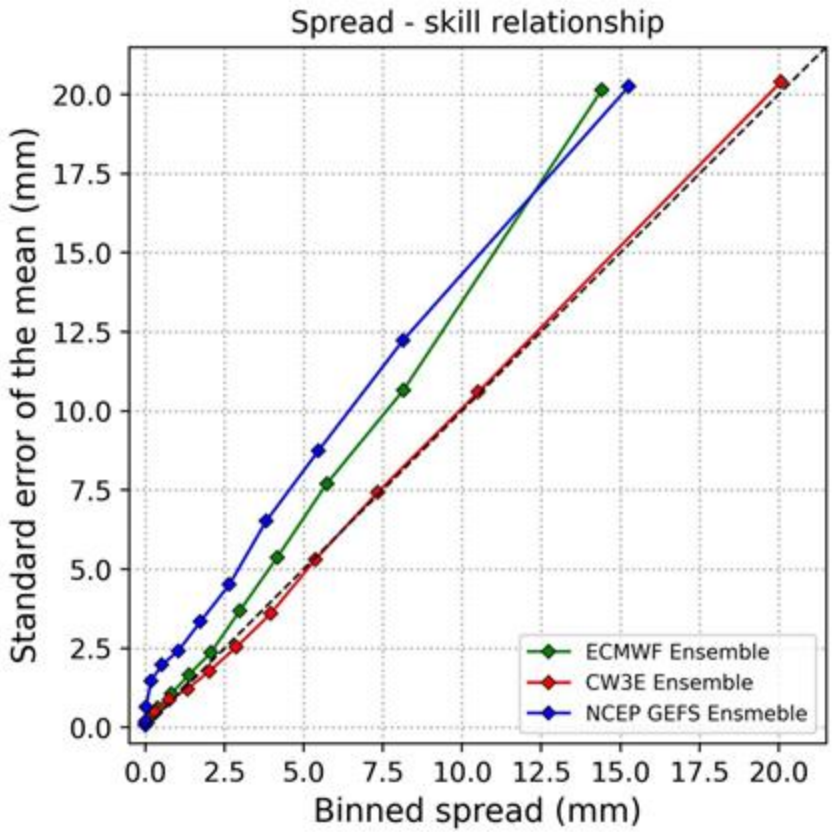
Day 1 (+12 to +36h)



Day 3 (+60 to +84 h)



Day 6 (+132 to +156h)



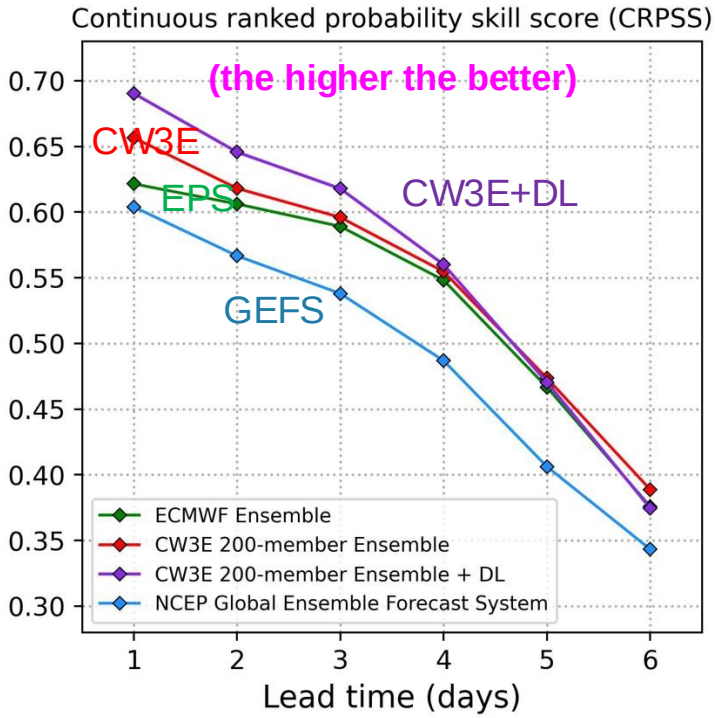
Key Result: Spread of 200-member CW3E West-WRF ensemble is better able to match error of ensemble mean.

- GEFS/EPS are under-dispersive relative to CW3E West-WRF Ensemble
- CW3E West-WRF Ensemble can is better able to capture extreme events

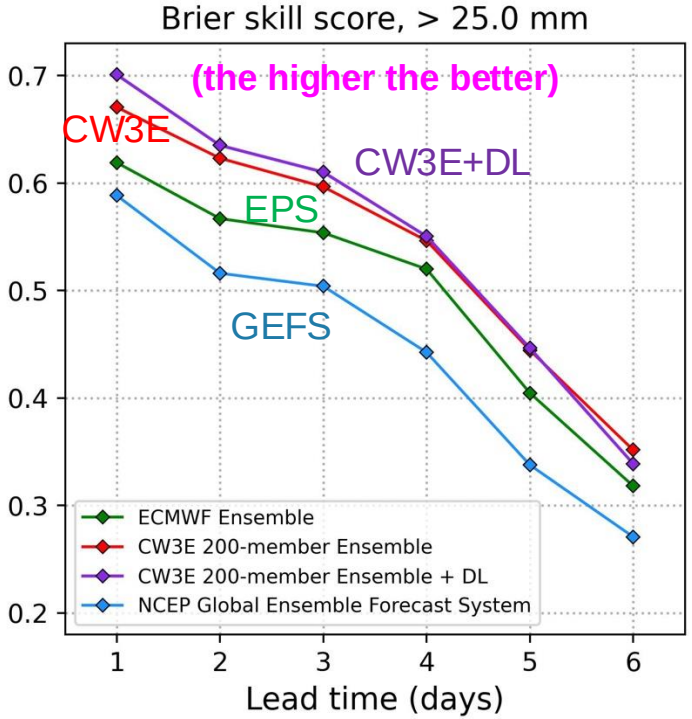
Delle Monache et al. (2024, in prep)

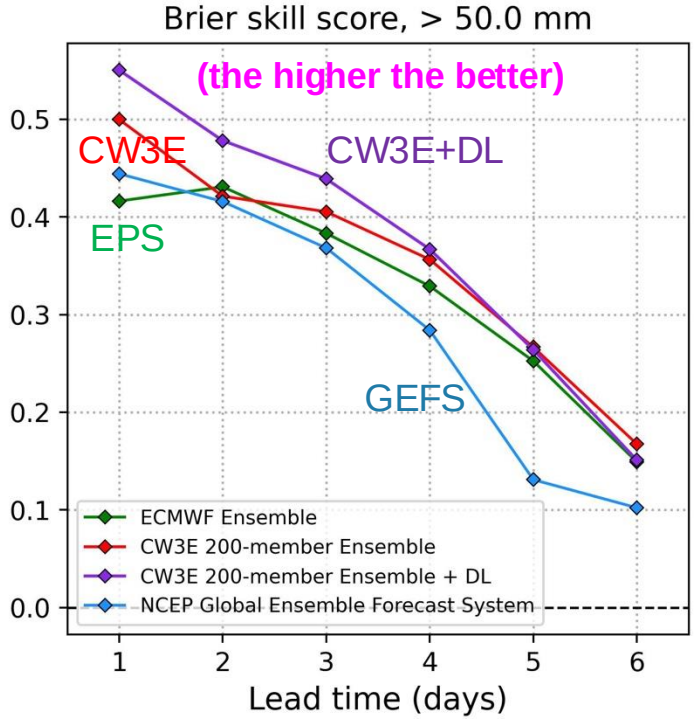
Model Development: WRF QPF skill for 25 Dec 2022–18 Jan 2023, California

Predictive skill of ensemble



Predictive skill for precipitation exceeding specific thresholds





Key Performance Metrics

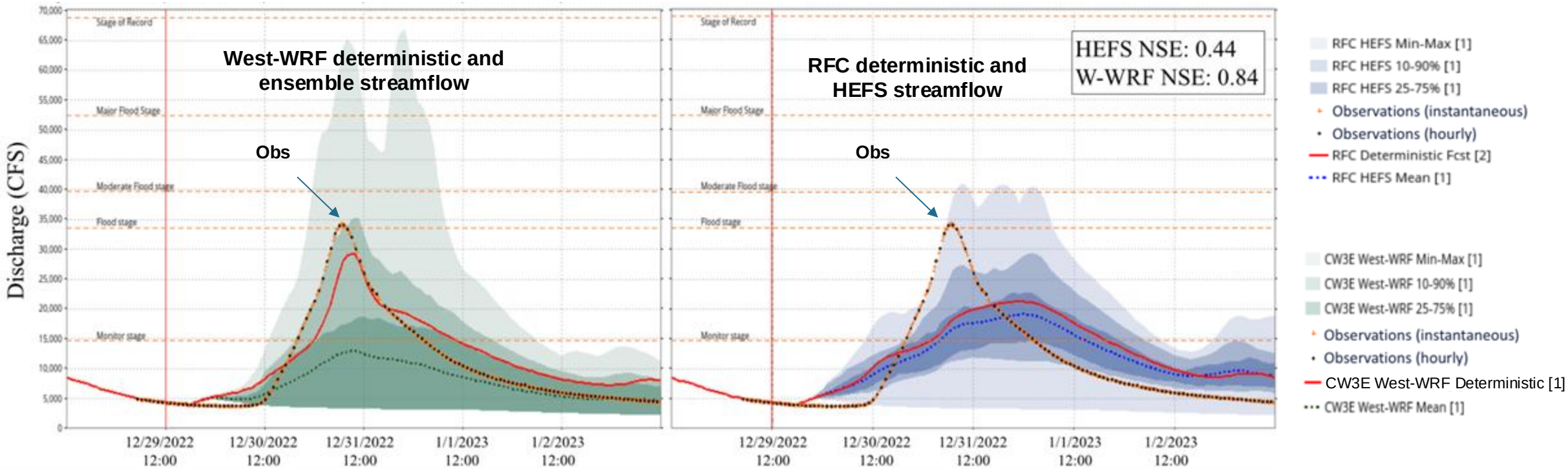
- West-WRF ensemble leverages GEFS and improves its predictions at all lead times
- West-WRF ensemble leverages EPS and improves its predictions from Day 1 to Day 4
- **Deep learning further improves the 200-member ensemble skill from Day 1 to Day 4**

Ghazvinian et al. (2024)

Model Development: WWRF forcing streamflow forecasts (Dec 2022)

Mad River (at Arcata, CA): inputting West-WRF precipitation predictions for 31 Dec 2022 AR into RFC hydrologic model yields improved streamflow predictions (vs operational RFC forecasts, as shown by NSE)

Deterministic West-WRF (red) better captures peak timing/magnitude (than original RFC deterministic forecast), and 200-member West-WRF ensemble has more members closer to peak (than HEFS)



Thank you!

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