2021 CIRES Rendezvous

Virtual

AQPI: Evaluating California Atmospheric River Events with the HRRR Ensemble

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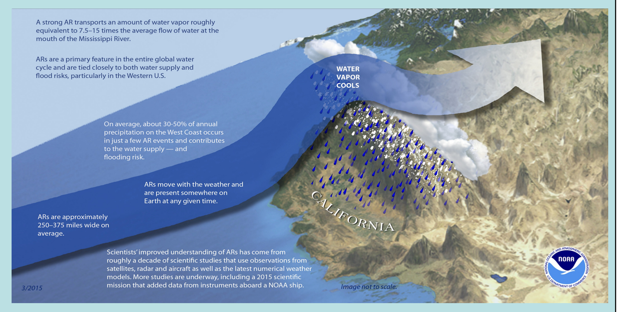
1. Introduction



- Atmospheric Rivers (ARs) transport moisture from the tropics and bring heavy rain to higher latitudes
- ARs provide ~40% of California's annual precip
- Better forecasts of rain timing/intensity, streamflow, reservoirs, and storm surge can minimize human, ecosystem, & economic impacts
- Large uncertainties with both QPE (Quantitative Precipitation Estimates) and QPF (Quantitative Precipitation Forecasts)
- QPE products include gauges, radars, etc
- QPF comes from NWP forecast models

Some Precip Evaluation Challenges

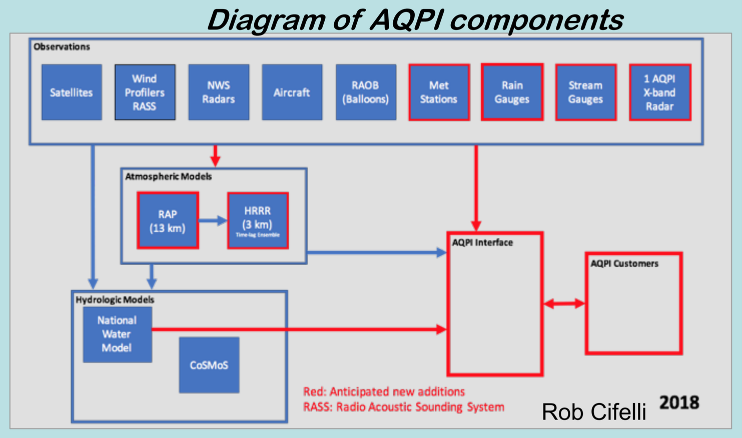
Challenge	Solution(s)
QPE products disagree due to errors, blockage, spatial/temporal limitations, etc	Compare multiple QPE products
Inconsistent treatment of snow in QPE products	Process results with or without frozen precip
Small errors in precip timing/location punish skill, esp for varying model resolutions	Quantify skill using several grid and neighborhood techniques

2. AQPI Project / Research Plan

What is the AQPI project?

- AQPI (Advanced Quantitative Precip. Info) Goal: improve research transition, monitoring, and prediction of precipitation, streamflow, and storm surge
- Deploy & assimilate AQPI radar & sfc met instruments; evaluate model predictions of precipitation, streamflow, and storm surge
- 4-year grant awarded by the DWR to NOAA, CSU, USGS, DWR, and NWS

Diagram of AQPI components

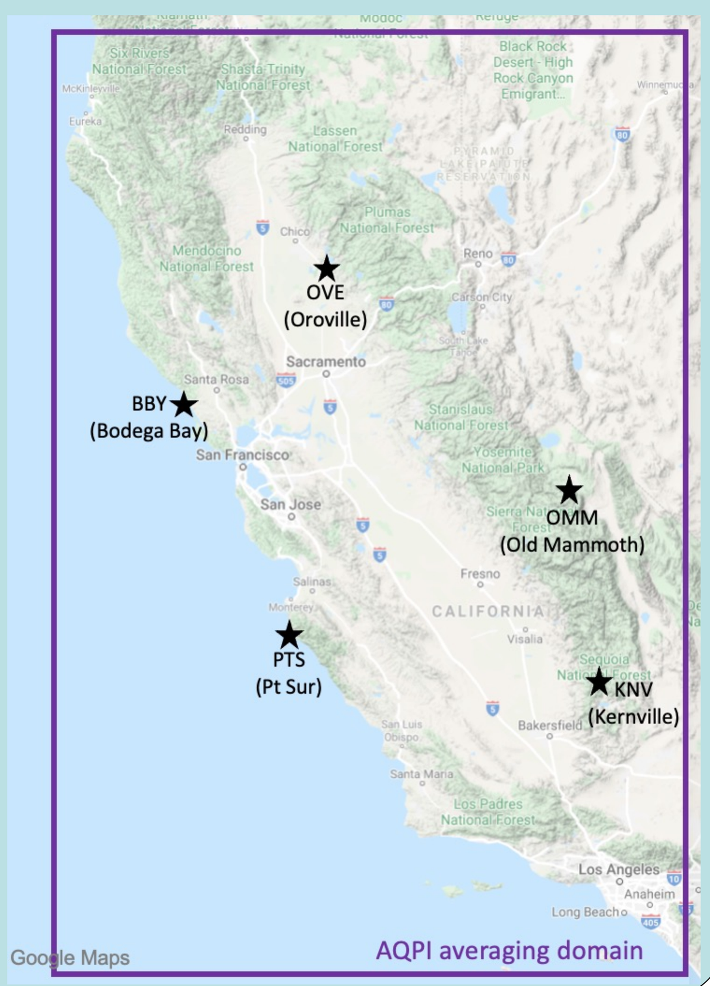


NOAA GSL Research Plan:

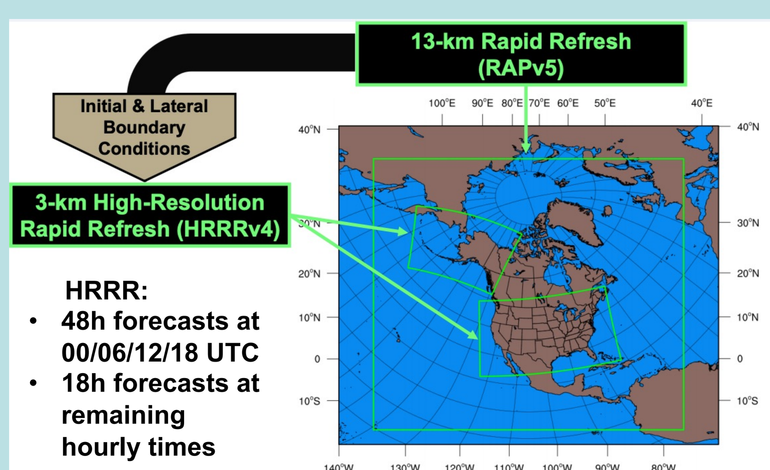
- Study five AR events that occurred in Feb/Mar 2019
- Evaluate forecasts from the HRRRE (Ensemble) and HRRR deterministic models
- Explore additional ensemble perturbations
- Compare model QPF to QPE Products and other meteorological fields
- AQPI domain and ARO meteorological stations noted on the right

AR Events
2-4 Feb 2019
13-15 Feb 2019
25-27 Feb 2019
2-4 Mar 2019
5-7 Mar 2019

Stage-IV QPE	Mesonet QPE
6h accum (every 6h) on a 4.7km grid, Mtn mapper climatology adjusted with trusted gauges; no radar data; manual QC at CNRFC	1h accum (every 1h) database of rain gauges from three networks: MesoWest, RAWS, and HADS; liquid precip only



4. The RAP/HRRR Model



Model	Run at:	Domain	Grid Points	Grid Spacing	Vertical Levels	Vertical Coordinate	Pressure Top	Boundary Conditions	Initialized
RAP	GSD, NCO	North America	953 x 834	13 km	50	Sigma-Isob Hybrid	10 mb	GFS	Hourly (cycled)
HRRR	GSD, NCO	CONUS	1799 x 1059	3 km	50	Sigma-Isob Hybrid	15 mb	RAP	Hourly (pre-forecast hour cycle)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Cumulus Param	PBL	LSM
RAP	WRF-ARW v3.9.1+	GSI Hybrid Ensemble 0.85	13-km DFI, ½ Strength	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	GF + Shallow	MYNN v3.9.1+	RUC v3.9.1+
HRRR	WRF-ARW v3.9.1+	GSI Hybrid HRRRDAS Ensemble 0.85	3-km 15-min LH	RRTMG/ RRTMG	Thompson Aerosol v3.8.1	None	MYNN v3.9.1+	RUC v3.9.1+

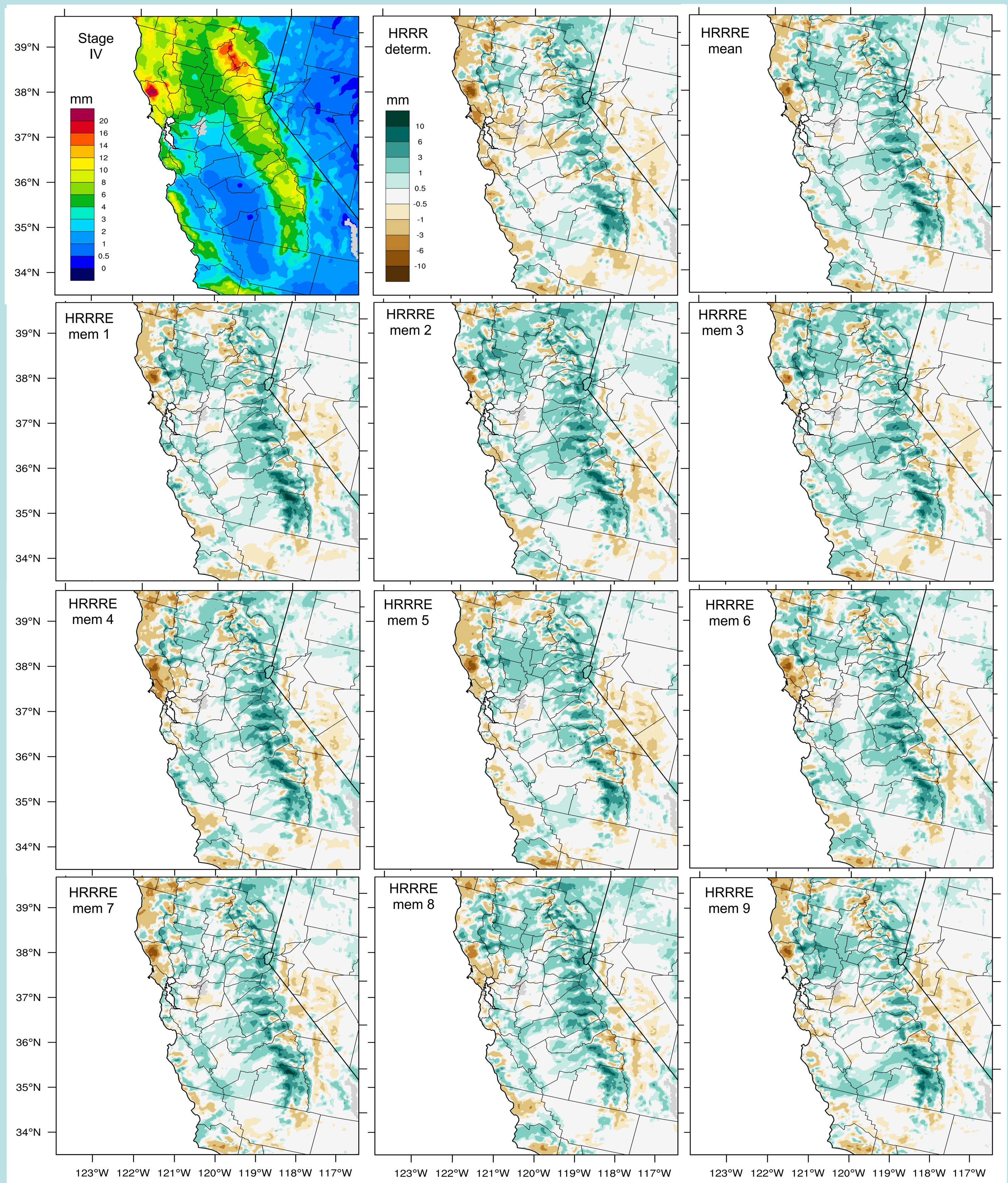
Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	Diffusion Option	6th Order Diffusion	SW Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	20 min	MODIS Seasonal	None	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Full (2)	Yes 0.12/0.04	15 min with SW-dt	MODIS Seasonal	None	20 s

C. Alexander

- RAP/HRRR is a high-resolution mesoscale model for weather forecasts (0-48h)
- NOAA/ESRL/GSD develops improved versions of RAP/HRRR and release them to NCEP operations every ~2 years
- RAPv5/HRRRv4, the version used in this study, became operational in Dec 2020
- HRRRE (based on HRRRv4) contains nine ensemble members with perturbed initial conditions (ICs) and is initialized twice a day (00 and 12 UTC) for this study
- HRRRE and HRRRv4 utilize a new HRRRDAS (data assimilation system)

5. HRRR QPF vs Stage IV QPE (6h acc)

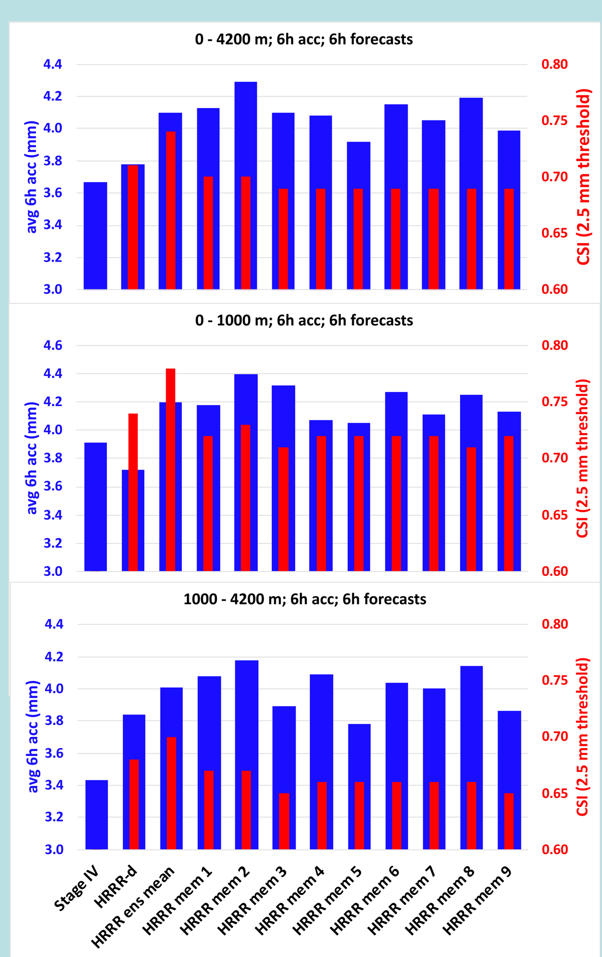
A. Spatial maps (average of five ARs)



Avg 6h accum precip across five AR events (each event 36-48h duration)

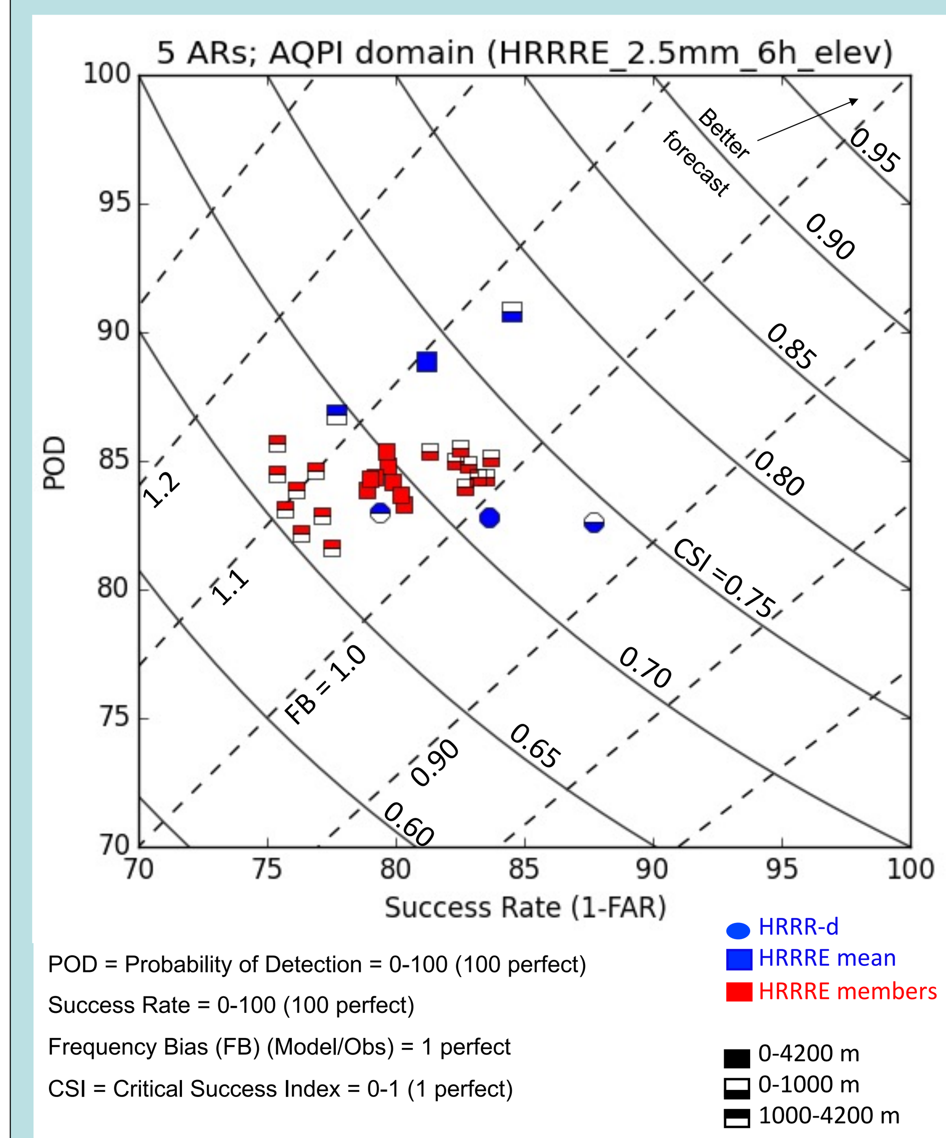
- HRRR forecasts generally capture the spatial distribution of Stage IV, but are drier in the Bay Area and along the Pacific Coast, and wetter in the Sierra Nevadas
- HRRR ensembles have some variation but the spatial patterns are generally the same
- HRRR ensemble mean is a little wetter than deterministic HRRR, resulting in a reduced dry bias along the coast but an enhanced wet bias to the east
- The HRRR dry bias along the coast may be due to insufficient column water vapor, or low level temperature or wind biases in the model (*English et al. 2021, under review*)
- The HRRR wet bias in the Sierra Nevadas is partly attributed to challenges with Stage IV detecting frozen precip in mountainous terrain (*English et al. 2021, under review*)

B. Categorizing bias and CSI by altitude domains



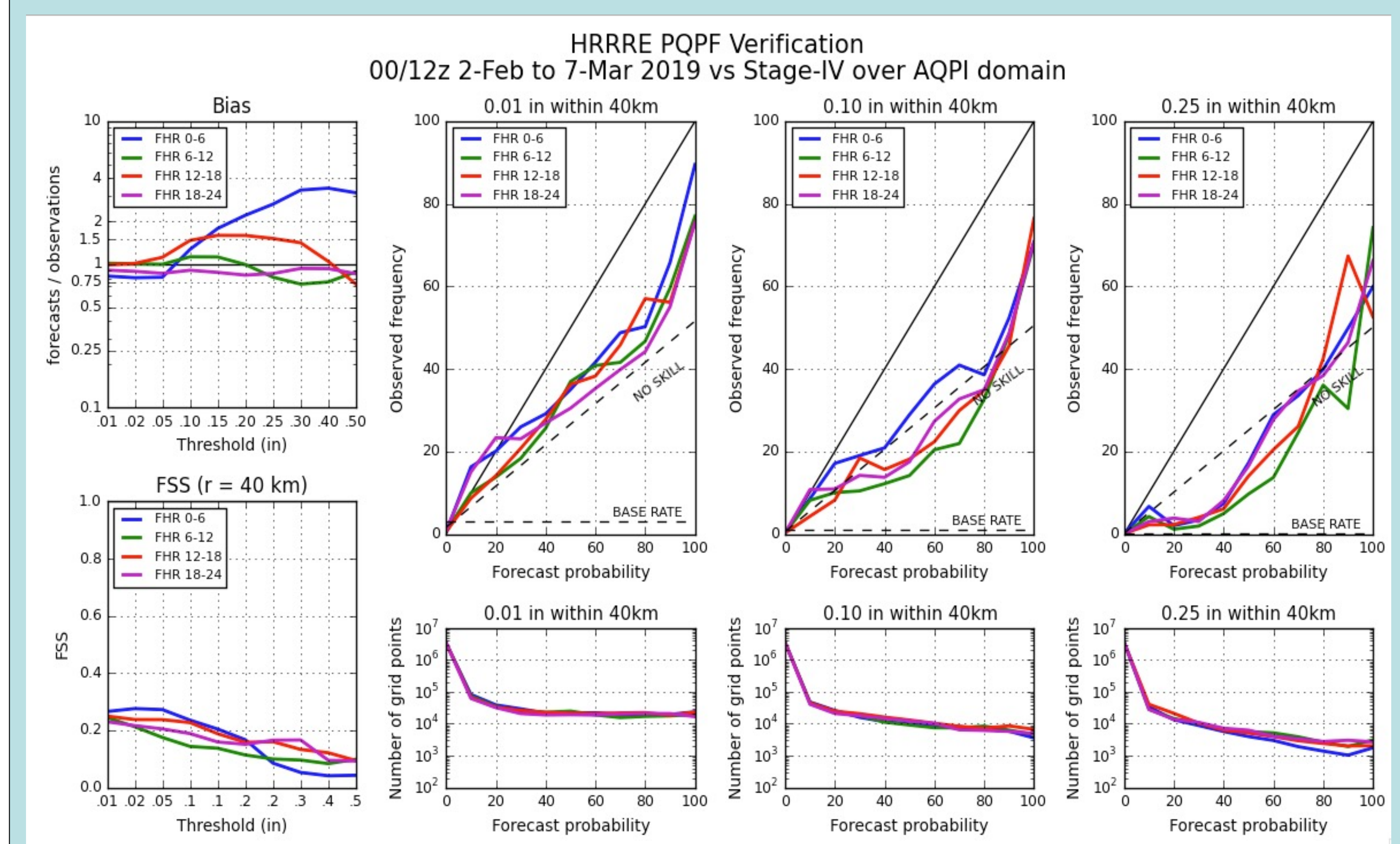
- The deterministic HRRR is drier than Stage IV across lower altitudes (0-1000 m) and wetter than Stage IV at higher altitudes (1000-4200m)
- The HRRRE is consistently wetter than the deterministic HRRR, which translates to an improvement at lower altitudes but a larger wet bias at higher altitudes
- QPF for HRRRE individual ensemble members vary by about 10%, which is not large enough to encompass the value of QPE from Stage IV
- Ensemble members usually have correlated QPF at both altitude ranges (e.g. members 2, 6, 8 are higher in both; member 5 is lower in both), but there are exceptions (e.g. members 3, 4)
- The HRRRE ensemble mean has higher Critical Success Index (CSI) than its individual ensemble members as well as the deterministic HRRR, although an increased wet bias could translate to higher CSI

6. Performance Diagram



- Overall, HRRRE mean performs better than HRRR-d, with higher CSI, POD, and Success Rate, but also has higher frequency bias
- All HRRR versions perform better at low altitude than high altitude, likely partly due to Stage IV errors with frozen precipitation
- HRRR-d has a dry bias at low altitude (0-1000 m) but HRRRE has a wet bias. Why?
- HRRR ensemble members have some variance but spread is not large, and all members have a frequency bias greater than 1
- Want to explore other lead times and thresholds (this is 2.5 mm threshold; 6h forecasts)
- Can other ensemble perturbations create more spread?

7. Metrics at different lead times



- HRRRE frequency bias looks good at 6-12h and 18-24h forecasts, but is too high for 0-6h forecasts at higher thresholds, likely driven by errors at the shortest lead times with assimilating radar reflectivity data
- Forecast skill is better at lower thresholds (typically seen)
- Fractions Skill Score (FSS) is better at shorter lead times for lower thresholds, but better at long lead times for higher thresholds

8. Summary / Next Steps

- We evaluated forecasts of five AR events from the deterministic HRRR and the nine-member HRRRE and compared QPF to Stage IV QPE
- Overall, HRRR QPF compares reasonably well to Stage IV, but has a dry bias in the Bay Area / Pacific Coast, and a wet bias in the Sierra Range
- Prior work suggests the HRRR dry bias in the Bay Area could be due to insufficient water vapor, or low level temperature or wind biases, and the wet bias in the Sierras is at least partly due to challenges with QPE products detecting snow
- HRRRE mean has improved CSI, POD, FAR, and Success Rate over the deterministic HRRR, but higher frequency bias
- HRRRE members do not perform as well as the deterministic HRRR, and their wet bias is larger in the Sierras, but they eliminate the dry bias in the 0-1000m altitude domain (however, they still have a dry bias in the Bay Area)
- Next steps: Explore more lead times and thresholds; compare to available meteorology measurements; re-run HRRRE with other perturbations and examine forecast skill, ensemble mean, and spread