The U.S. West Coast Network of Atmospheric River Observatories: Tools for Improving Situational Awareness in Operational Forecasting

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Boulder, Colorado

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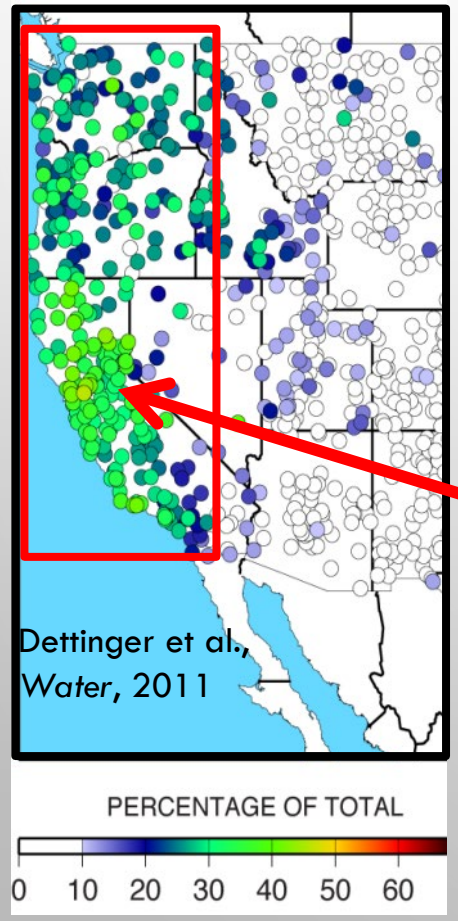
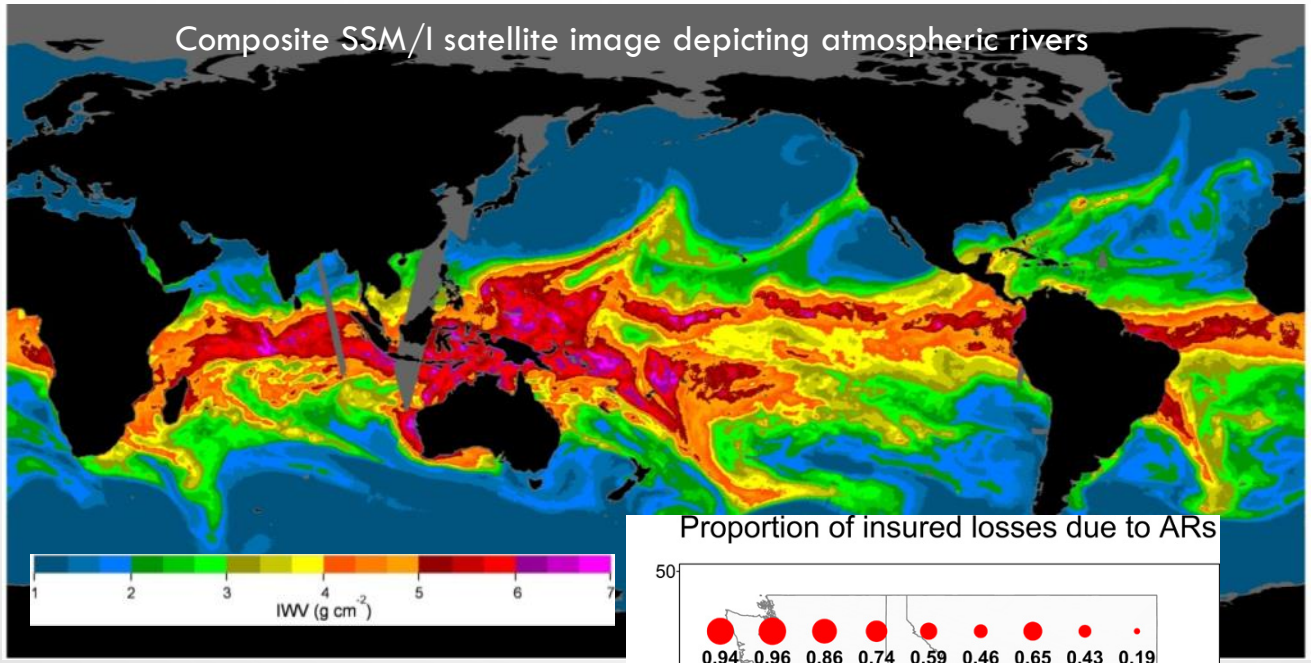
Atmospheric Rivers (ARs)

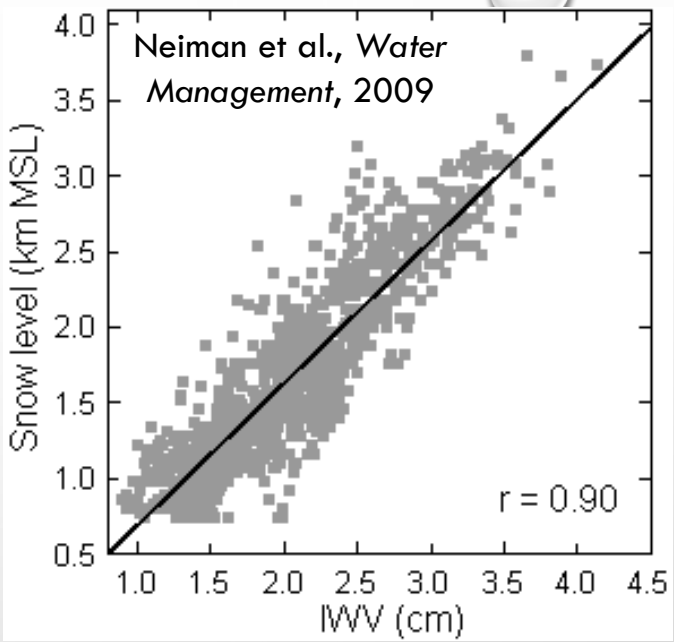
ARs Provide beneficial rain and snow for water supply

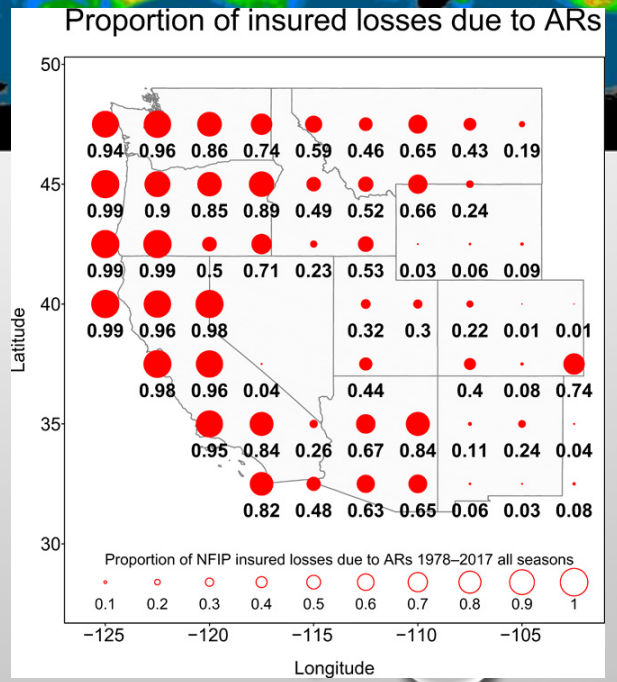


Dettinger et al., *Water*, 2011

25% - 45% of annual precip. in the U.S. west coast states falls in association with ARs, and ARs are a major source (up to 99%) of property losses due to flood damages, especially along the U.S. West Coast.

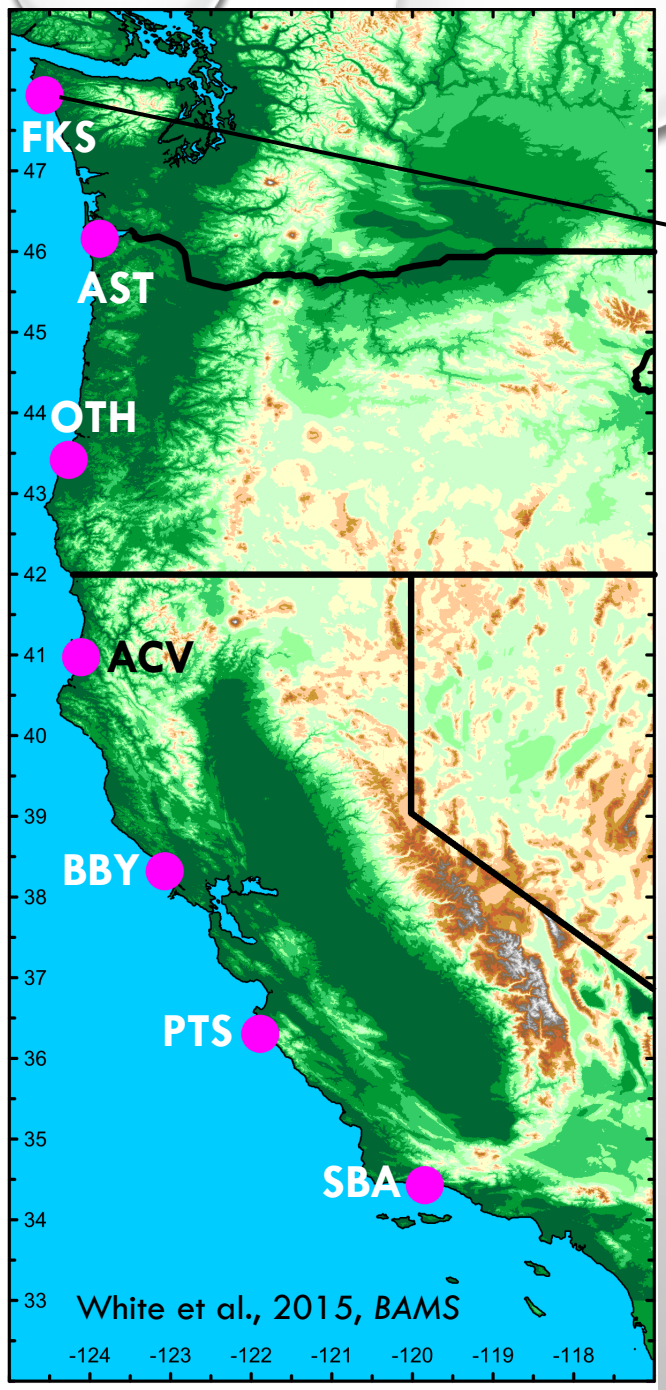


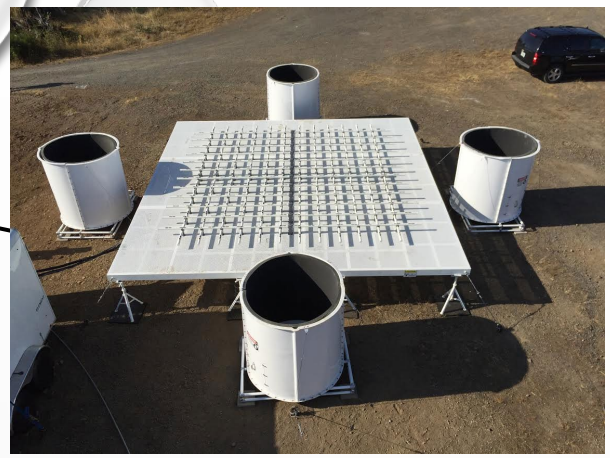




Corringham et al., 2019, *Science Advances*

ARs are warm and wet. Stronger ARs with larger integrated water vapor (IWV) are associated with higher snow levels and heavier precipitation. In the mountains, greater area exposed to rain vs snow, which exacerbates the flood threat.

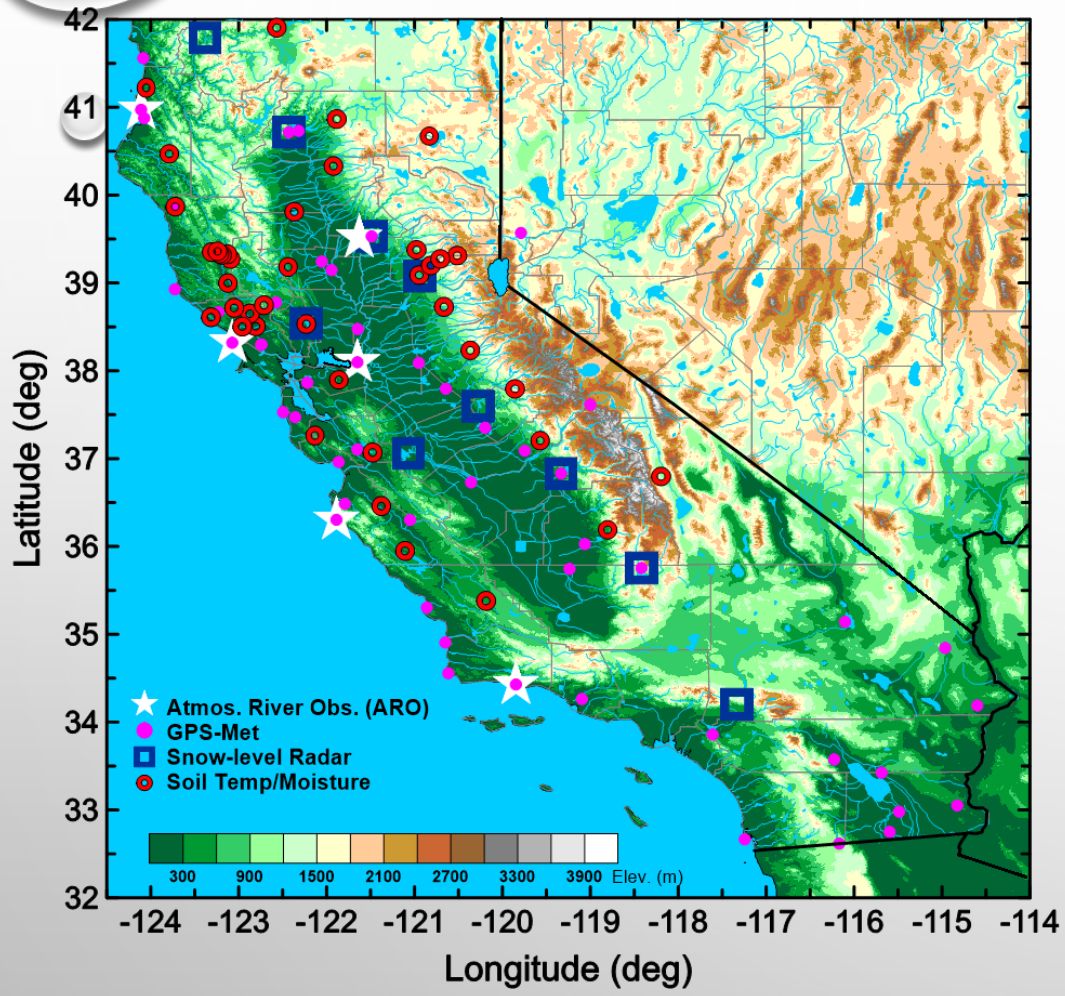




- NOAA's Hydrometeorology Testbed (HMT) has installed a "picket fence" of atmospheric river observatories (AROs) along the U.S. West Coast for weather and wind energy applications.
- Funding for the network was provided by the California Department of Water Resources (CA-DWR) and the U.S. Department of Energy.

Location	ID	Lat. (°)	Lon. (°)	Elev. (m)
Forks, WA	FKS	48.97	-124.40	95
Astoria, OR	AST	46.16	-123.88	3
North Bend, OR	OTH	43.42	-124.24	5
McKinleyville, CA	ACV	40.97	-124.11	56
Bodega Bay, CA	BBY	38.32	-123.07	15
Point Sur, CA	PTS	36.30	-121.89	10
Santa Barbara, CA	SBA	34.43	-119.85	2

In California, a multi-decade collaboration between CA-DWR and NOAA-HMT has created a more comprehensive statewide observing network



Atmospheric River Observatory (6)

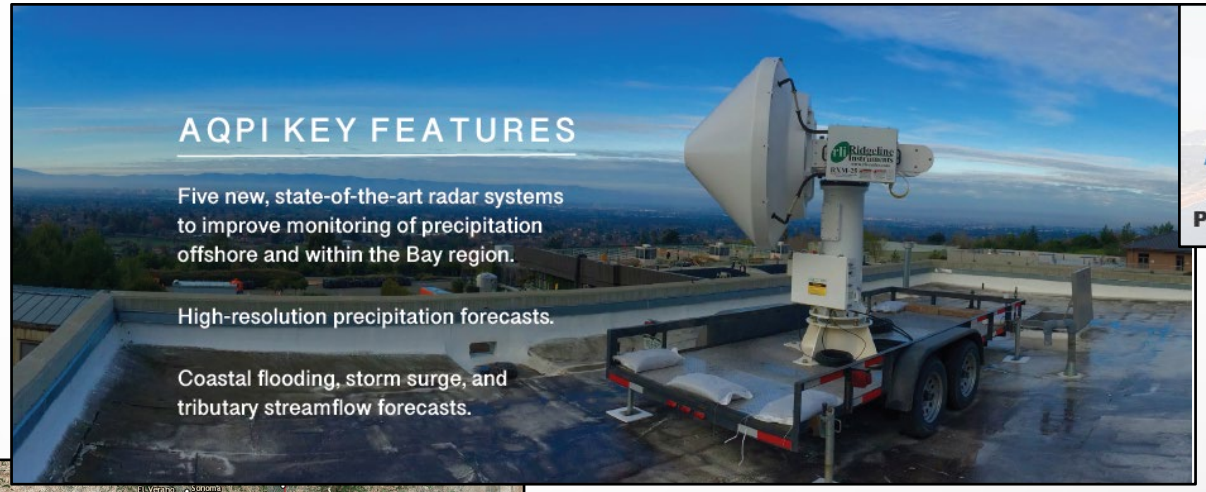
GPS-Met (52)

Snow-level Radar (10)

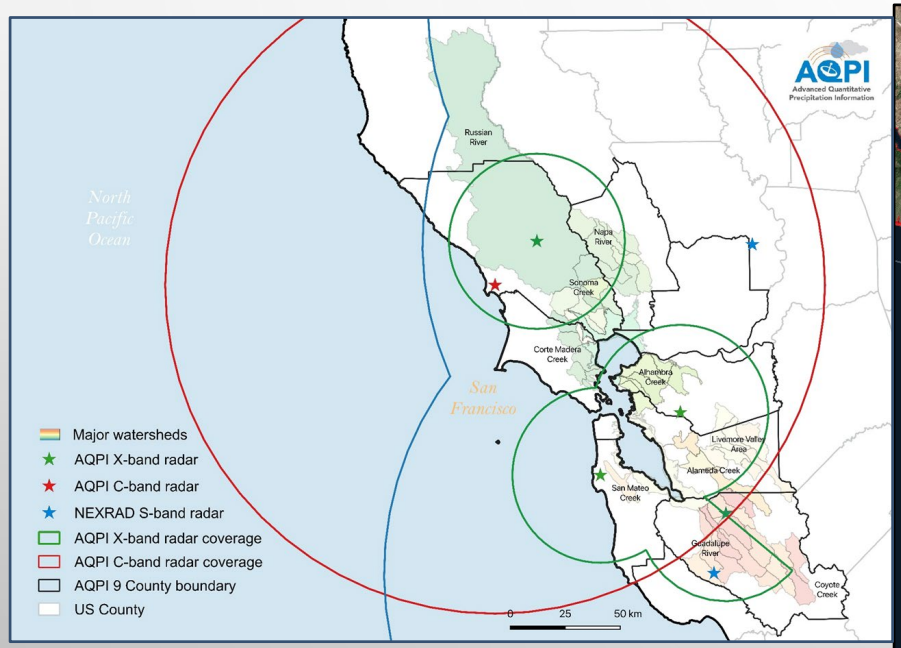
Soil Temp. & Moisture and Surface Met. (40)

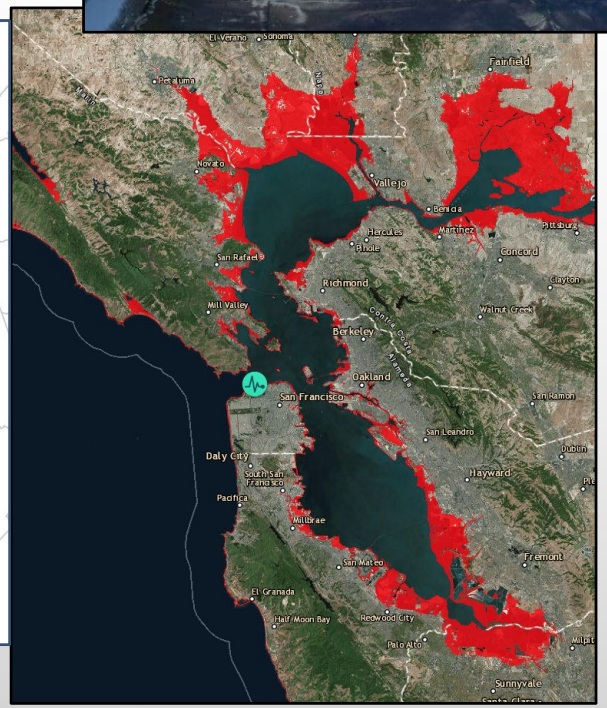
For further details, see White et al., 2013, *JTech*

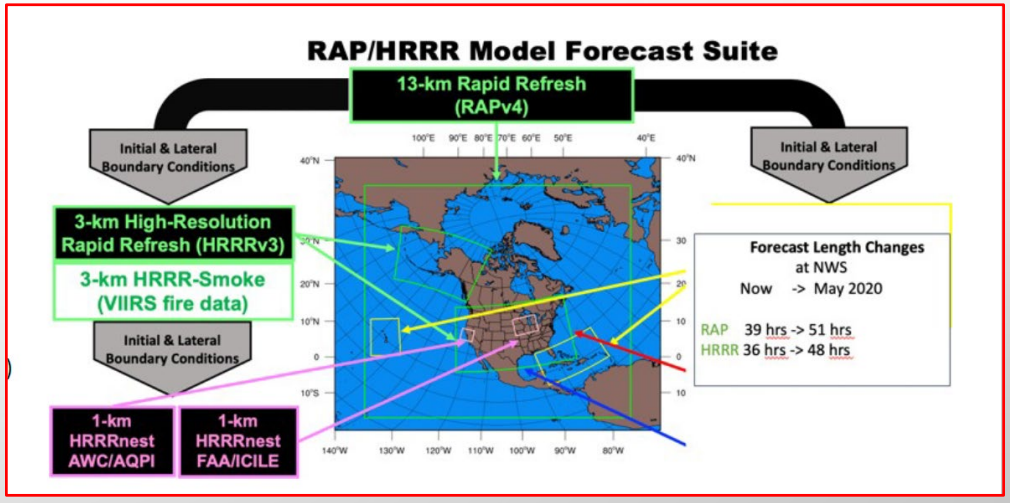
The successful collaboration between NOAA-HMT and CA-DWR has lead to the ongoing **Advanced Quantitative Precipitation Information (AQPI)** project, designed to improve the spatial/temporal resolution and accuracy of rainfall measurements and forecasts for the San Francisco Bay region.



AQPI
Advanced Quantitative Precipitation Information







NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

Department of Water Resources State of California

USGS science for a changing world

Center for Western Weather and Water Extremes

BACWA Bay Area Clean Water Agencies

Bay Area Flood Protection Agencies Association

CIRA

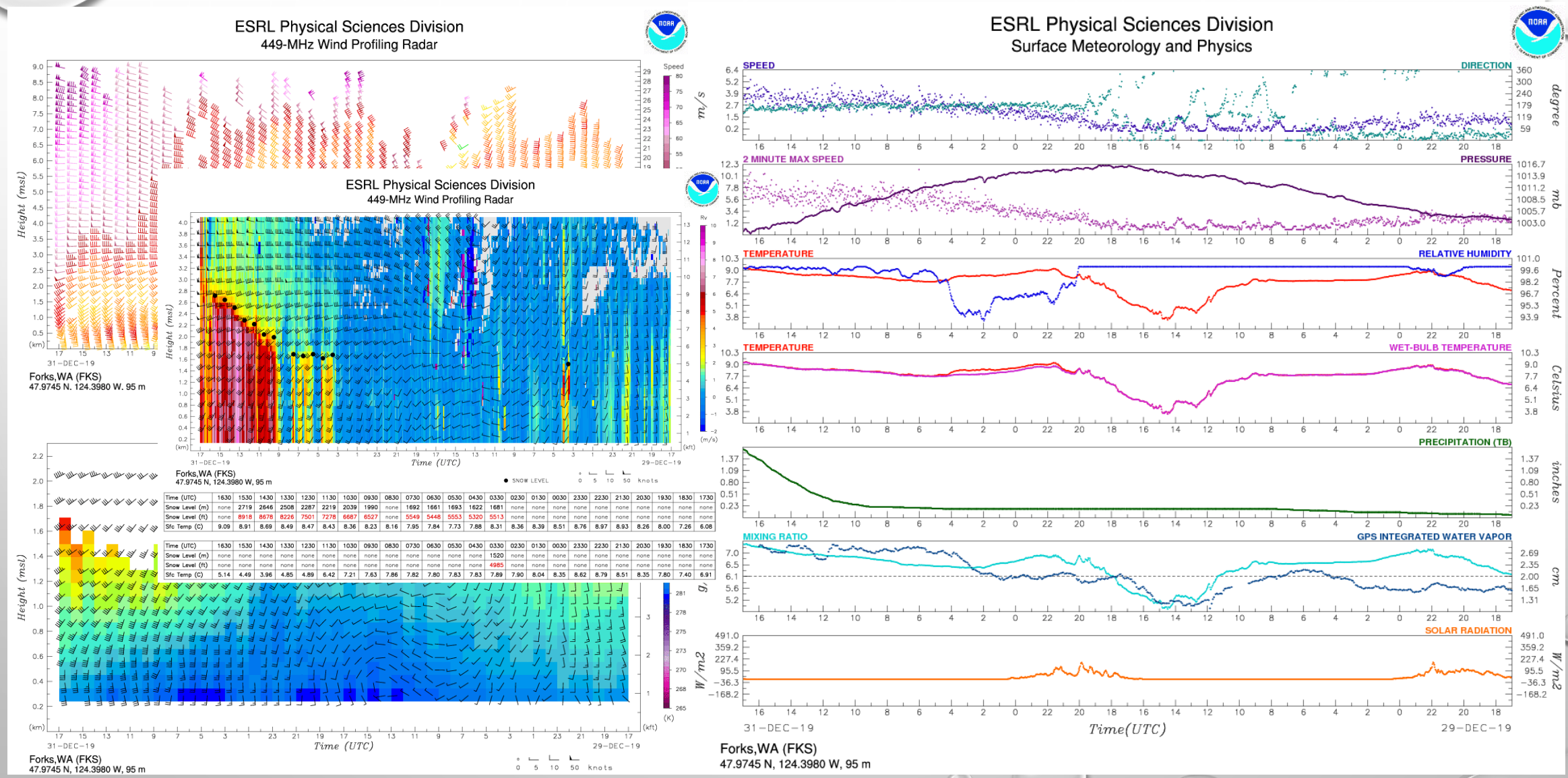
Sonoma Water

Jennifer Krebs

Valley Water

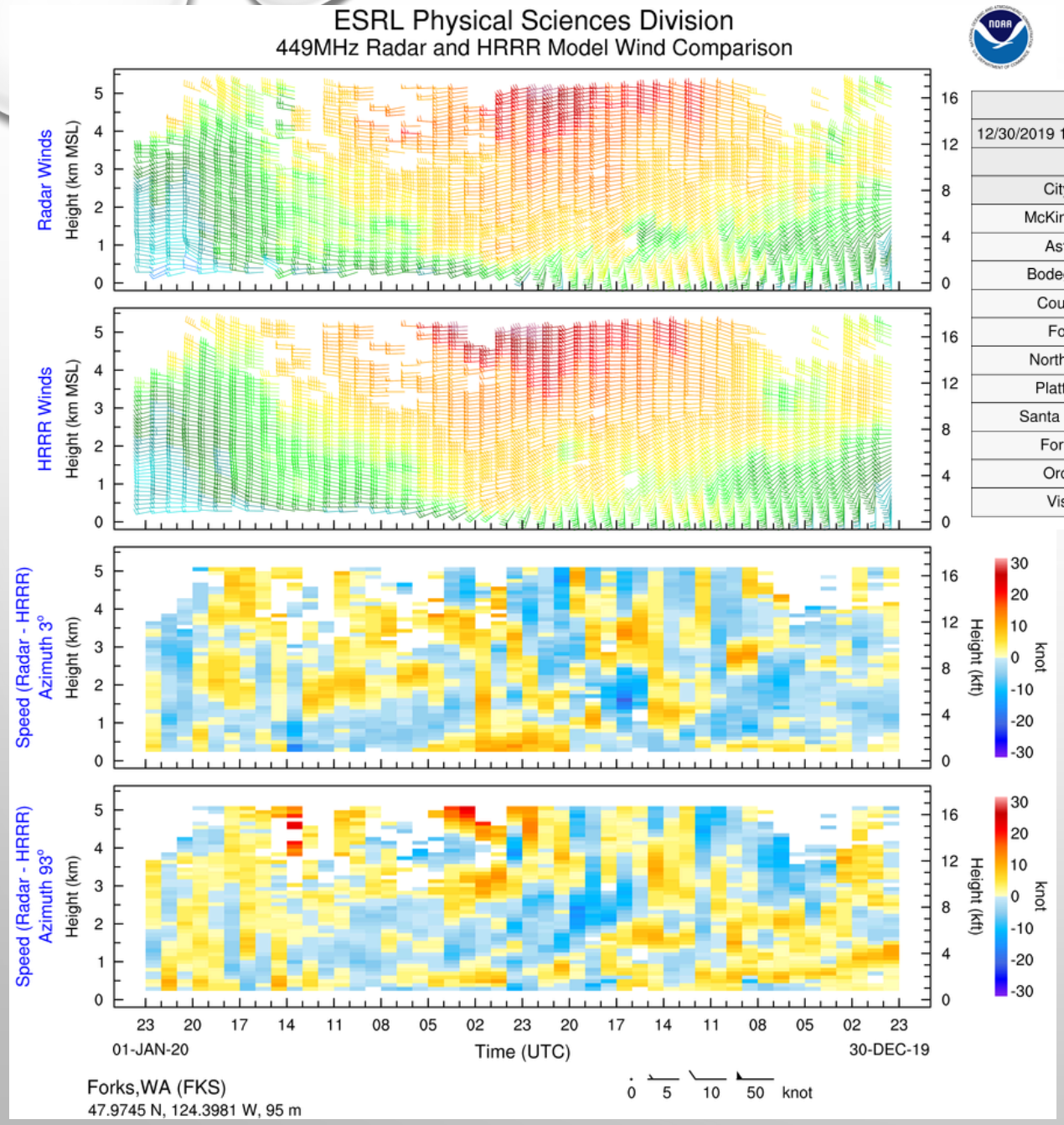
San Francisco Water Power Sewer
Services of the San Francisco Public Utilities Commission

AROs measure the forcings in atmospheric rivers that lead to heavy precipitation and flooding



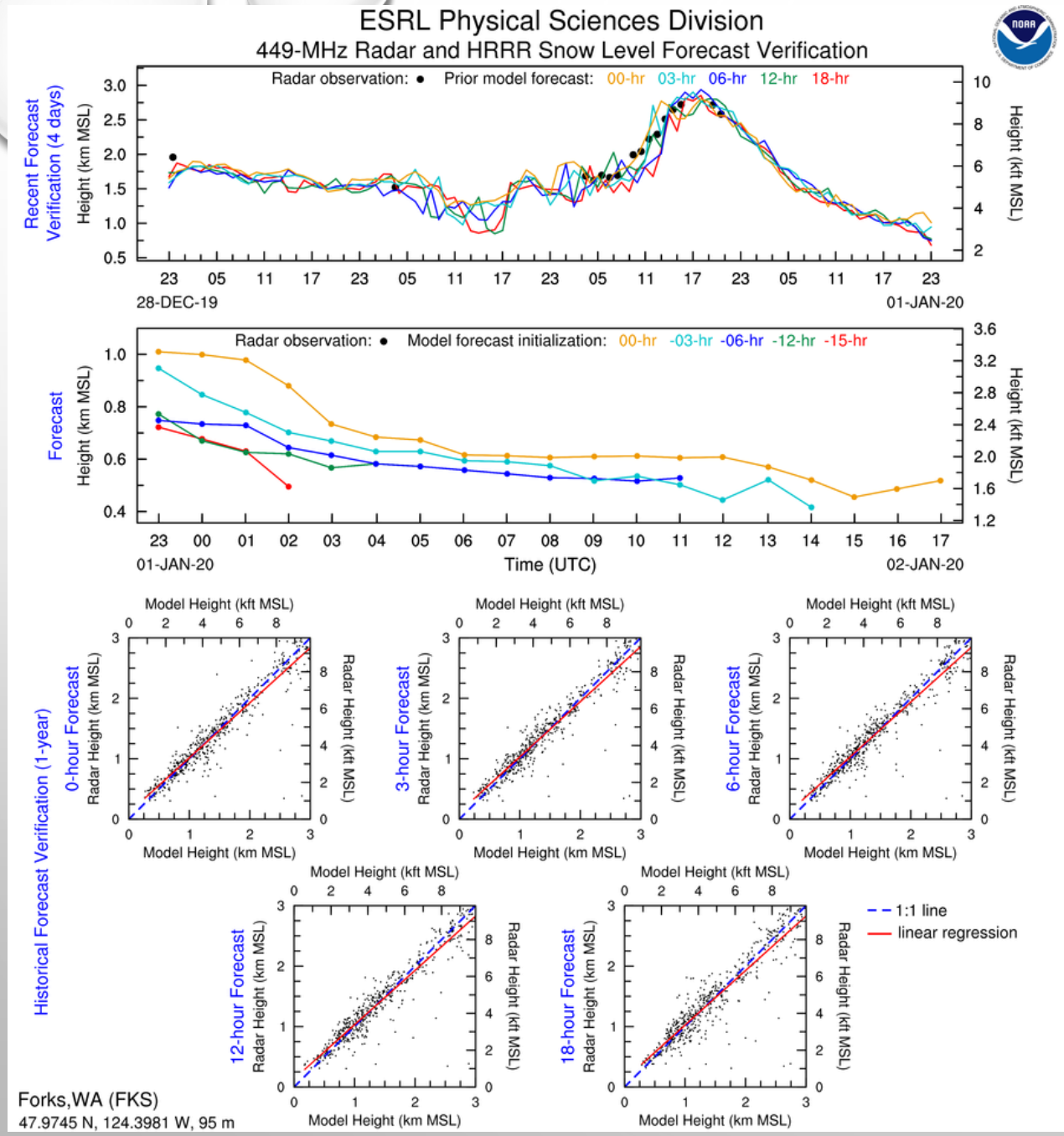
Wind and temperature profiles plus snow level

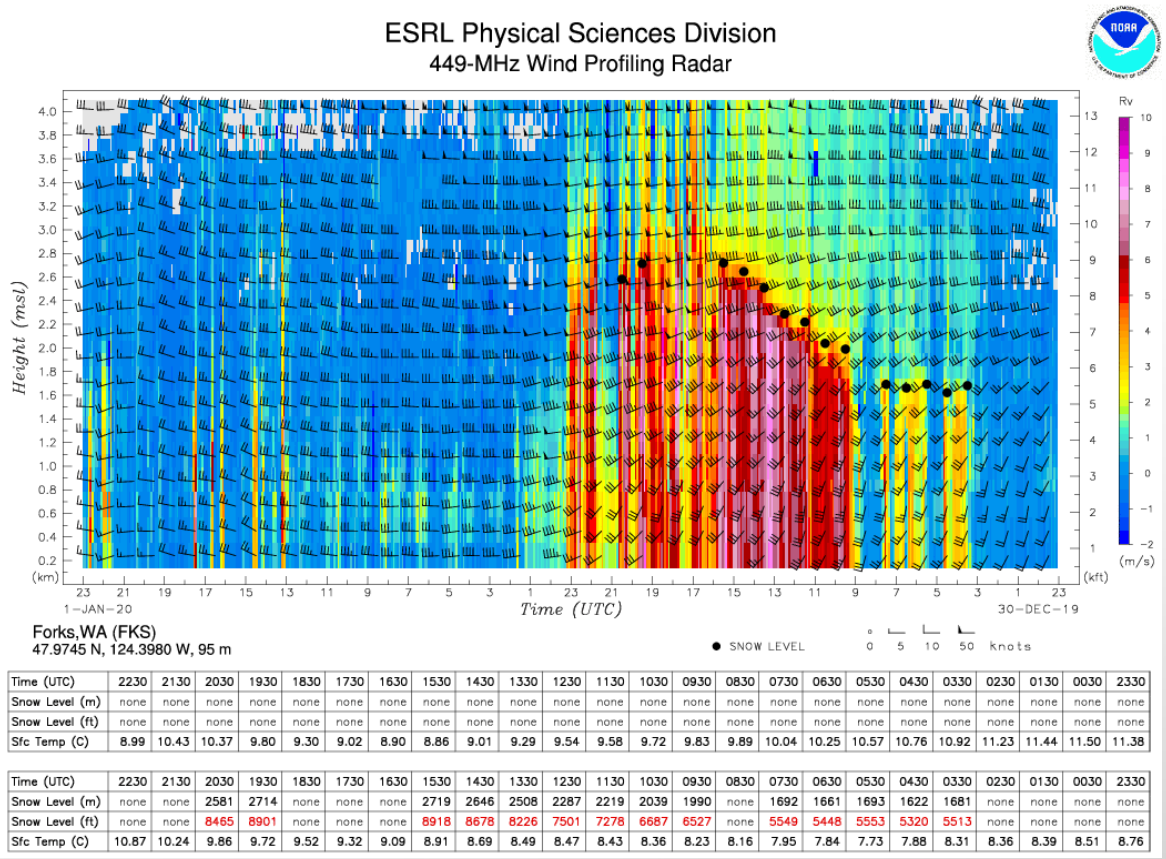
Surface meteorology including integrated water vapor and rainfall



Wind-Profiler/HRRR Oblique Beam Velocity Comparison Statisitics										
12/30/2019 19:00 UTC - 01/01/2020 19:00 UTC			Average				Standard Deviation			
Radar Site Information			Radar Low Mode		Radar High Mode		Radar Low Mode		Radar High Mode	
City & State	ID	Freq	Oblique 1	Oblique 2	Oblique 1	Oblique 2	Oblique 1	Oblique 2	Oblique 1	Oblique 2
McKinleyville, CA	acv	449	-0.98	0.66	-1.47	0.68	4.76	3.75	5.13	4.46
Astoria, OR	ast	449	-1.43	0.42	-1.26	0.17	4.59	4.85	6.25	5.46
Bodega Bay, CA	bby	449	3.18	4.36	4.71	6.36	4.73	4.77	6.15	5.40
Courtland, AL	ctd	449	-0.33	-1.58	-0.34	-1.45	2.87	3.56	2.62	3.03
Forks, WA	fks	449	-0.28	0.30	0.16	0.12	4.49	4.74	5.08	6.10
North Bend, OR	oth	449	-0.42	1.20	-0.59	1.38	4.71	4.92	4.88	5.98
Platteville, CO	pvl	449	-2.95	-3.39	-1.15	-1.48	14.82	15.62	7.16	5.93
Santa Barbara, CA	sba	449	0.11	0.40	-0.23	0.63	5.32	4.69	5.20	4.15
Fort Ord, CA	nps	915	1.18	-0.12	-1.05	0.24	3.27	3.84	2.82	3.71
Oroville, CA	ove	915	0.87	0.34	0.76	1.17	4.70	5.60	4.85	5.87
Visalia, CA	vis	915	0.21	2.53	0.17	1.33	2.76	3.75	3.46	4.80

Wind comparison product allows users to compare observed wind profiles with HRRR analyzed winds. Bottom panels show speed differences (radar-HRRR) for the horizontal wind components measured with each oblique radar beam and the table above allows users to see quick look statistics of wind comparisons at all of PSD's wind profiler sites.



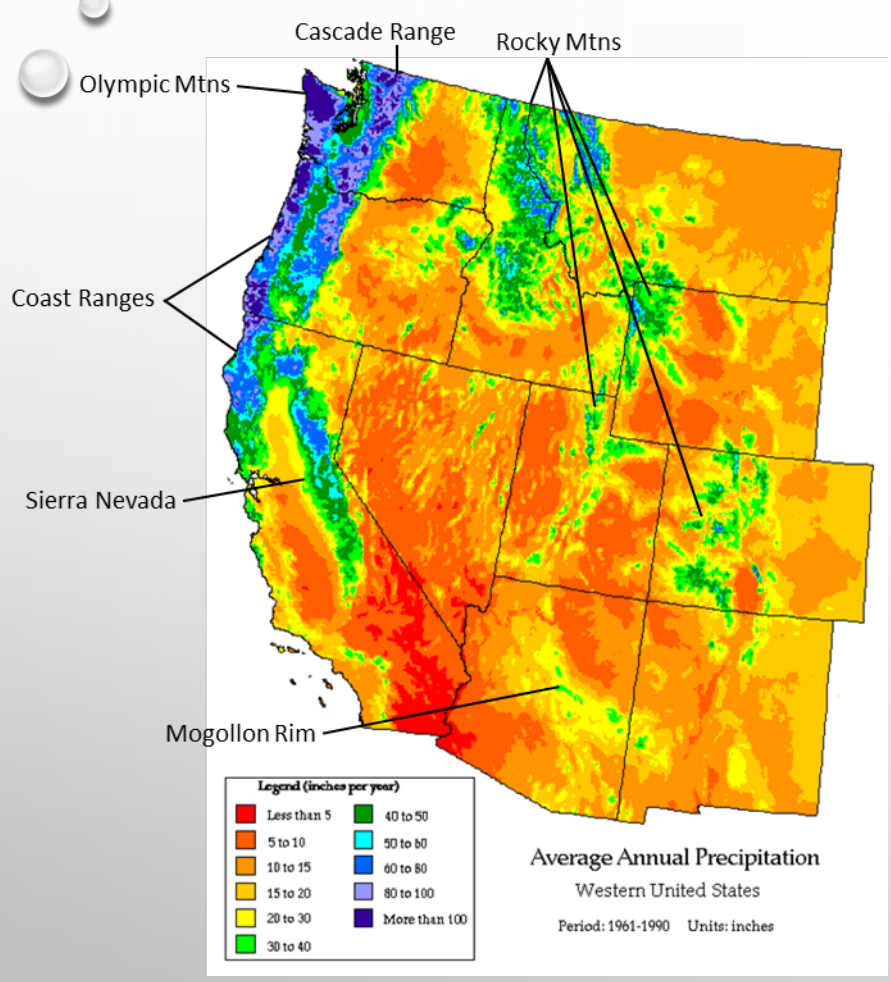


Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Snow Level (ft)	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none	none
Sfc Temp (C)	8.99	10.43	10.37	9.80	9.30	9.02	8.90	8.86	9.01	9.29	9.54	9.58	9.72	9.83	9.89	10.04	10.25	10.57	10.76	10.92	11.23	11.44	11.50	11.38

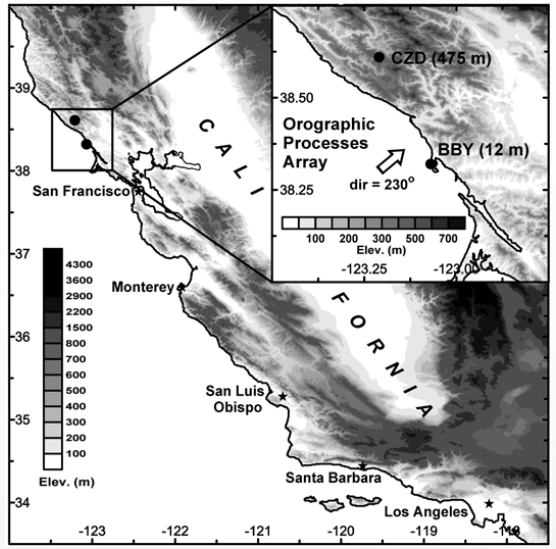
Time (UTC)	2230	2130	2030	1930	1830	1730	1630	1530	1430	1330	1230	1130	1030	0930	0830	0730	0630	0530	0430	0330	0230	0130	0030	2330
Snow Level (m)	none	none	2581	2714	none	none	none	2719	2646	2508	2287	2219	2039	1990	none	1692	1661	1693	1622	1681	none	none	none	none
Snow Level (ft)	none	none	8465	8901	none	none	none	8918	8678	8226	7501	7278	6687	6527	none	5549	5448	5553	5320	5513	none	none	none	none
Sfc Temp (C)	10.87	10.24	9.86	9.72	9.52	9.32	9.09	8.91	8.69	8.49	8.47	8.43	8.36	8.23	8.16	7.95	7.84	7.73	7.88	8.31	8.36	8.39	8.51	8.76

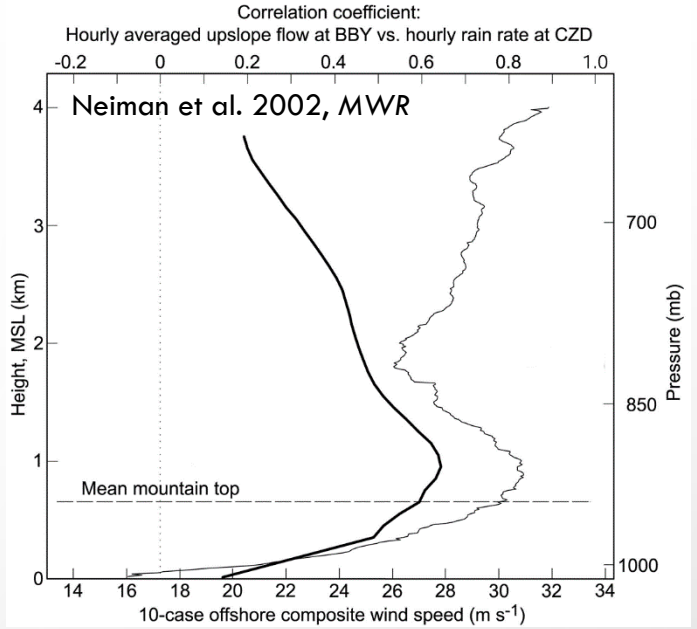
HRRR snow-level verification product allows users to view snow-level forecasts and obs for the prior 4-day period, the current snow-level forecasts, and the snow-level forecast performance over the past year for different forecast verification times.

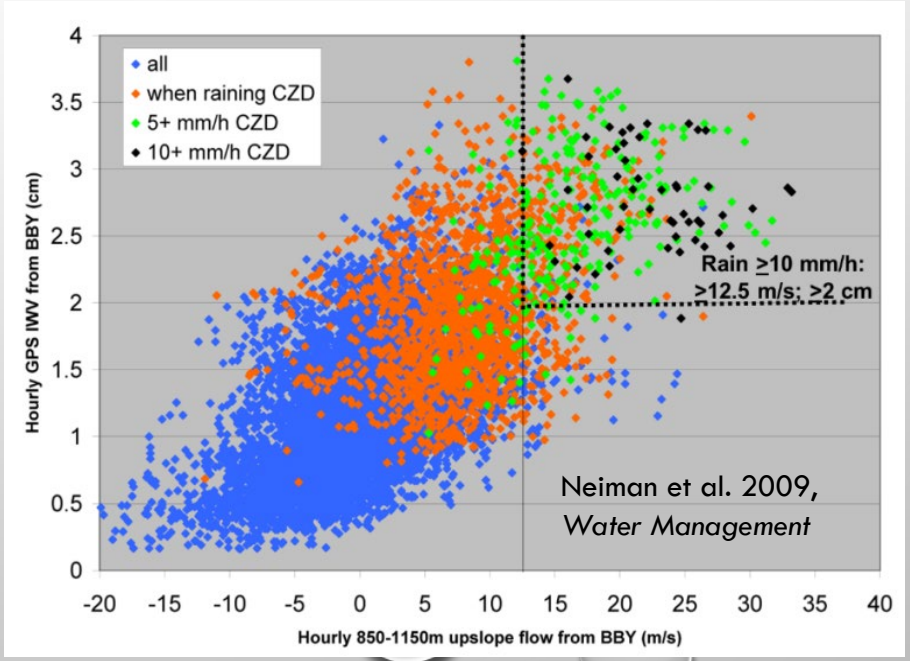
Orographic Precipitation in the Western U. S.

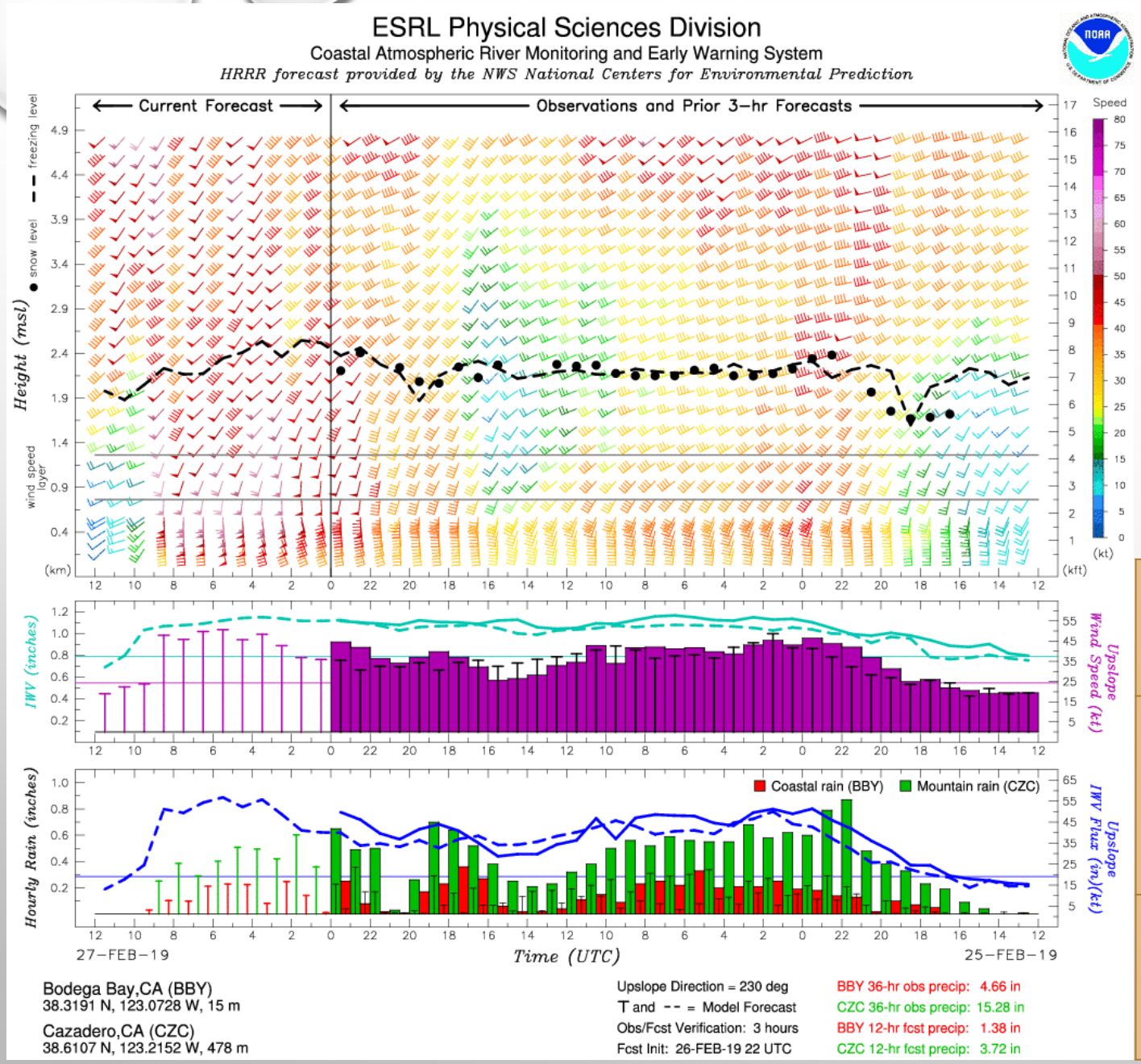


Source: Western Region Climate Center



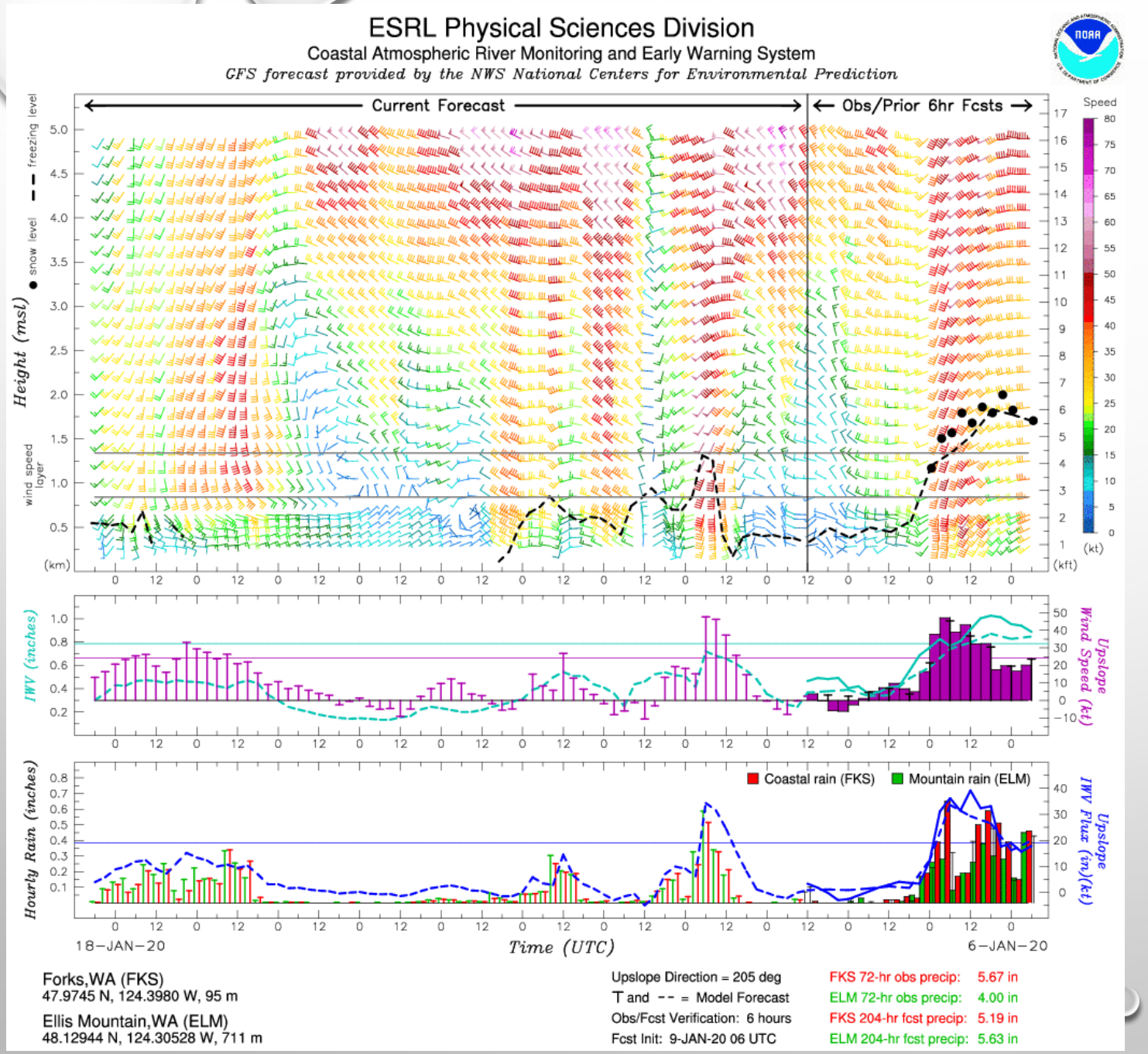






- The ARO Water Vapor Flux Tool displays the AR forcings and thresholds that lead to heavy orographic precipitation.
- The tool also allows users to validate NOAA's operational NWP models (RAP or HRRR) or the research version of the HRRR.
- Right of vertical line shows obs and prior 3-hr forecasts every hr for 36 hr. Left of line shows the current forecast out to 12 hr.

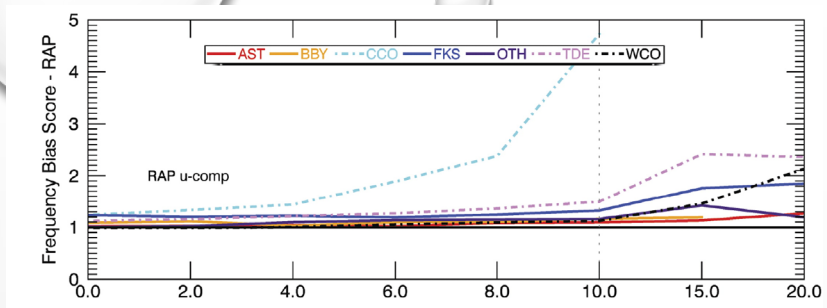
Top panel	Right of line	Observed wind profiles and snow level; forecast freezing level
	Left of line	Forecast wind profiles and freezing level
Middle panel	Right of line	Observed and forecast upslope component of wind in controlling layer and integrated water vapor (IWV)
	Left of line	Forecast upslope component of wind in controlling layer and IWV
Bottom panel	Right of line	Observed and forecast bulk IWV flux, coastal and mountain precipitation
	Left of line	Forecast bulk IWV flux, coastal and mountain precipitation

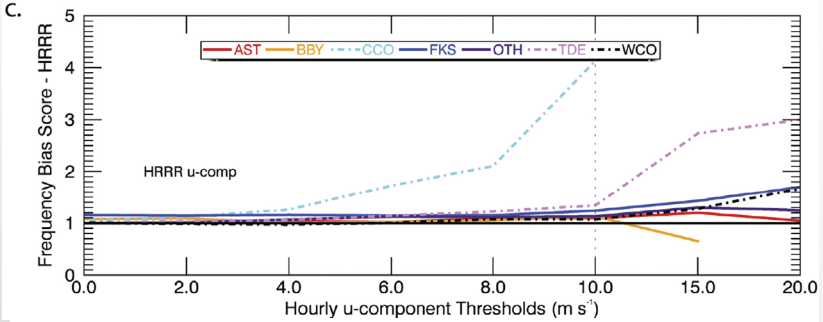


- New option with the ARO Water Vapor Flux Tool incorporates **GFS forecasts** to provide a longer look ahead.

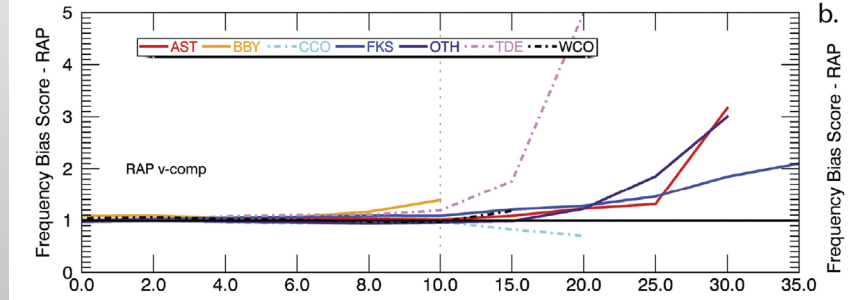
rap | hrrr | hrrrexp | gfs | obs

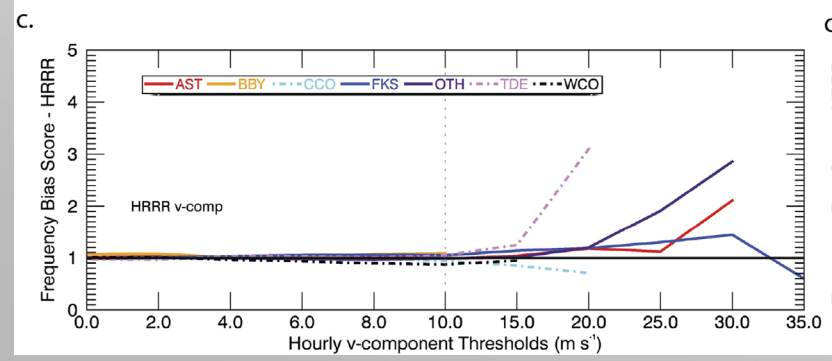
- Obs and GFS forecasts are displayed every three hours for a total of 72 hr of observations and 204 hr (8.5 dy) of the current GFS forecast.
- Obs are compared to prior 6-hr GFS forecasts and the plot is updated with each new GFS model run (i.e., every 6 hr).
- Rainfall observations and forecasts are also 3-hr accumulations.

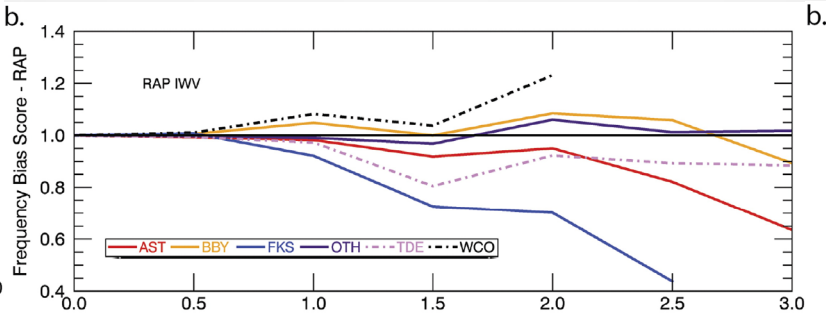


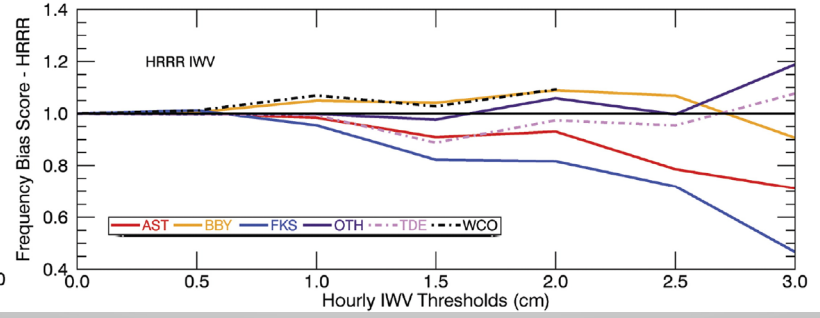


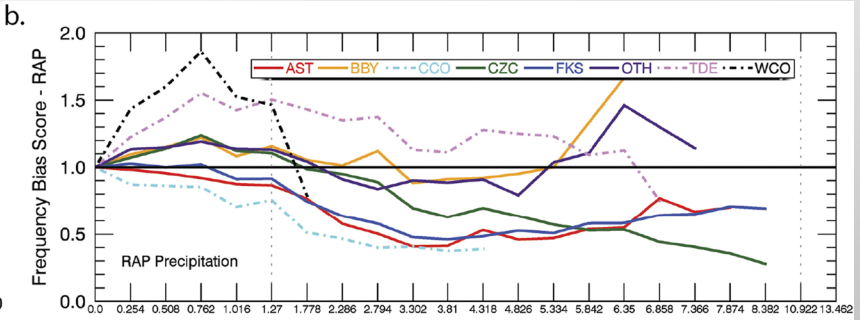
- Darby et al. (2019, *Wea. For.*) evaluated RAP and HRRR forecasts with observations from eight AROs over the 2015/16 winter season.
- Frequency bias score (FBS) is shown here, where
  FBS = # forecasts ≥ threshold / # observations ≥ threshold
- Winds were over predicted, especially when components > 10 m s^{-1}, IWV was well predicted, but precipitation was under predicted for the most part, especially for higher precipitation thresholds and at the wettest stations (AST, CZC, and FKS). Further research is needed to understand this behavior.

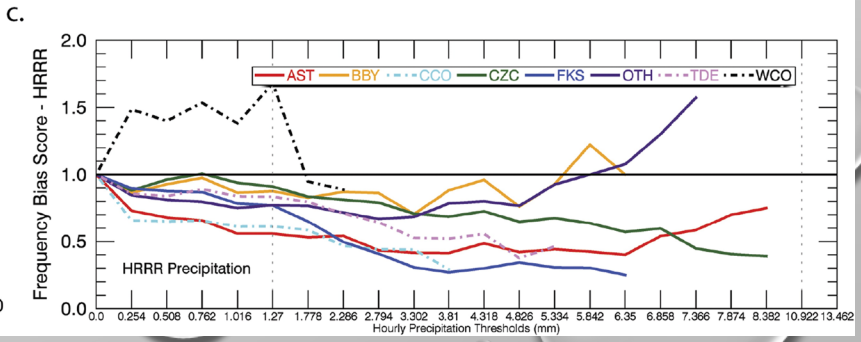




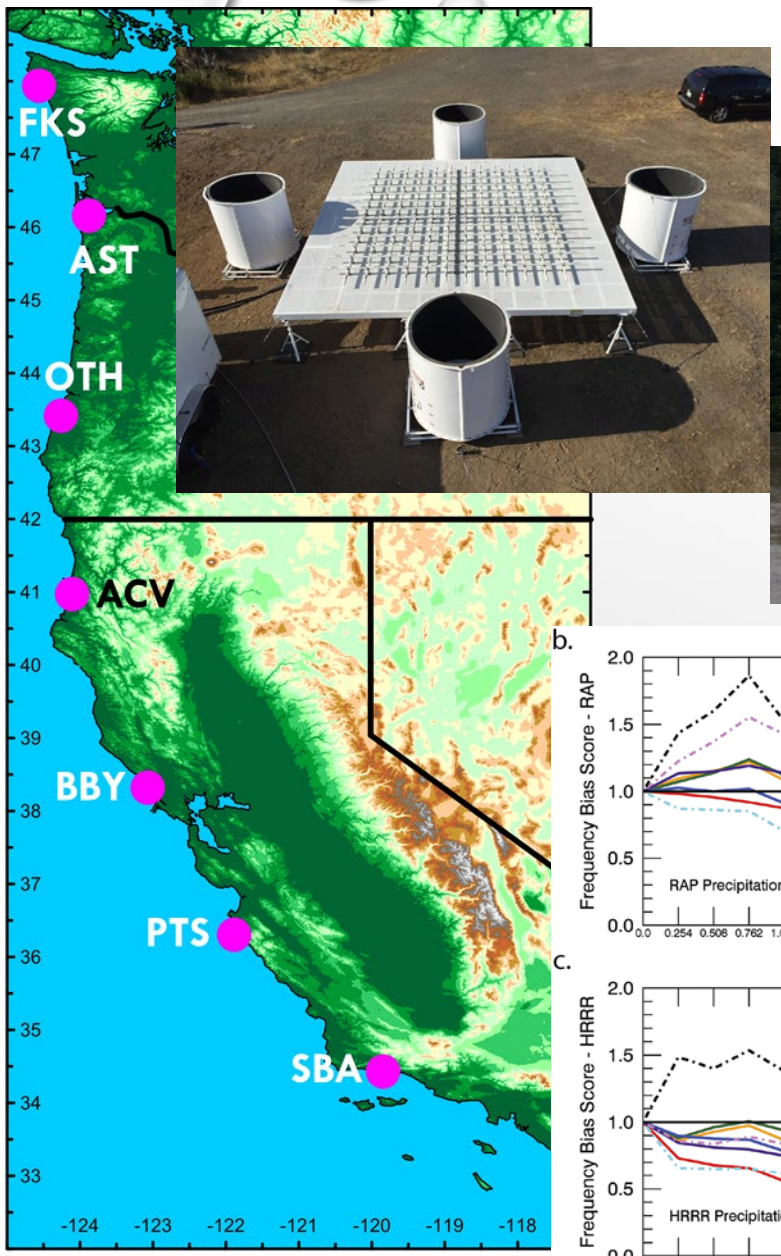








SUMMARY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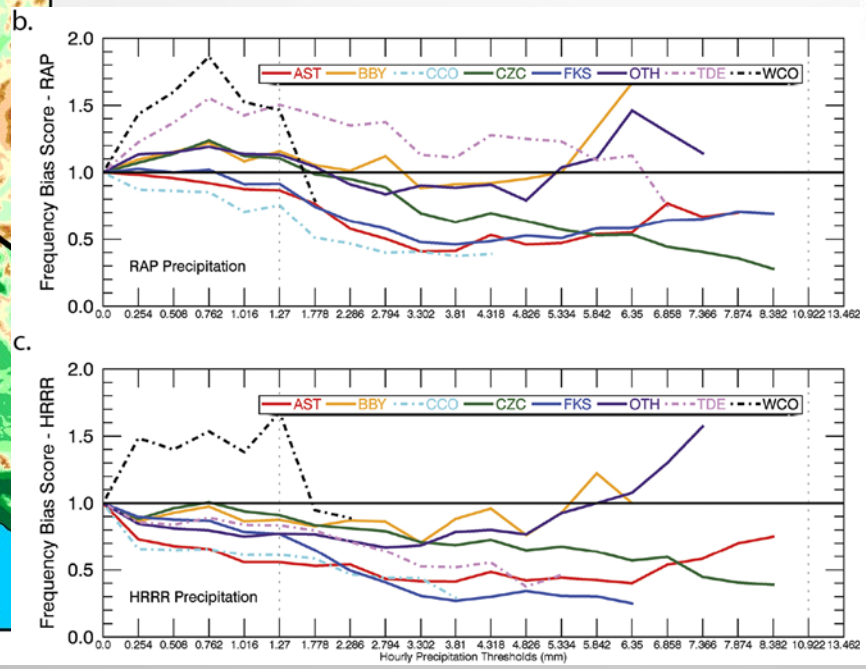
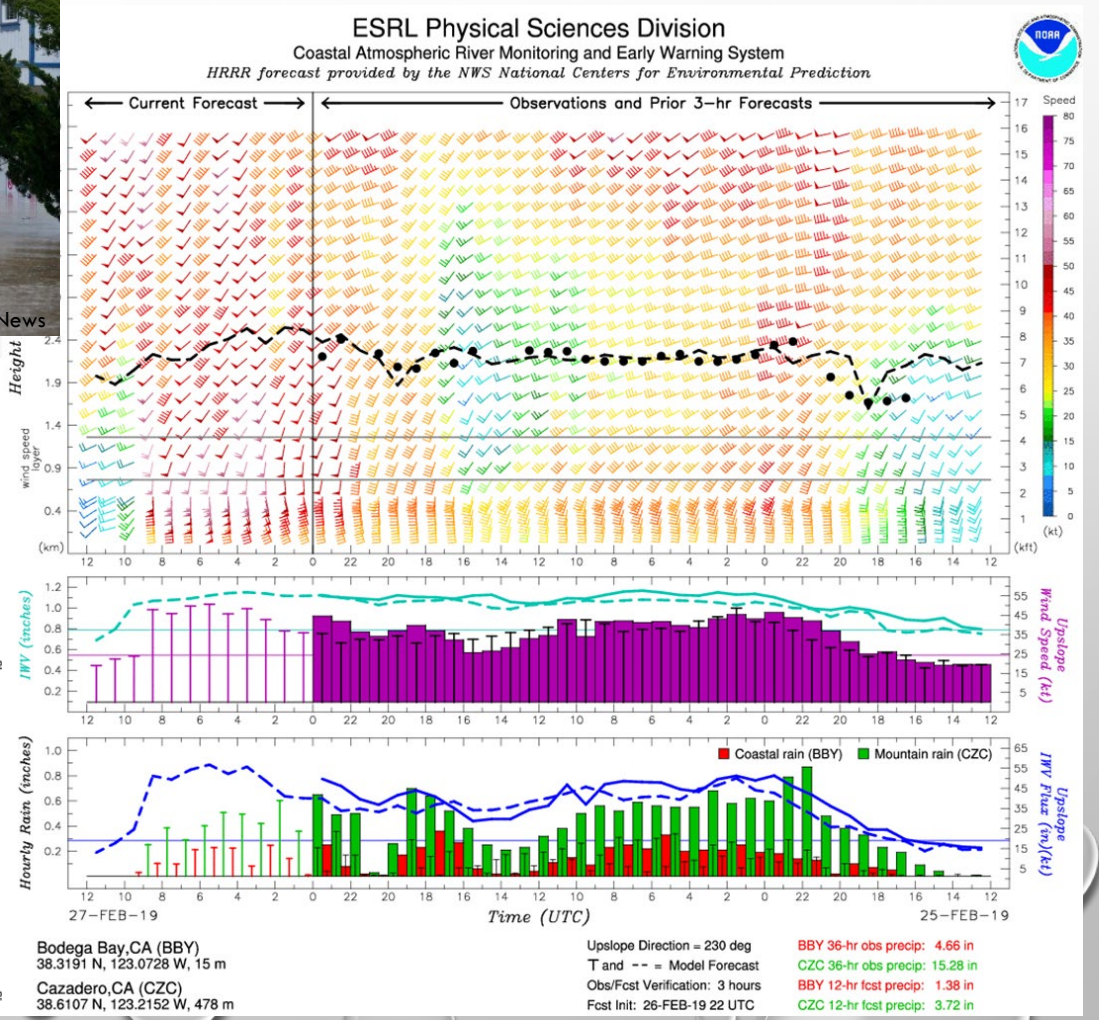
Russian River flooding – 27 Feb. 2019, Guerneville, CA
PEE WEE
Mercury News


b.
Frequency Bias Score - RAP
AST BBY CCO CZC FKS OTH TDE WCO
RAP Precipitation
c.
Frequency Bias Score - HRRR
HRRR Precipitation
Hourly Precipitation Thresholds (mm)


ESRL Physical Sciences Division
Coastal Atmospheric River Monitoring and Early Warning System
HRRR forecast provided by the NWS National Centers for Environmental Prediction
Current Forecast
Observations and Prior 3-hr Forecasts
Speed
Height
IWV (inches)
Upslope Wind Speed (kt)
Hourly Rain (inches)
Coastal rain (BBY)
Mountain rain (CZC)
Upslope IWV Flux (in)(kt)
27-FEB-19
Time (UTC)
25-FEB-19
Bodega Bay,CA (BBY)
38.3191 N, 123.0728 W, 15 m
Cazadero,CA (CZC)
38.6107 N, 123.2152 W, 478 m
Upslope Direction = 230 deg
T and -- = Model Forecast
Obs/Fcst Verification: 3 hours
Fcst Init: 26-FEB-19 22 UTC
BBY 36-hr obs precip: 4.66 in
CZC 36-hr obs precip: 15.28 in
BBY 12-hr fcst precip: 1.38 in
CZC 12-hr fcst precip: 3.72 in


Thank you!

SUMMARY

- HMT operates a picket fence of coastal atmospheric river observatories (AROs) along the U.S. West Coast stretching from NW Washington to SW California. These AROs provide the first ground truth data on landfalling ARs that can be used to verify weather forecasts.
- In California, the network is enhanced by other sensors to monitor the inland impacts of ARs.
- The ARO Water Vapor Flux Tool gives forecasters and other users a quick glimpse of the conditions in ARs that could lead to heavy orographic precipitation, flooding, and other hazards.
- This tool can now be viewed with GFS forecasts to increase the forecast lead time to 8.5 days.
- Evaluation of HRRR and RAP forecasts using the Flux Tool indicate that the models predict winds and water vapor fairly well but still underestimate precipitation, especially precipitation enhanced by orogrphay.