CW3E's Atmospheric River Monitoring and Forecast Product Development: Water Year 2018 S2S and AR Recon Highlights

F. Martin Ralph

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CW3E Advances in Atmospheric River Science, Observations, and Tools

Visualizations, Monitoring and Analysis: Monitoring and Prediction Tools – strength and location tracking; watershed scale products; regular outlooks → decision support

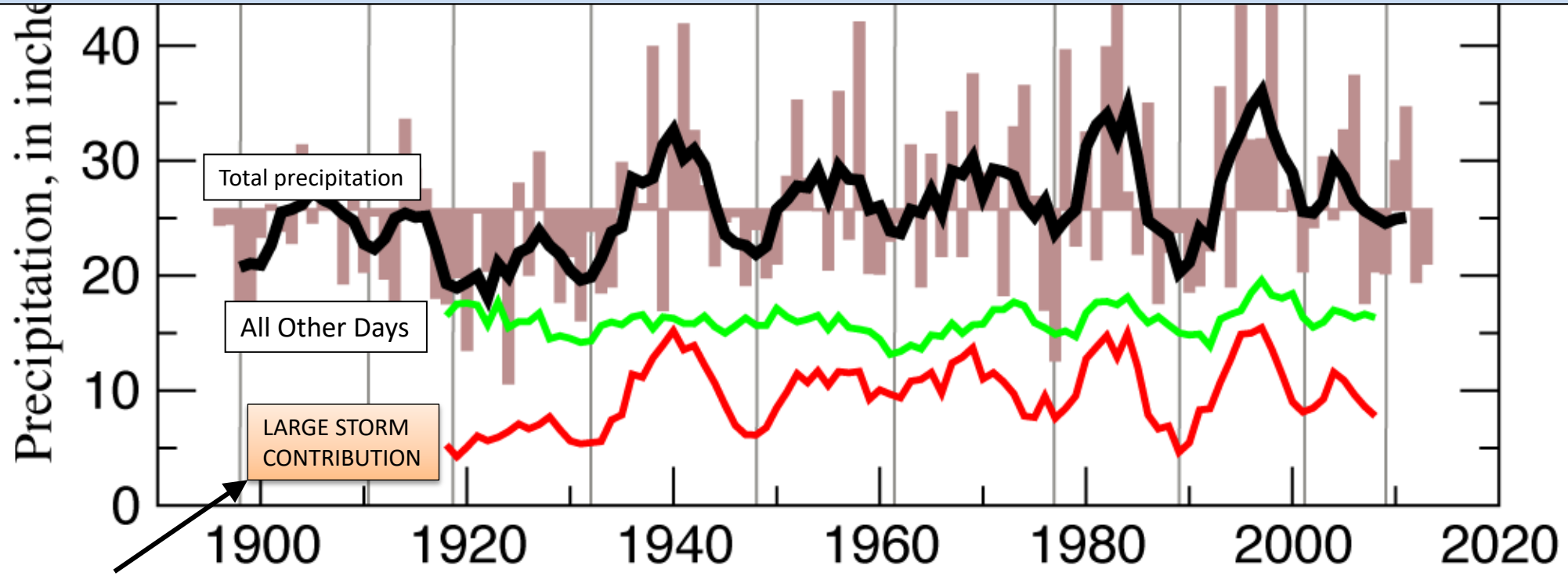
Forecasts: Example of significant forecast error in 2018
Week 2 and 3 AR outlooks
West-WRF – performance assessment relative to global models

Observations: Atmospheric River Reconnaissance 2018

A few large storms (or their absence) account for a disproportionate amount of California's precipitation variability

a) Water-Year Precipitation, Delta Catchment

WHETHER A YEAR WILL BE WET OR DRY IN CALIFORNIA IS MOSTLY DETERMINED BY THE NUMBER AND STRENGTH OF ATMOSPHERIC RIVERS STRIKING THE STATE.



- 85% of interannual variability results from how wet the 5% wettest days are each year.
- These days are mostly atmospheric river events.

Dettinger and Cayan **Drought and the Delta—A Matter of Extremes**
San Francisco Estuary and Watershed Science, April 2014

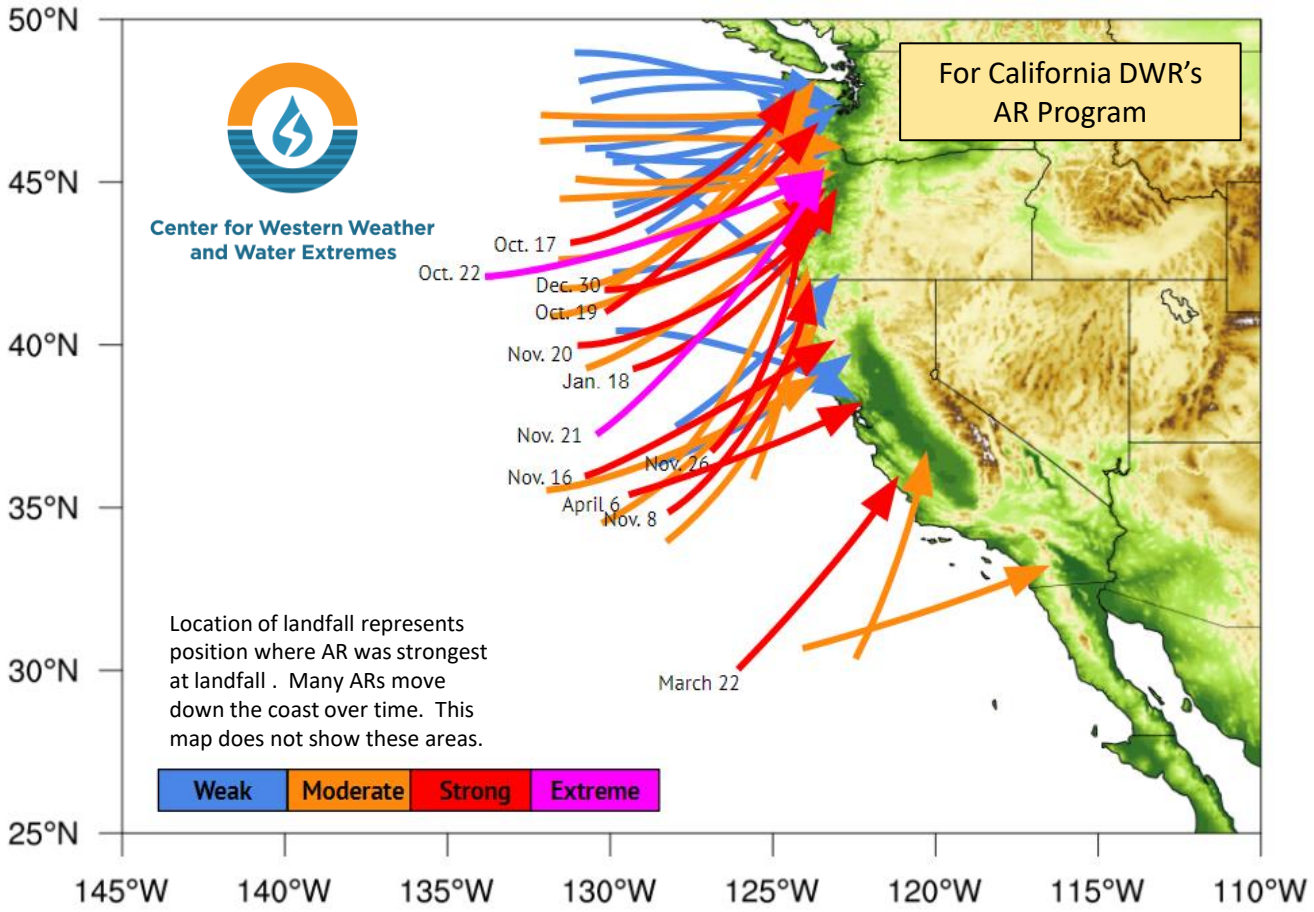
Distribution of Landfalling Atmospheric Rivers on the U.S. West Coast During Water Year 2018 Through April

AR Strength	AR Count
Weak	16
Moderate	16
Strong	10
Extreme	2
Exceptional	0

Ralph/CW3E AR Strength Scale

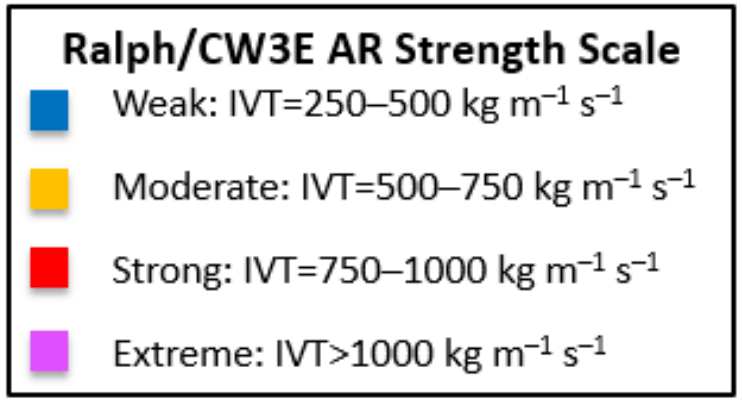
- Weak: IVT=250–500 kg m^{-1} s^{-1}
- Moderate: IVT=500–750 kg m^{-1} s^{-1}
- Strong: IVT=750–1000 kg m^{-1} s^{-1}
- Extreme: IVT=1000–1250 kg m^{-1} s^{-1}
- Exceptional: IVT>1250 kg m^{-1} s^{-1}

- **44** Atmospheric Rivers made landfall on the West Coast during the 2018 water year through April



AR Strength by Month 2018

AR Strength	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Weak	2	1	2	3	4	2	2
Mod.	0	2	3	7	1	3	0
Strong	2	4	1	1	0	1	1
Extreme	1	1	0	0	0	0	0
Excep.	0	0	0	0	0	0	0
Total	5	8	6	7	5	6	3



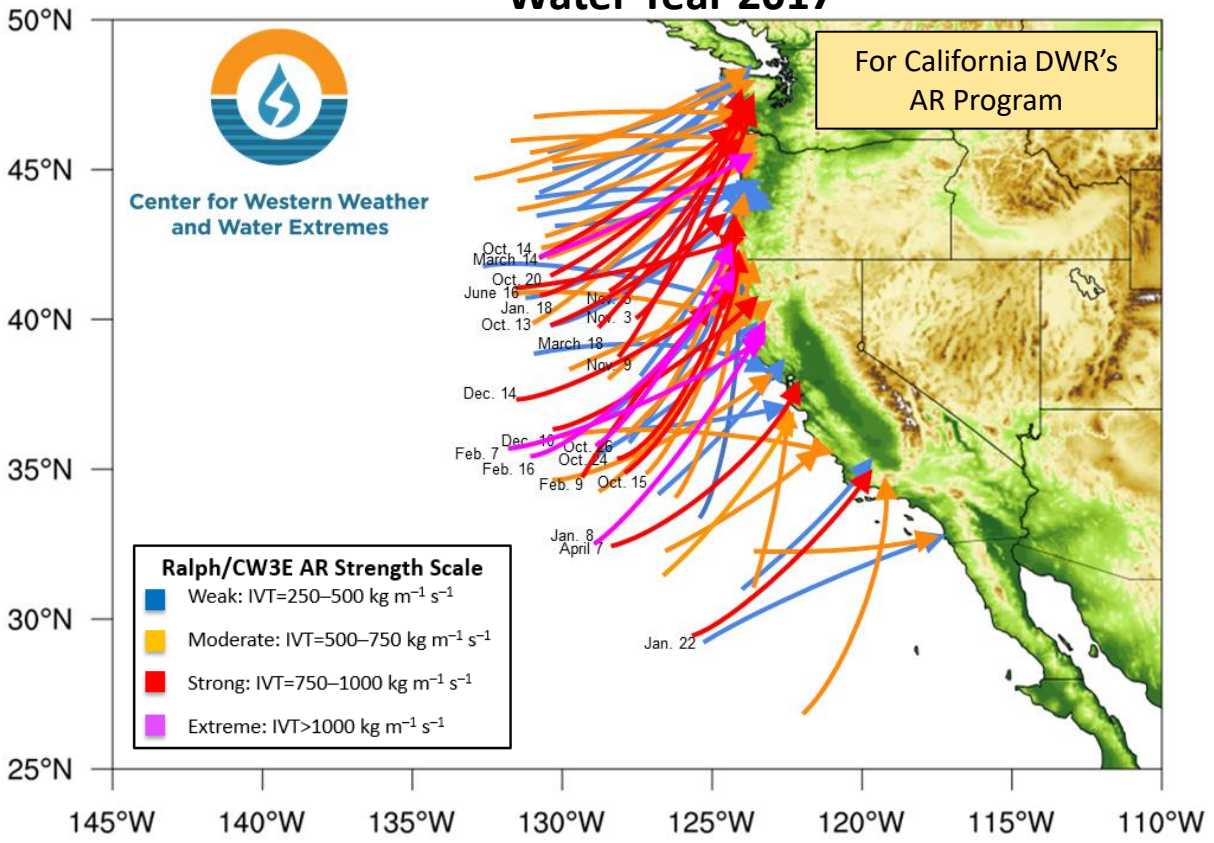
Number of AR occurrences by state/region

Washington	Oregon	NorCal	SoCal
38	43	31	17

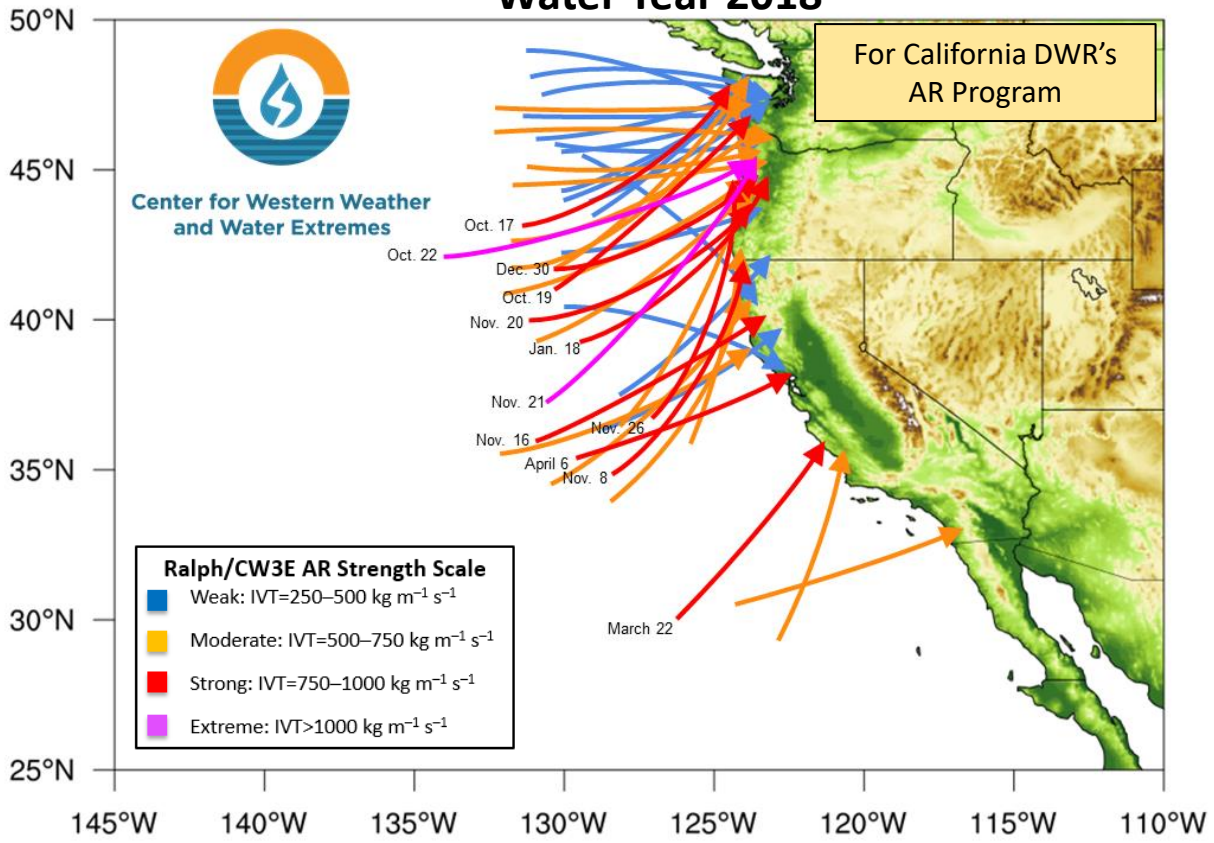
WY 2018 Compared to WY 2017

- The record breaking WY 2017 experienced a total of 68 landfalling ARs over the U.S. West Coast
- 60 of the total 68 ARs occurred through April 2017, compared to 44 experienced this WY through April

Water Year 2017

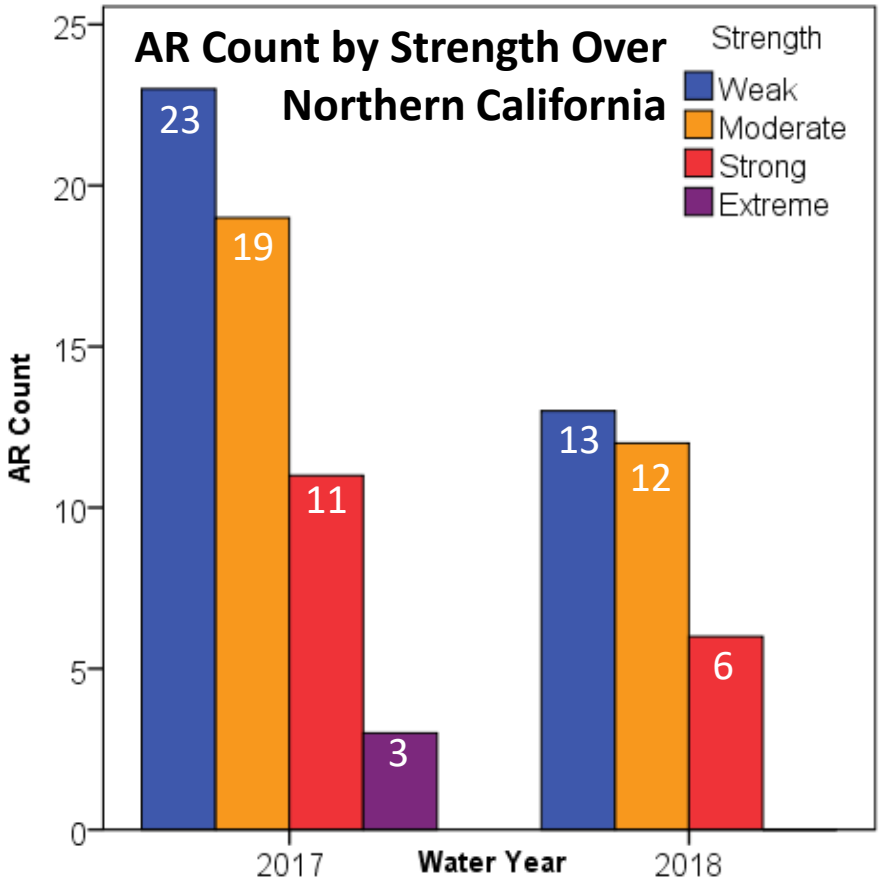


Water Year 2018

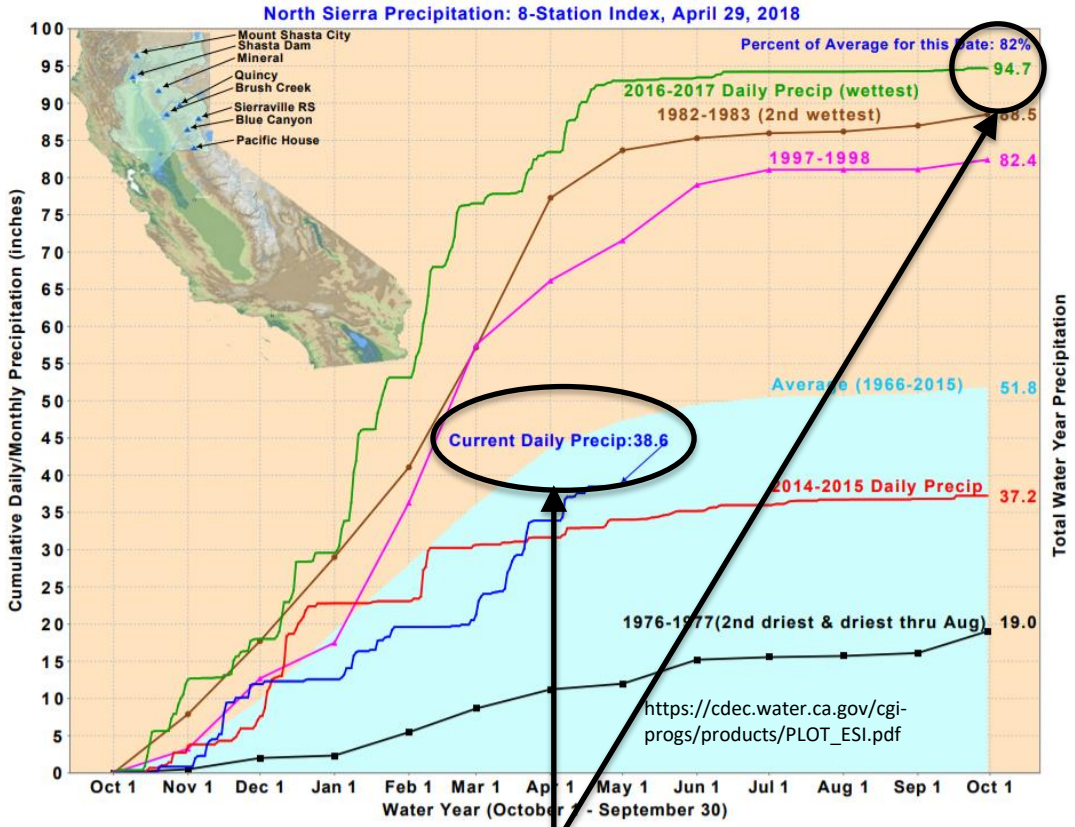


- When compared to WY 2017, a larger proportion of landfalling ARs during WY 2018 made landfall over the Pacific Northwest

Northern California Analysis



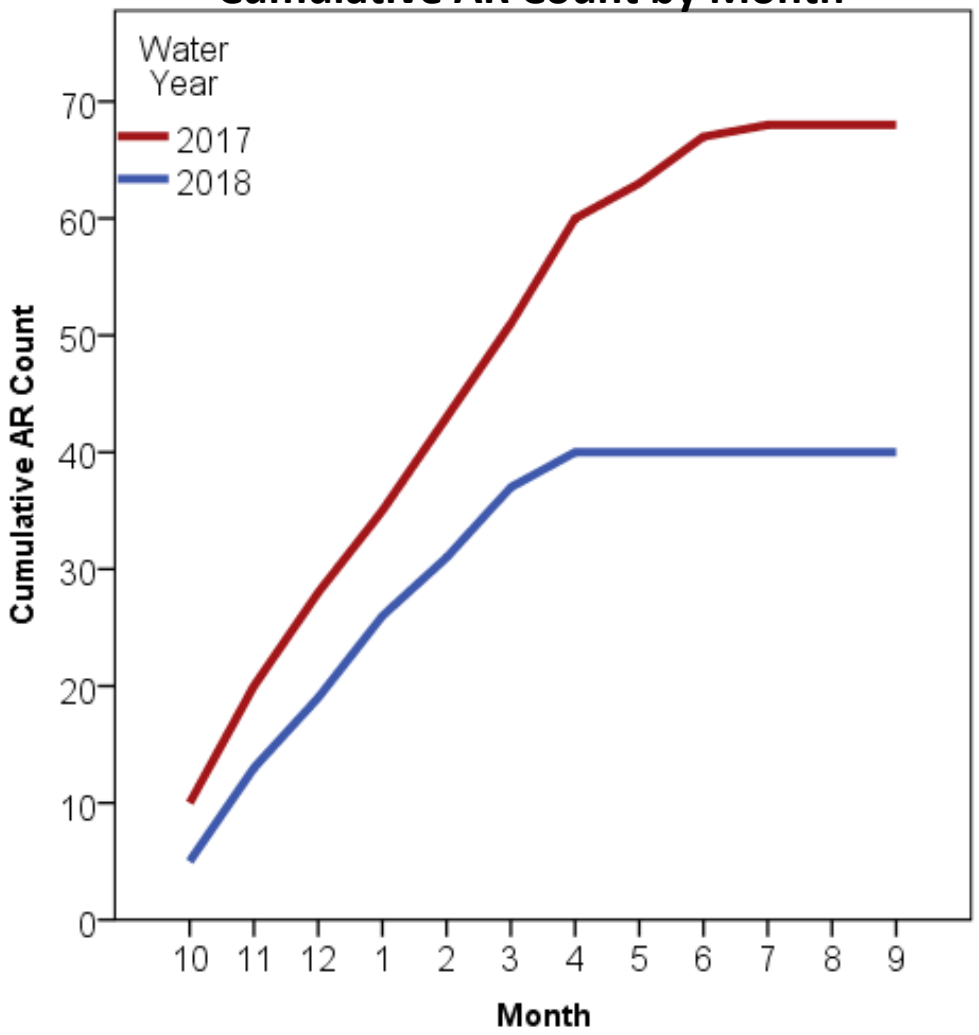
- 42 weak or mod. ARs occurred over Northern CA during WY 2017, compared to 25 during WY 2018
- WY 2017 also experienced 14 strong or extreme ARs compared to only 6 strong ARs during WY 2018



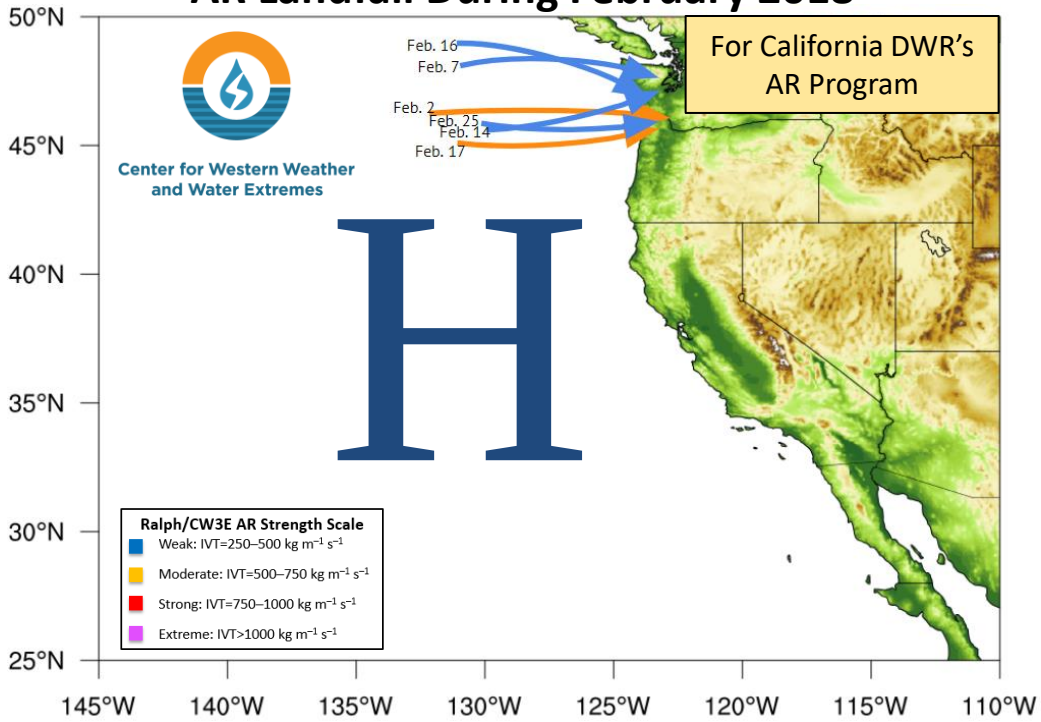
- The differences in frequency and strength of landfalling ARs resulted in large differences in WY precipitation over the Northern Sierra 8-Station Index
- The index received ~56 more ins. of precipitation during WY 2017 than WY 2018 to date (94.7 in. vs. 28.6 in.)

Atmospheric Rivers by Month

Cumulative AR Count by Month



AR Landfall During February 2018



- WY 2017 experienced several more AR landfalls per month when compared to WY 2018
- Feb. 2018 was also dominated by persistent ridging and high pressure over the Eastern Pacific
- All ARs that made landfall during Feb. 2018 were westerly/northwesterly oriented and over the Pacific Northwest likely leading to small impacts and leaving California dry

AR Forecasts at S2S Lead Times

CW3E Partnership for Week 2-3 Outlooks

CW3E S2S Advisory Panel: Marty Ralph (**PI**; Chair), Dan Cayan, Duane Waliser, Bruce Cornuelle, Art Miller, Elizabeth Barnes

For California DWR's AR Program

Center for Western Weather and Water Extremes

CW3E-SIO Team: Aneesh Subramanian (Lead), Sasha Gershunov, Zhenhai Zhang, Kristen Guirguis, Will Chapman, Tamara Shulgina, Anna Wilson, Minghua Zheng, Brian Kawzenuk

Jet Propulsion Laboratory
California Institute of Technology

JPL: Duane Waliser, Bin Guan, Mike DeFlorio, Alex Goodman

Plymouth State University

PSU: Jay Cordeira

Colorado State University

CSU: Elizabeth Barnes, Kyle Nardi

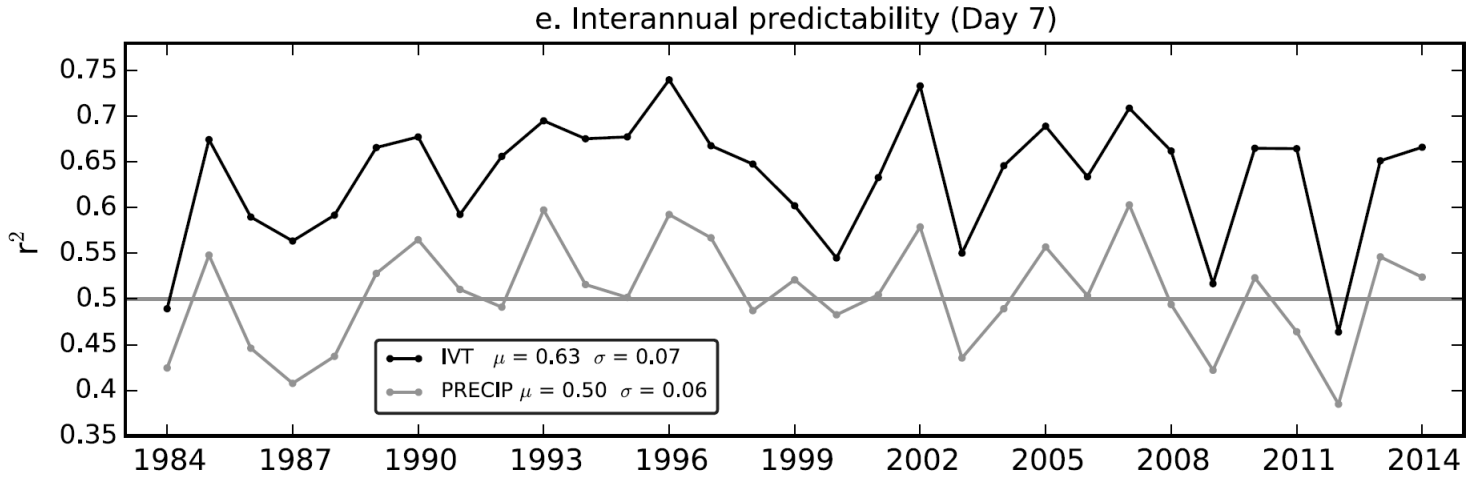
WCRP World Climate Research Programme
WWRP World Weather Research Programme

Data and collaborations from WCRP / WWRP S2S Project

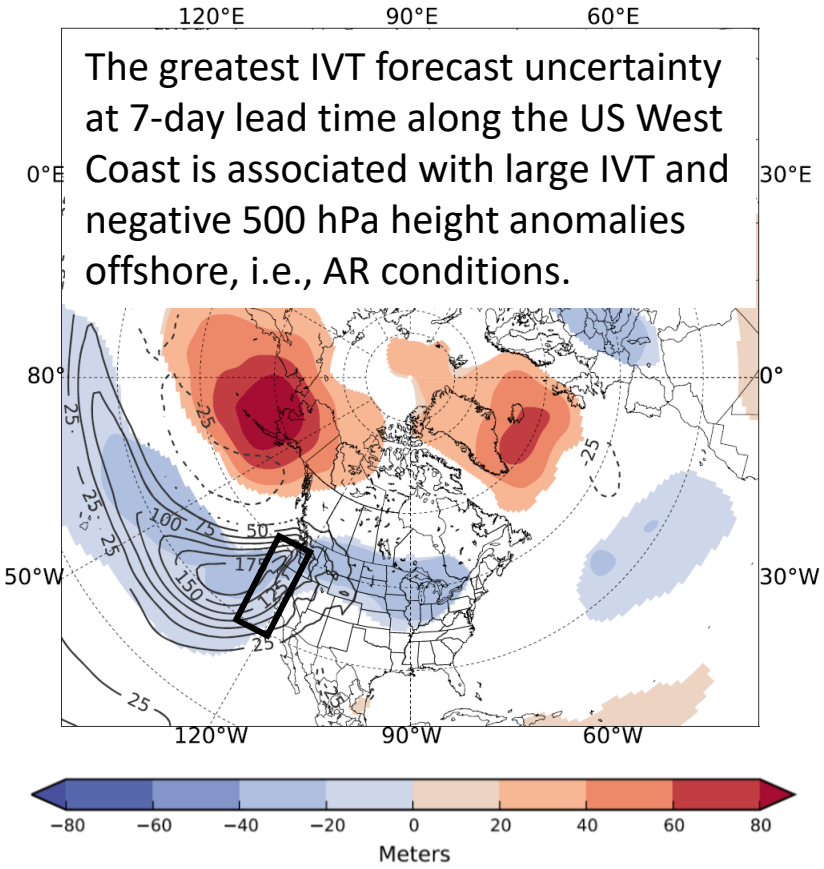
Predictability of horizontal water vapor transport relative to precipitation: Enhancing situational awareness for forecasting western U.S. extreme precipitation and flooding

David A. Lavers, Duane E. Waliser, F. Martin Ralph, Michael D. Dettinger, *Geophys. Res. Lett. 2016*

Applying the potential predictability concept to NCEP global ensemble reforecasts, acro
31 winters, IVT is found to be more predictable than precipitation in the region 30-50°N
120-125° W



The greatest IVT forecast uncertainty at 7-day lead time along the US West Coast is associated with large IVT and negative 500 hPa height anomalies offshore, i.e., AR conditions.

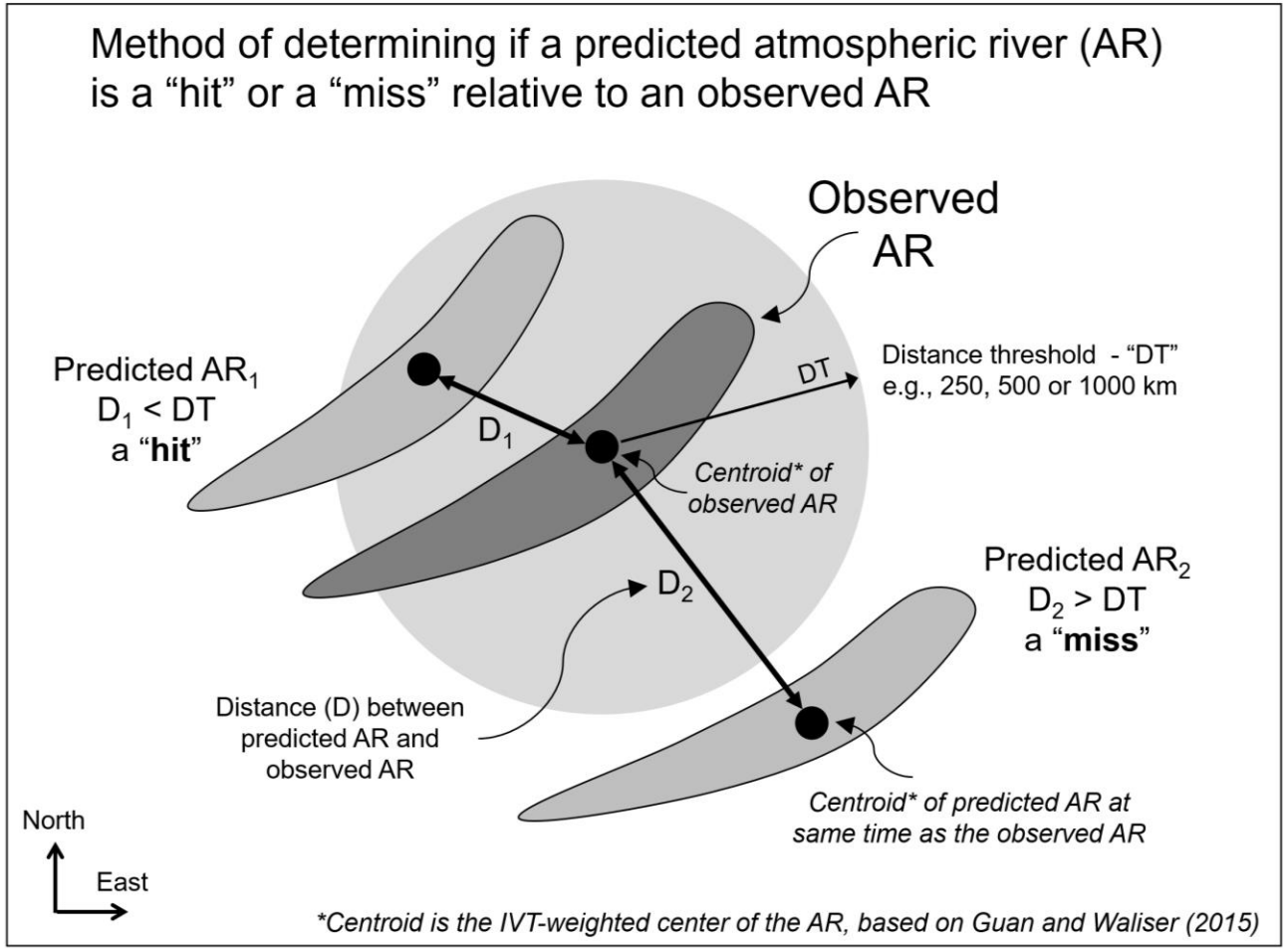


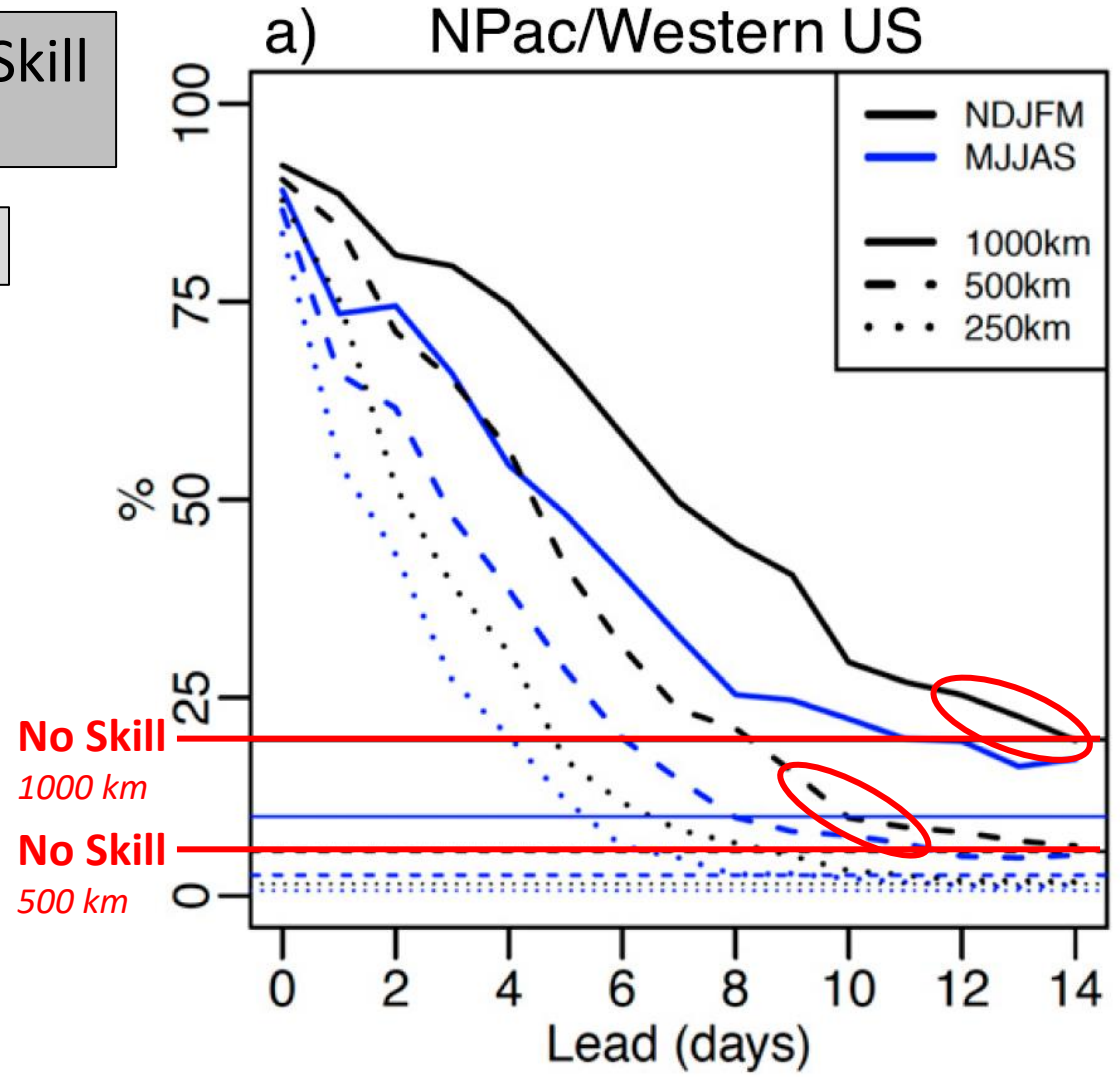
Composite mean of the 500 hPa geopotential height anomalies at the analysis time (shading, in meters) and of the ensemble mean IVT forecast anomalies (contours, dashed where less than climatology) during the 140 largest ensemble spreads on forecast day 7. Colored and contoured regions indicate areas where the composite mean is different from zero at the 90% significance level.

Global Assessment of Atmospheric River Prediction Skill

DeFlorio, Waliser, Guan, Lavers and Ralph (*JHM 2018)*

Uses ECMWF forecasts and Guana and Waliser (2015) AR Catalog

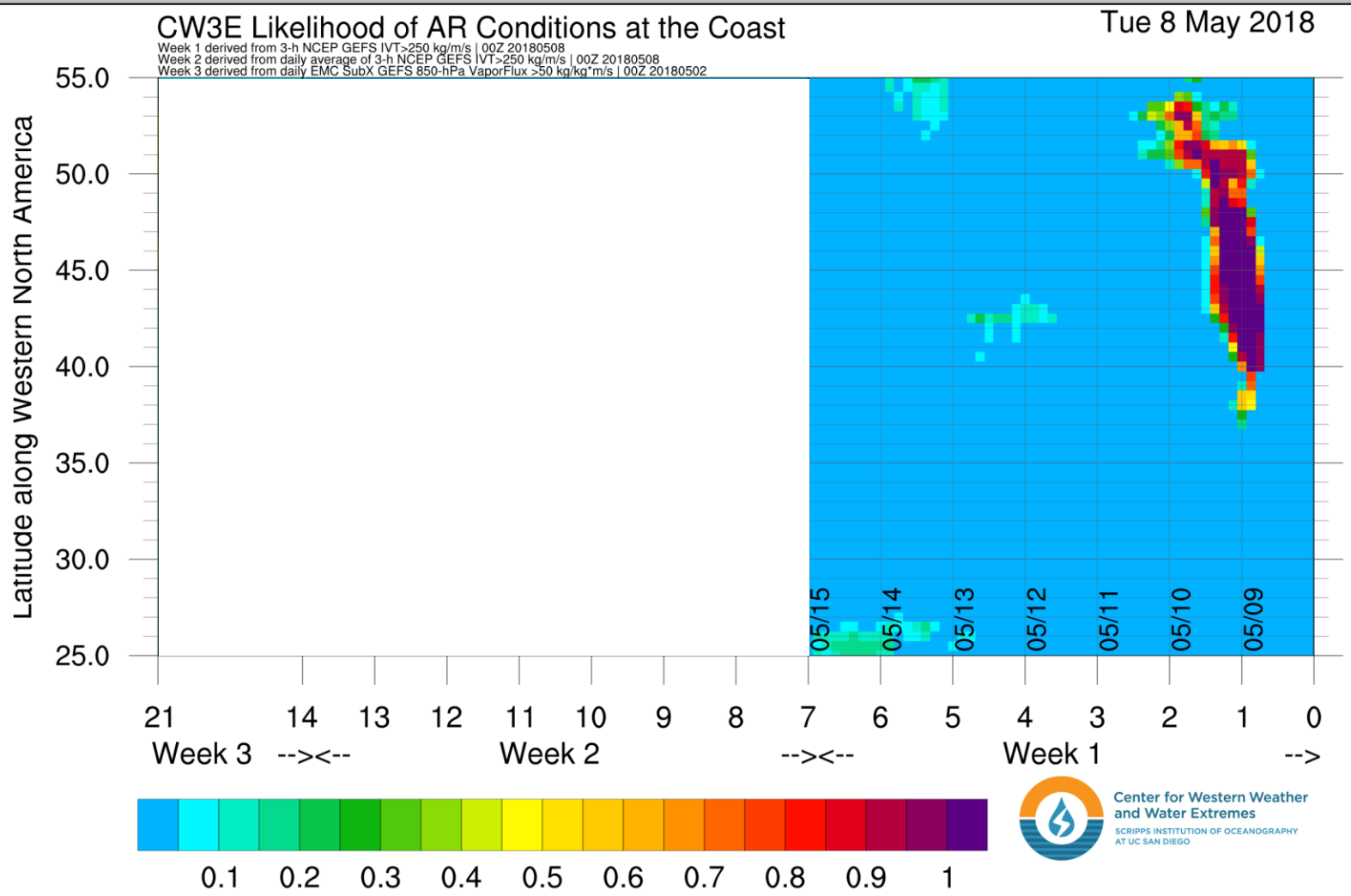




In Cool Season there is some AR forecast skill
for 500 km distance threshold out to 10 days
for 1000 km distance threshold out to 12 days

AR Landfall tool for week-1

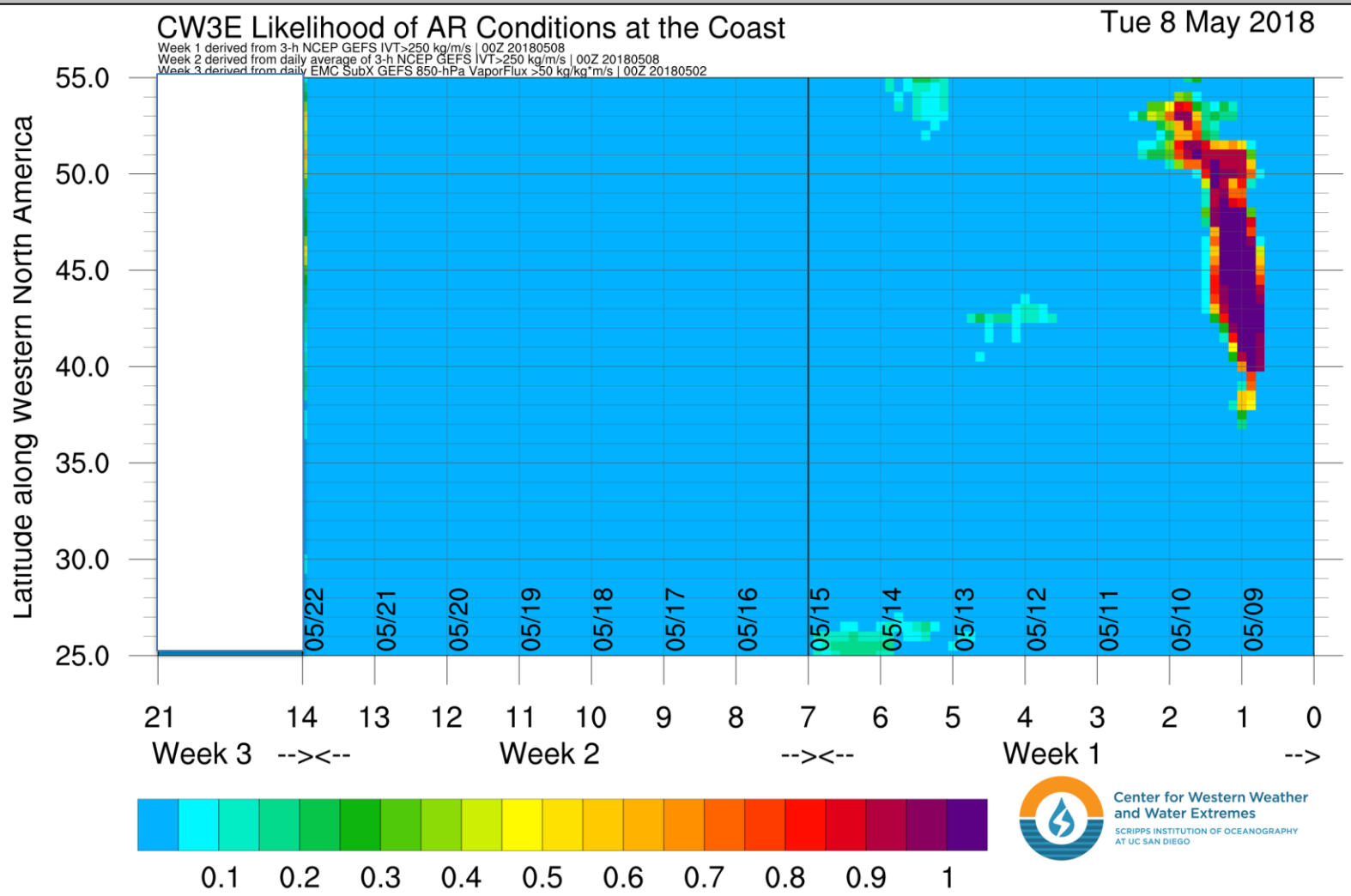
3 hourly probability values for IVT > 250 kg/m/s in week-1



J. Cordeira and F.M. Ralph

AR Landfall tool extended to week-2

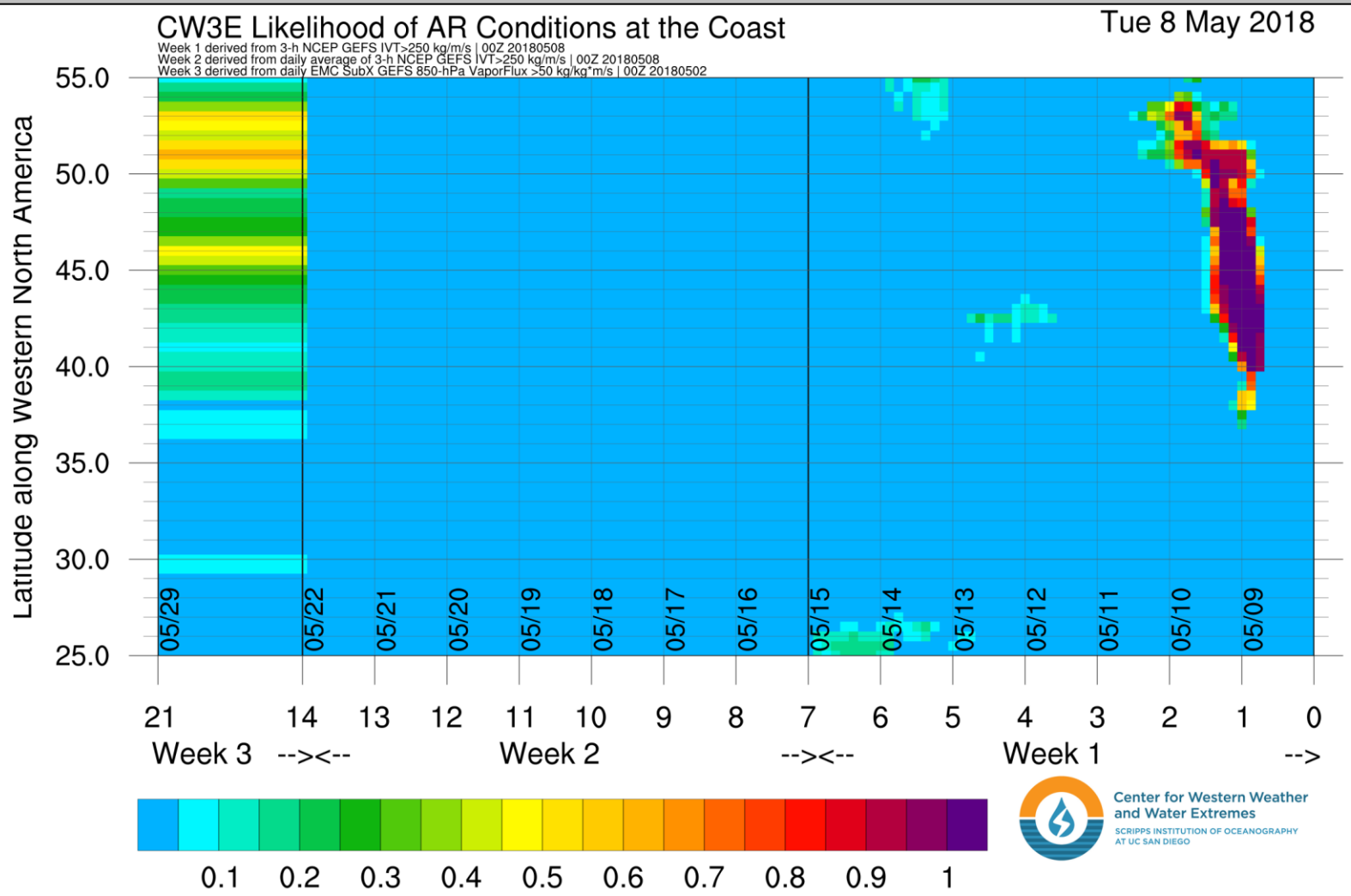
Daily probability values for IVT > 250 kg/m/s in week-2



J. Cordeira and F.M. Ralph

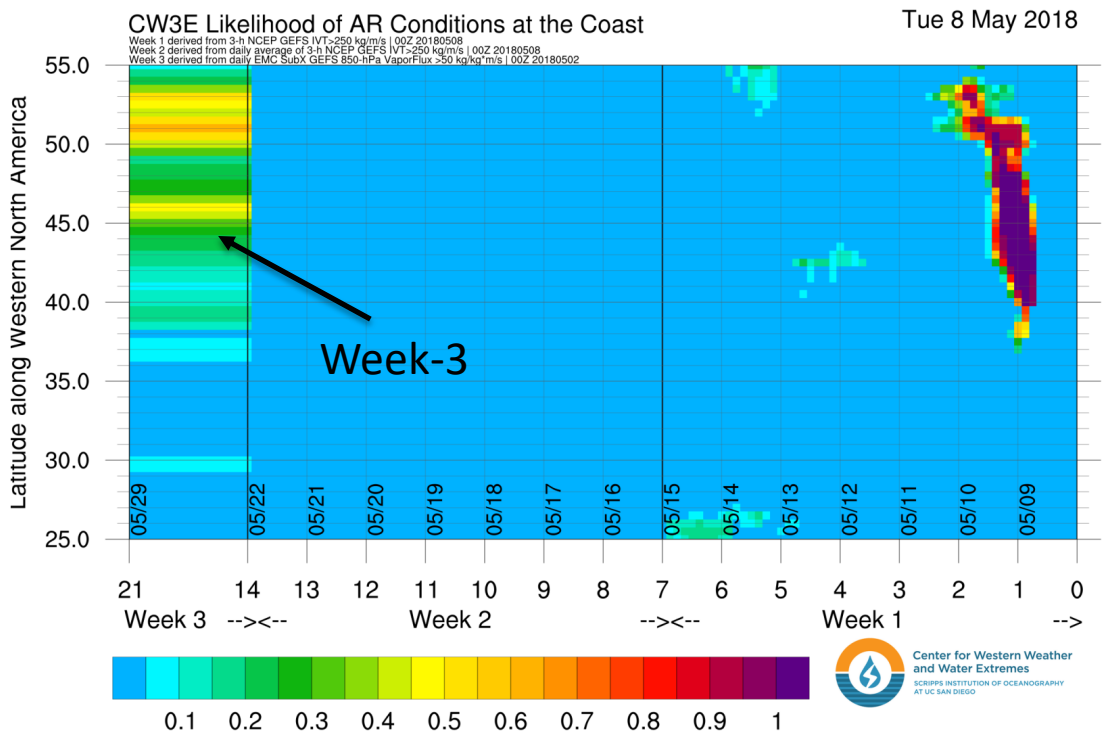
AR Landfall tool extended to week-3

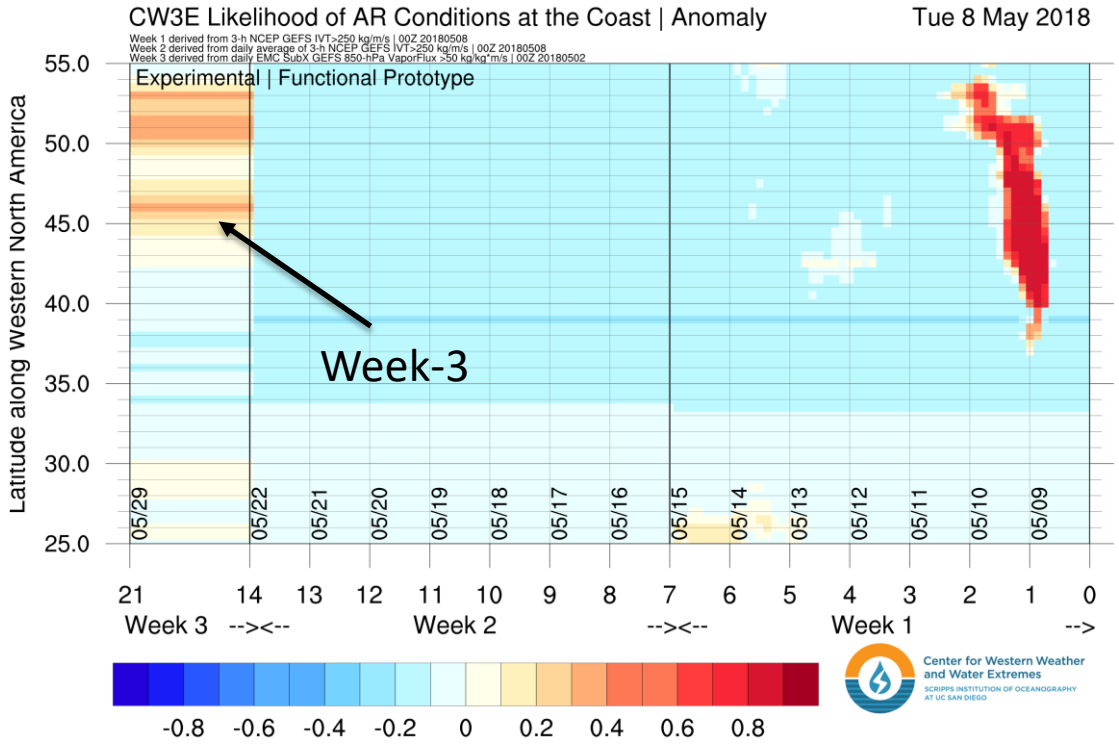
Weekly probability values for IVT > 250 kg/m/s in week-3



J. Cordeira and F.M. Ralph

AR Landfall tool extended to week-3





S2S version of AR Landfall Tool (Cordeira et al.)

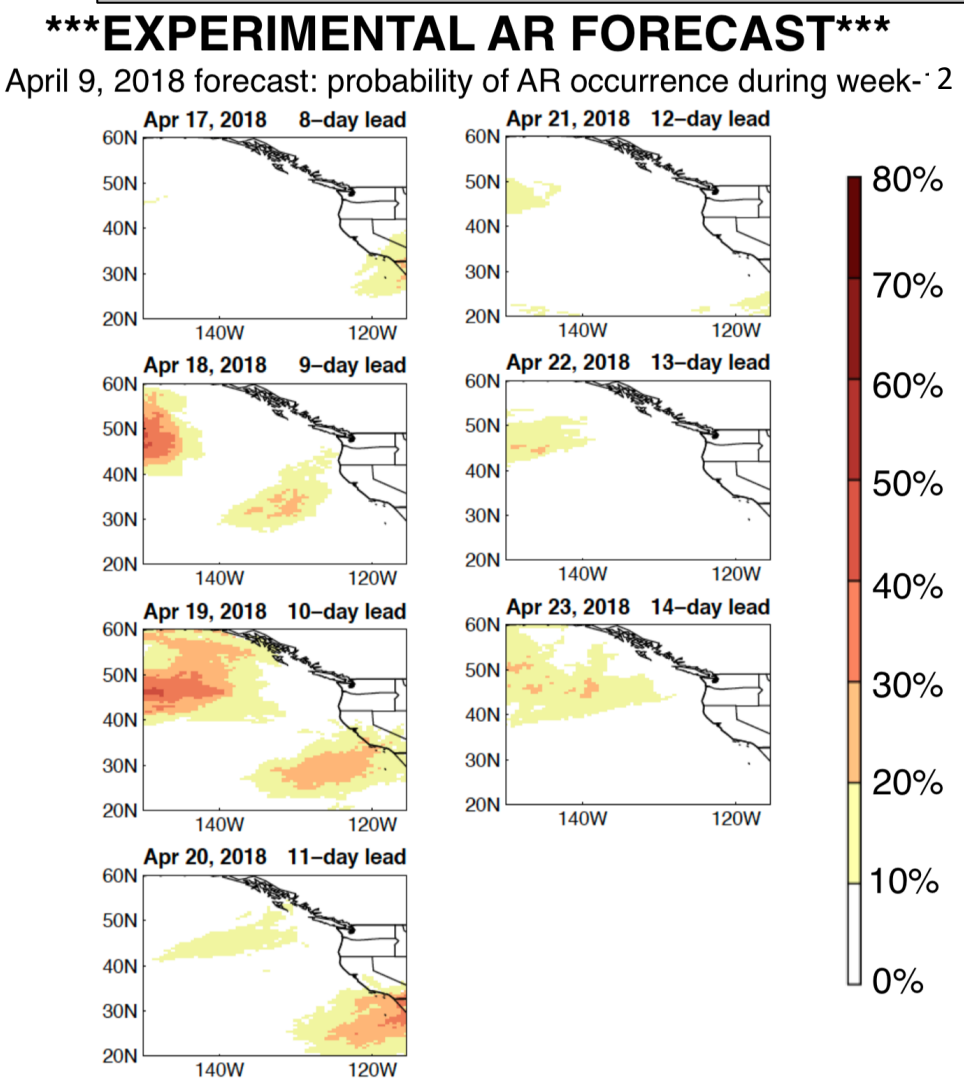
- Week-1: 3-h probability for IVT>250 kg m^{-1} s^{-1}
- Week-2: Daily probability for IVT>250 kg m^{-1} s^{-1}
- Week-3: Weekly probability values for *IVT proxy >250 kg m^{-1} s^{-1}*

S2S AR Landfall Tool minus climatology

- Probability relative to MERRA climo

Experimental AR Forecasting Research Activity
sponsored by California DWR
Contact: J. Cordeira (jcordeira@ucsd.edu)

AR Probability maps: week-2



Week-2

(8-day to 14-day lead)

ECMWF : 51 ensemble members

Experimental AR forecast issued on Monday, April 9, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

Jet Propulsion Laboratory
California Institute of Technology

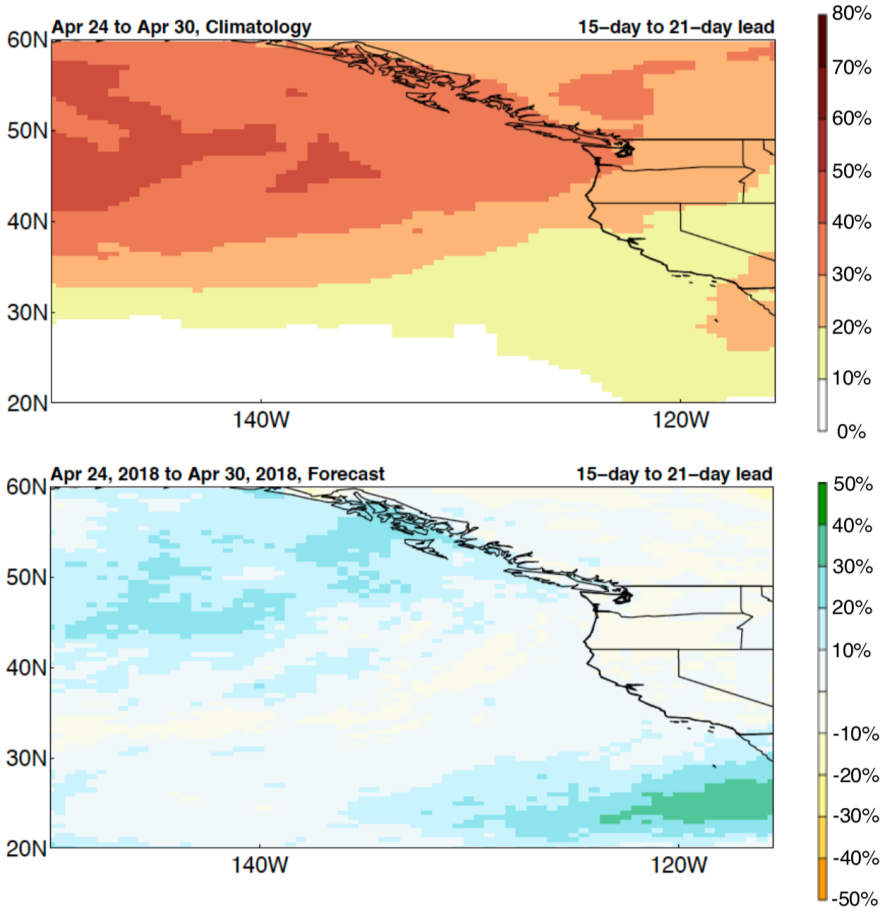
Center for Western Weather and Water Extremes

Contact: M. DeFlorio
(michael.deflorio@jpl.nasa.gov)

AR Probability maps: week-3

*****EXPERIMENTAL AR FORECAST*****

April 9, 2018 forecast: probability of AR occurrence during week-3
(chance of an AR occurring at any time during week-3)



Week-3

(Combined 15-day to 21-day lead)

Top row: hindcast climatology (ECMWF 1996-2015 data)
Bottom row: real-time forecast minus climatology (ECMWF 51-member ensemble)

Experimental AR forecast issued on Monday, April 9, 2018 by M. DeFlorio, A. Goodman, D. Waliser, B. Guan, A. Subramanian, and M. Ralph using 51-member real-time ECMWF data for an Experimental AR Forecasting Research Activity sponsored by California DWR

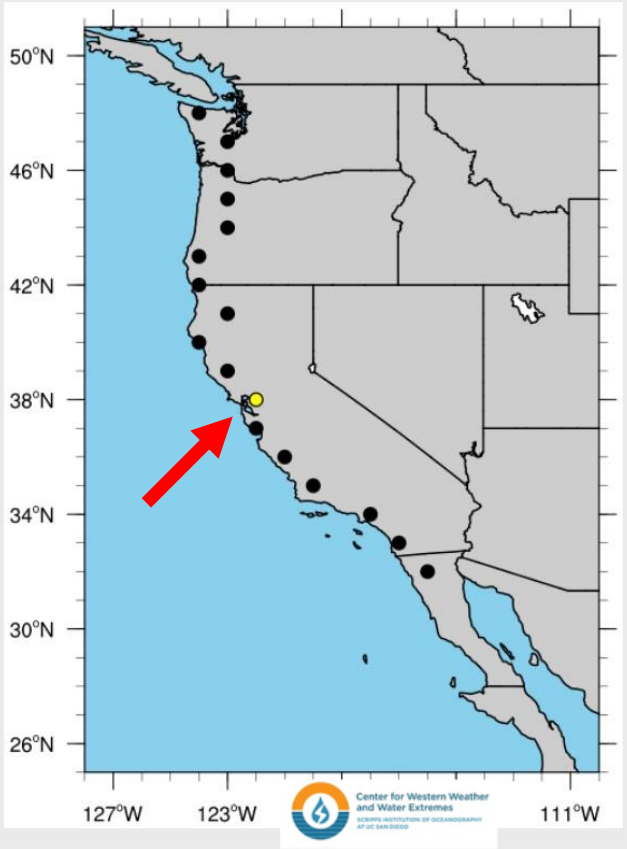
Jet Propulsion Laboratory
California Institute of Technology

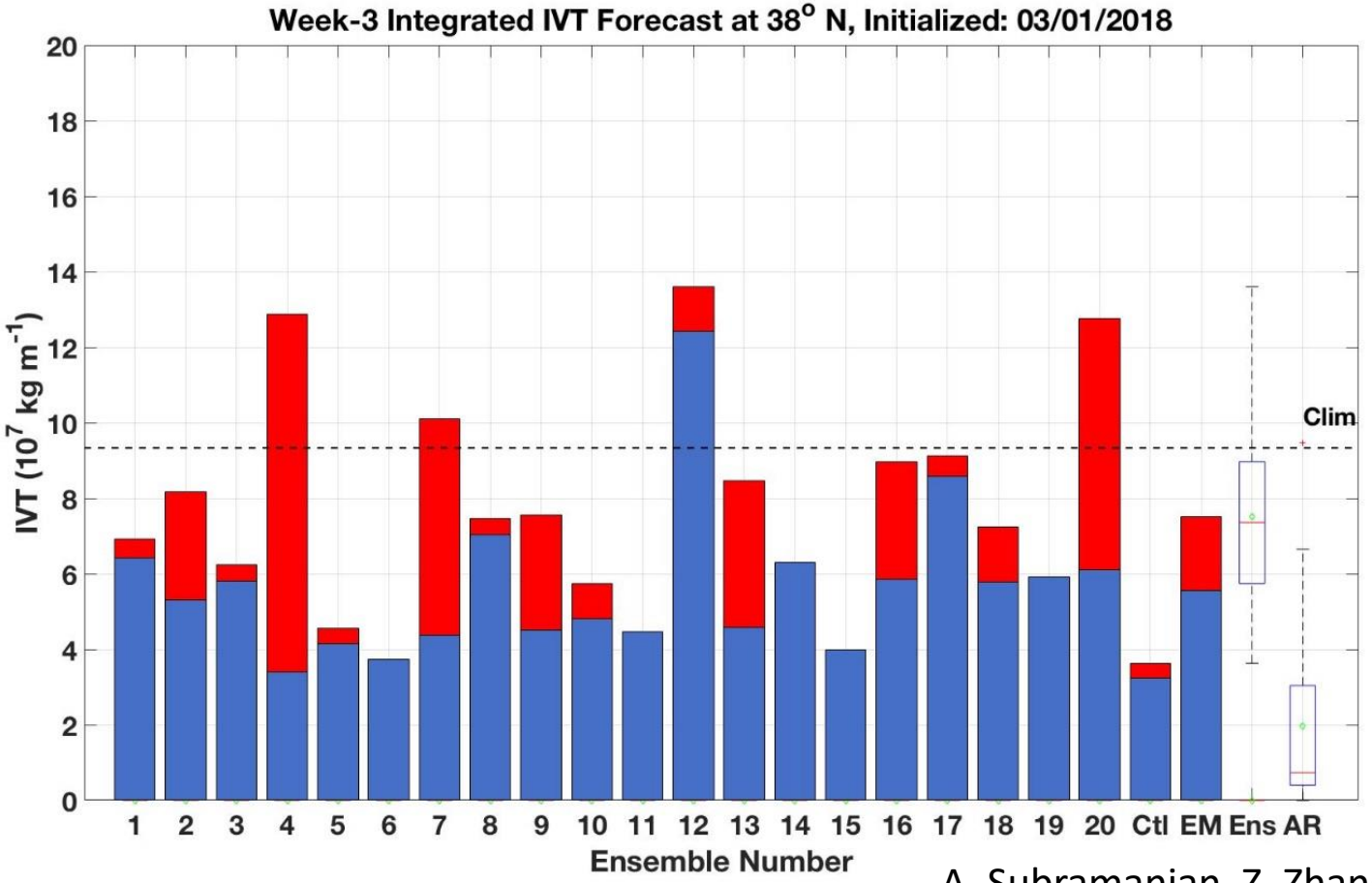
Center for Western Weather and Water Extremes

Contact: M. DeFlorio
(michael.deflorio@jpl.nasa.gov)

Week-3 Integrated Vapor Transport

Env. Canada subseasonal forecast of IVT

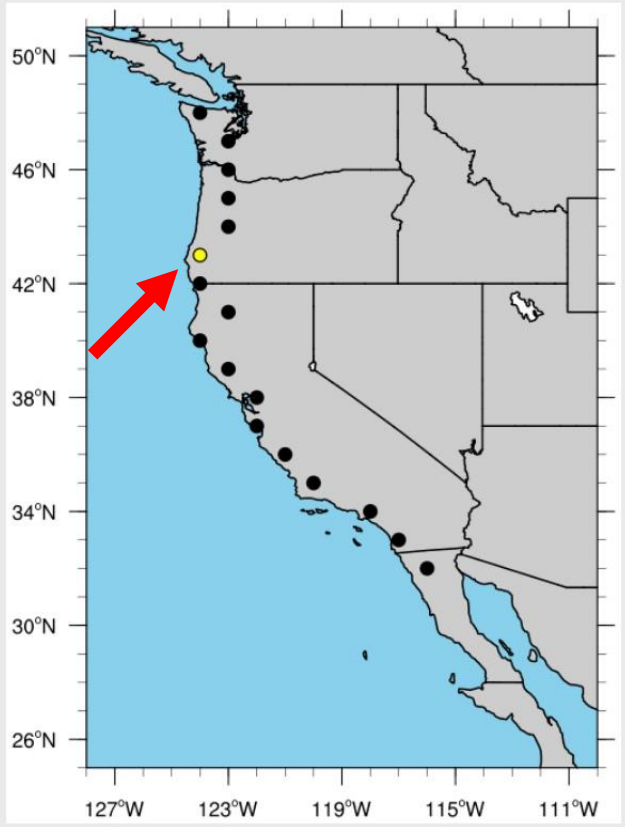


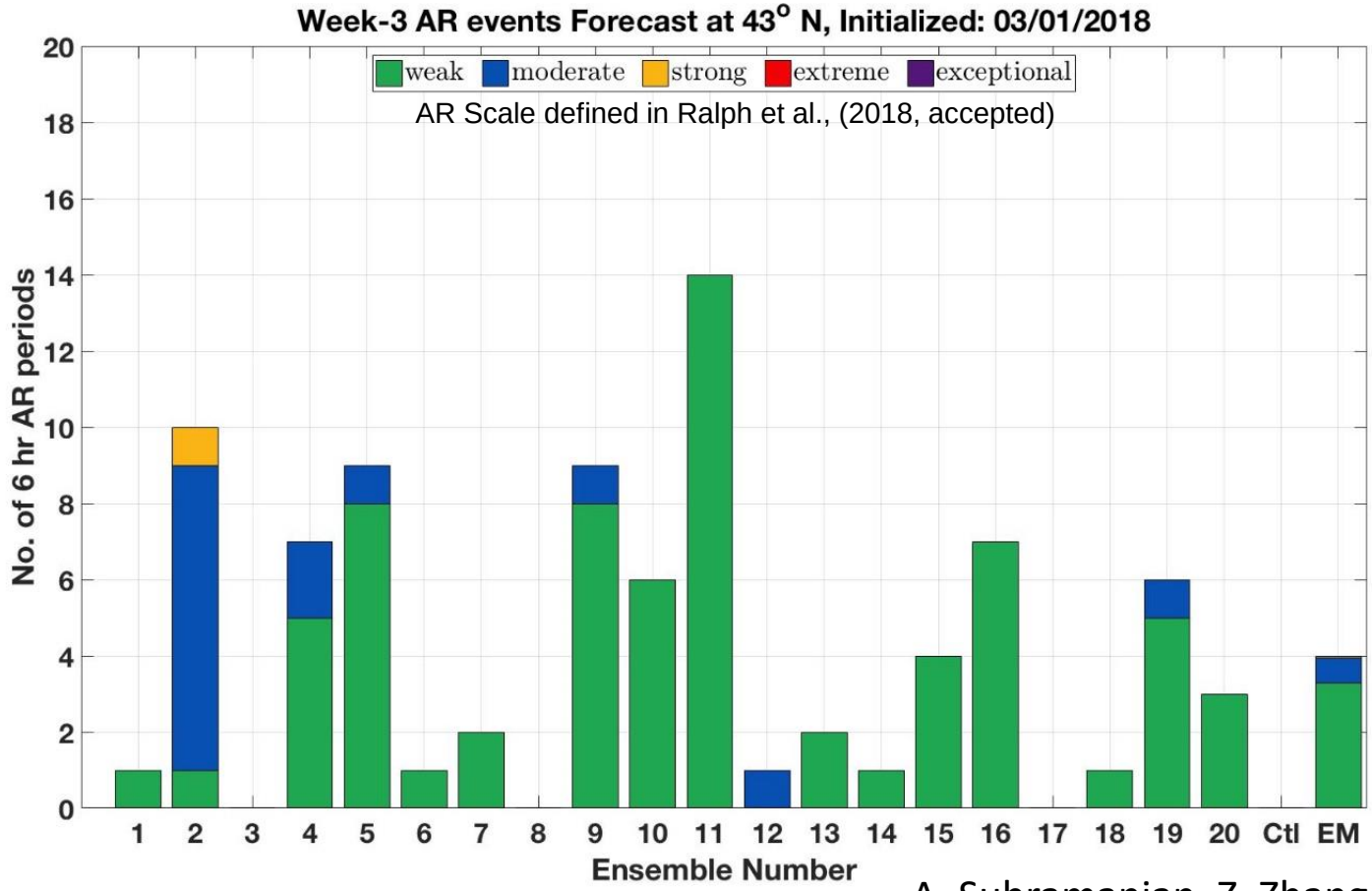


A. Subramanian, Z. Zhang et al.

Week-3 AR Activity (6 hr periods)

Env. Canada subseasonal forecast of ARs





A. Subramanian, Z. Zhang et al.

Mundhenk et al. (2018) introduced an empirical model for predicting anomalous AR activity at S2S leads based on the phase of the MJO and QBO.

Results showed the potential for skillful "forecasts of opportunity" at leads greater 2 weeks, the point beyond which dynamical models provide little additional skill.

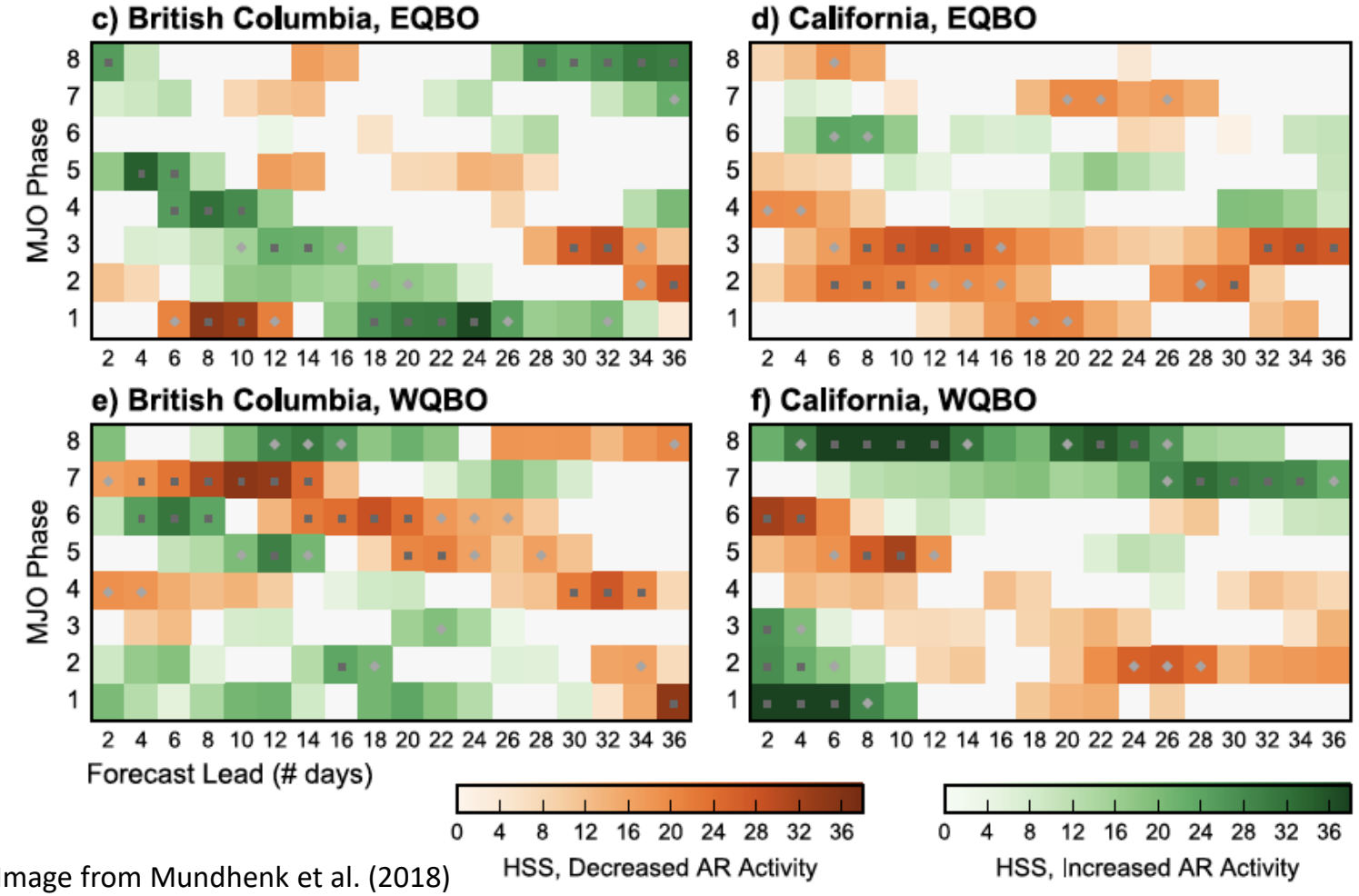


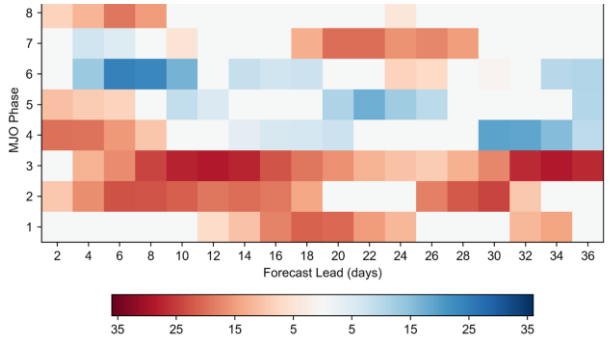
Image from Mundhenk et al. (2018)

The empirical model has been modified to forecast anomalous water vapor transport.

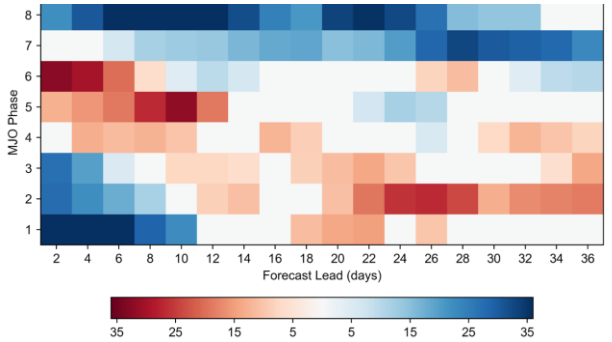
This model is also being modified to make precipitation forecasts.

AR Counts

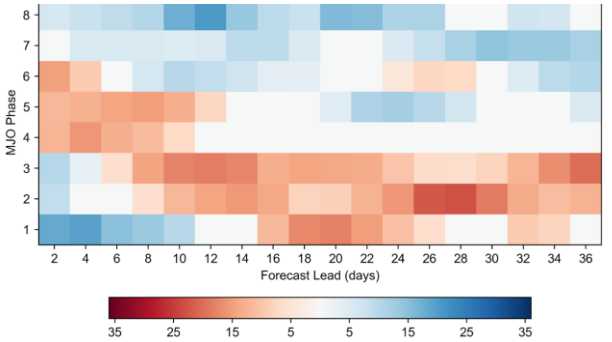
HSS for AR Count Forecasts
CA (EQBO)



HSS for AR Count Forecasts
CA (EQBO)

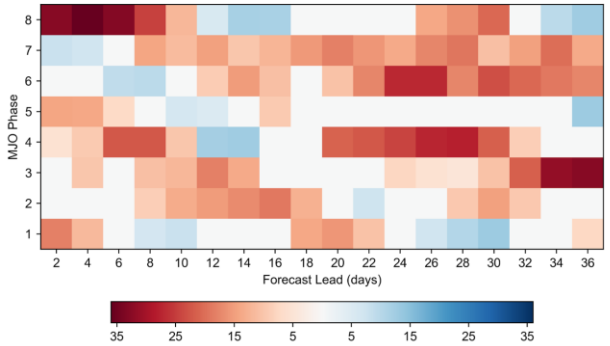


HSS for AR Count Forecasts
CA (QBO Independent)

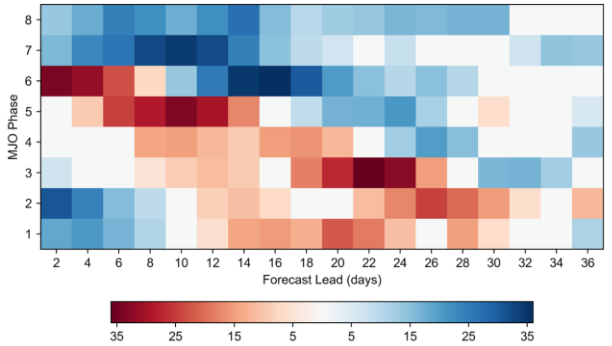


IVT

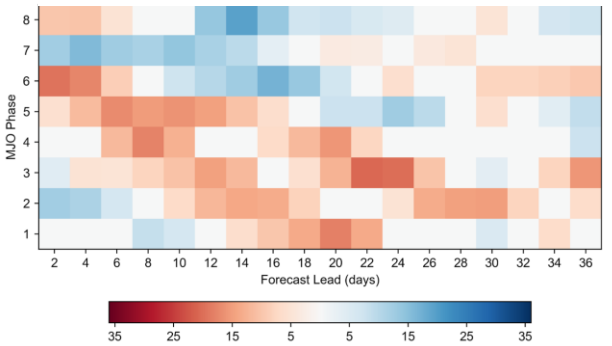
HSS for IVT Forecasts
CA (EQBO)



HSS for IVT Forecasts
CA (WQBO)



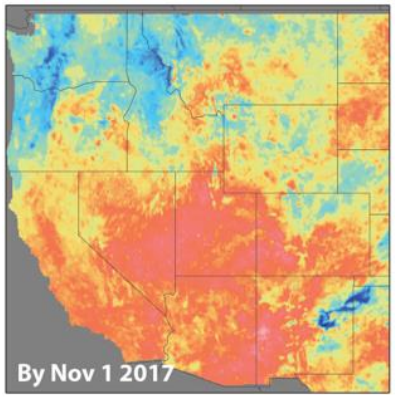
HSS for IVT Forecasts
CA (QBO Independent)



Odds of Reaching Water Year Normal

ODDS OF WY2018 REACHING 100% OF WATER-YEAR NORMAL PRECIPITATION TOTALS

[based on PRISM monthlies; normal = average of WY1981-2010]



Odds, in percent of the 70 wyears from 1948-2017

0 10 20 30 40 50 60 70 80 90 100

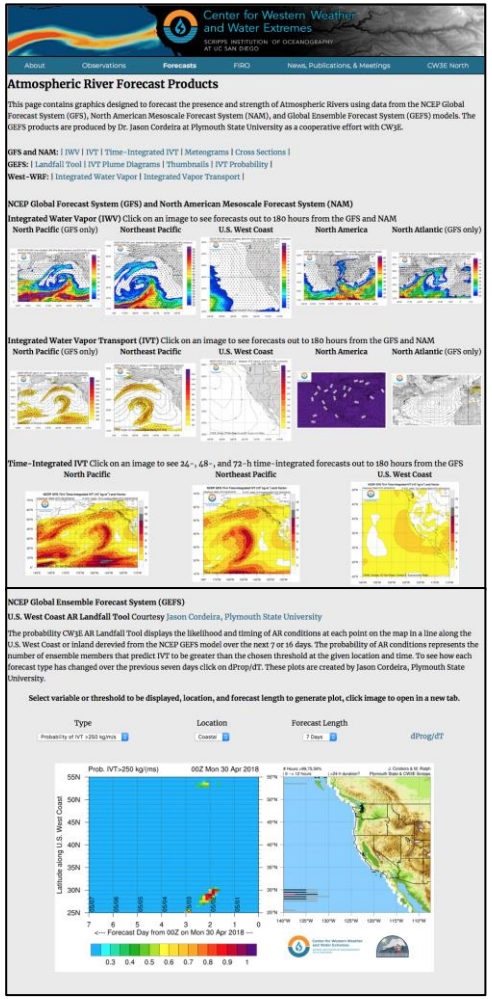
Evolution of the 2018 water year in terms of the odds of reaching 100% of normal precipitation by the end of the water year (30 Sep, 2018)

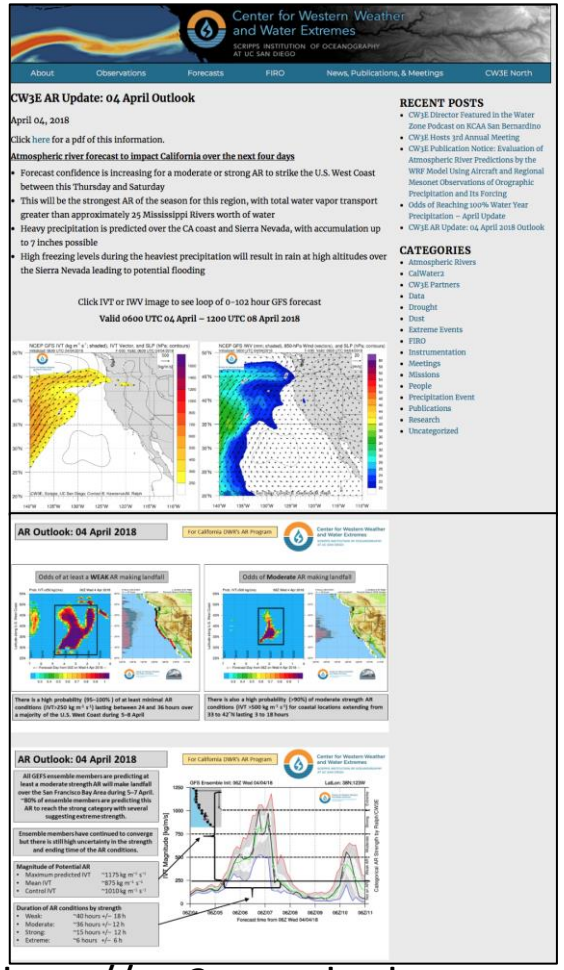
CW3E
Center for Western Weather and Water Extremes
For info: mddettin@usgs.gov

AR Forecasting at Short-Term Lead Times

AR Monitoring and Prediction Tools

- CW3E maintains a growing number of AR monitoring & prediction tools
- Expanding to include more decision support tools, interactive analyses and forecast, watershed-scale tools, pre-event outlooks, and post-event analyses
- Not just ARs





http://cw3e.ucsd.edu

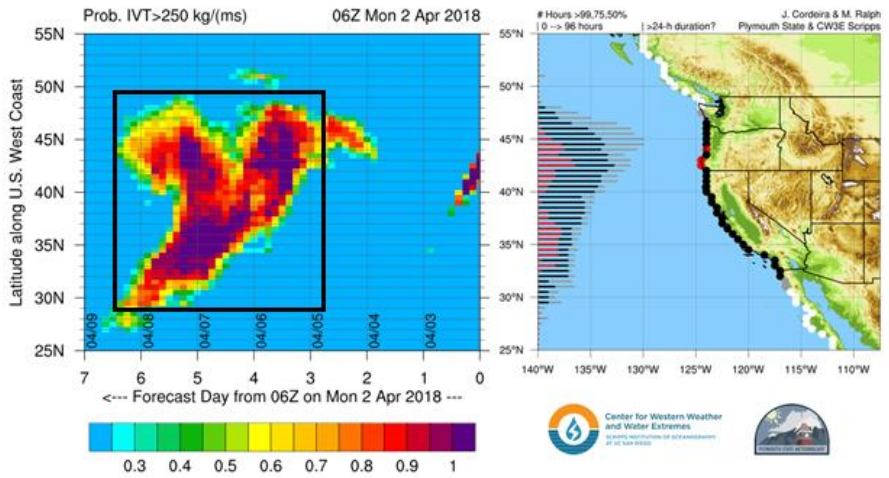
AR Monitoring and Prediction Tools

AR Outlook: 02 April 2018

For California DWR's AR Program

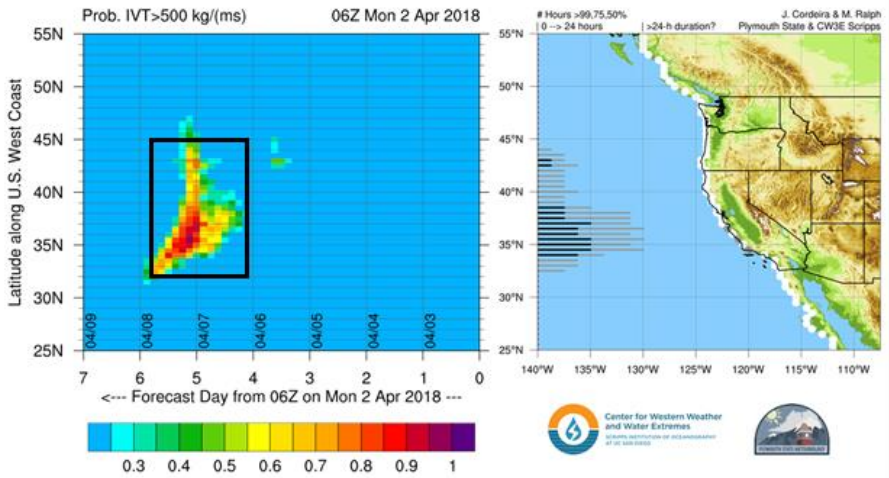
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Odds of at least a **WEAK** AR making landfall



- There is a high probability (95–100%) of AR conditions (IVT>250 kg m^{-1} s^{-1}) lasting between 24 and 36 over a majority of the U.S. West Coast

Odds of **Moderate** AR making landfall



- There is also a high probability (~90%) of moderate strength AR conditions (IVT >500 kg m^{-1} s^{-1}) for coastal locations extending from 34 to 39°N lasting 3 to 12 hours

Outlook by Hecht, Ralph, and Kawzenuk 2 April 2018

AR Monitoring and Prediction Tools

AR Outlook: 03 April 2018

For California DWR's AR Program

Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

There is high confidence that at least weak AR conditions will occur over the San Francisco Bay area for over 24 hours. Most ensemble members are suggesting this could be a strong AR with several forecasting for extreme conditions

While the ensemble members have converged over the past 24 hours the latest model run still shows uncertainty in the onset, duration, and magnitude of this AR

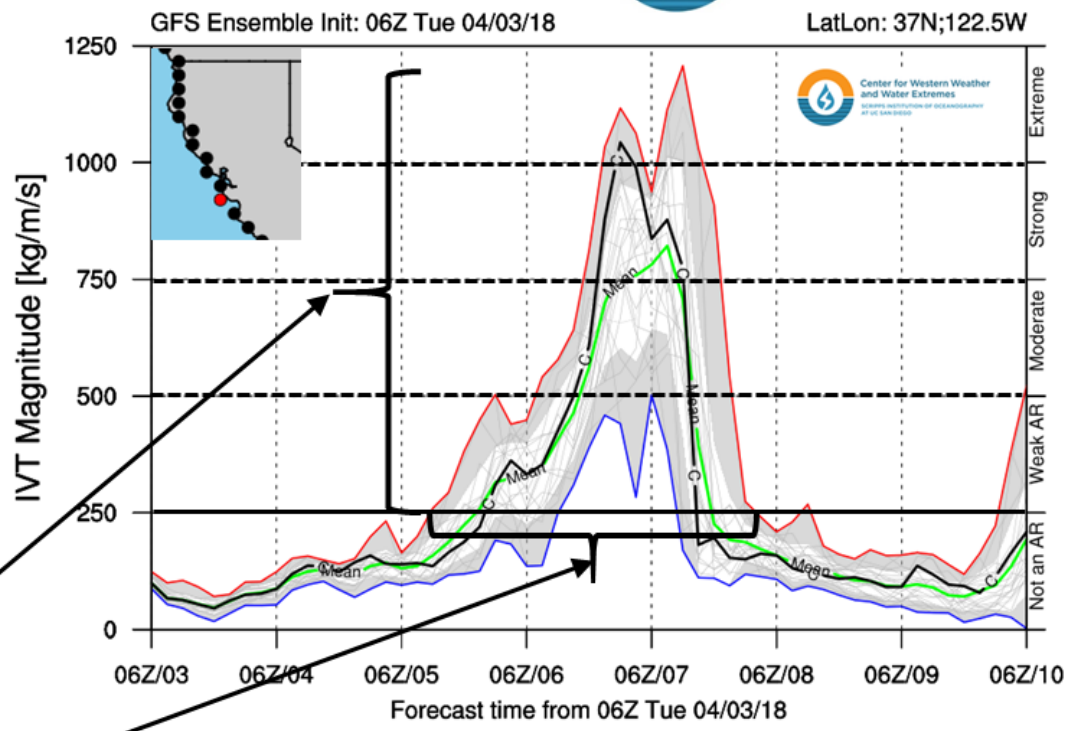
The control member has increased by ~100 kg m^{-1} s^{-1} at this location since yesterday's update

Magnitude of Potential AR

- Maximum predicted IVT ~1200 kg m^{-1} s^{-1}
- Mean IVT ~800 kg m^{-1} s^{-1}
- Control IVT ~1050 kg m^{-1} s^{-1}

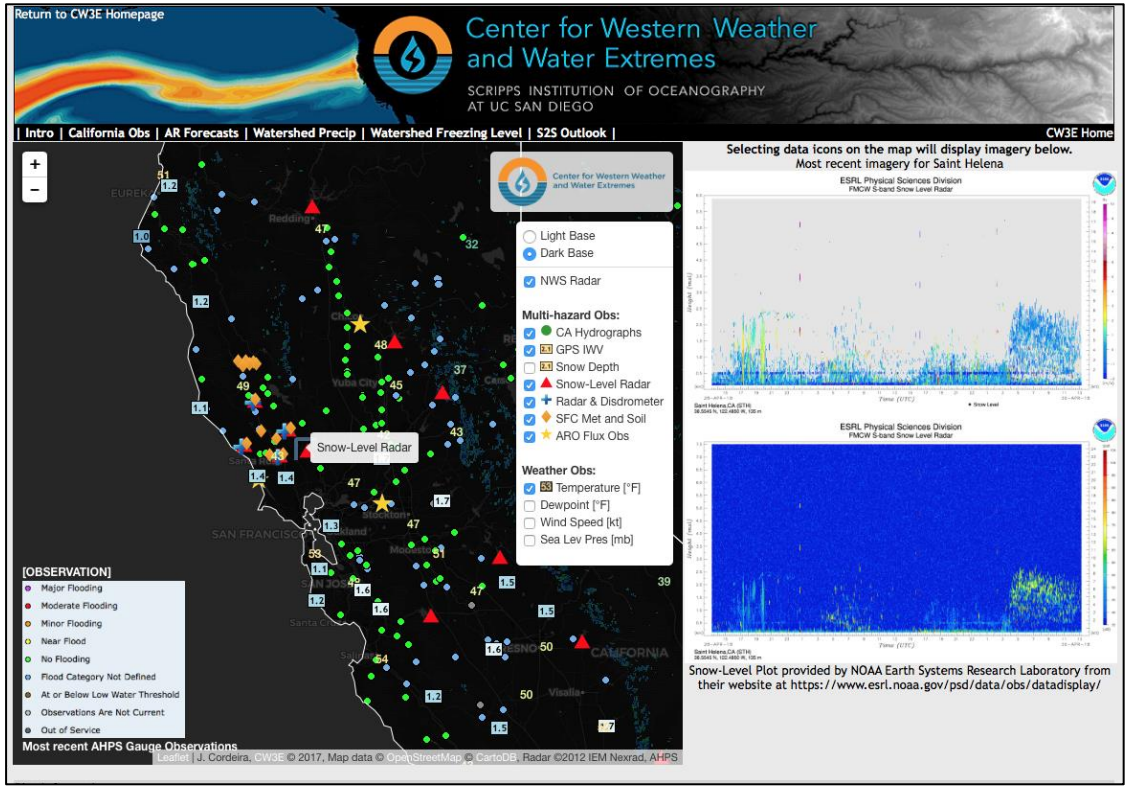
Duration of AR conditions by strength

- Weak: ~36 hours +/– 18 h
- Moderate: ~24 hours +/– 12 h
- Strong: ~18 hours +/– 12 h
- Extreme: ~6 hours +/– 6 h

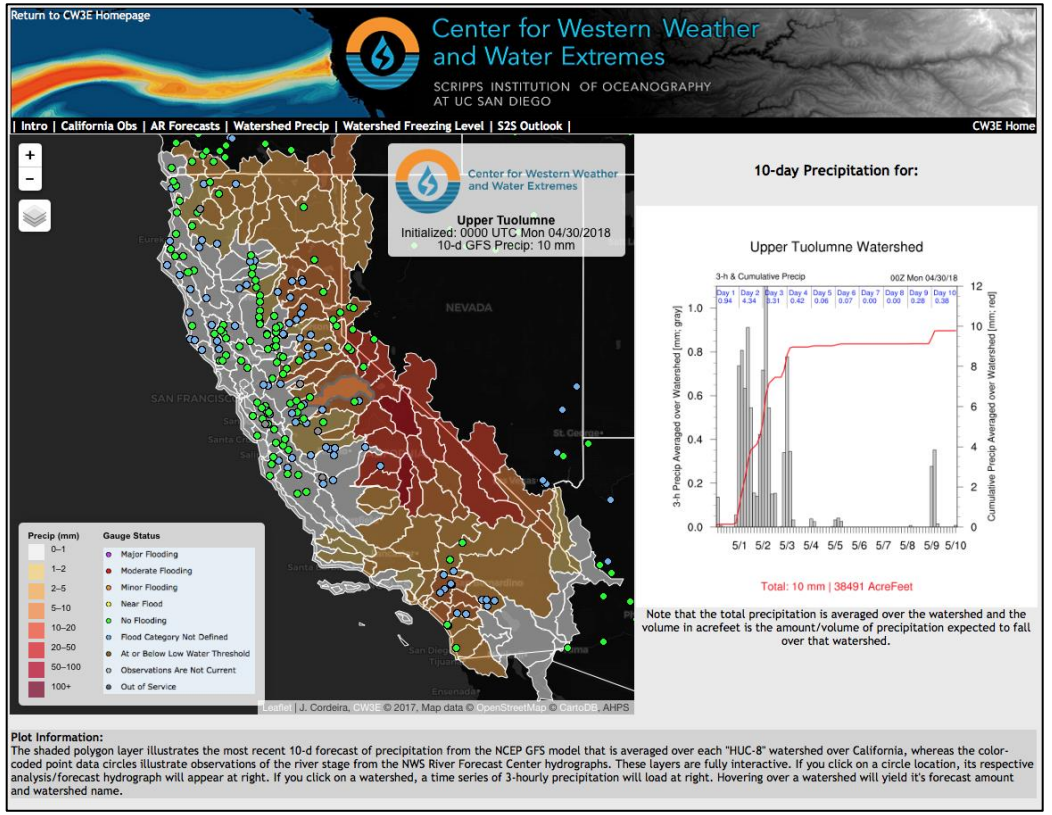


Outlook by Kawzenuk, Ralph, and Hecht 3 April 2018

AR Monitoring and Prediction Tools

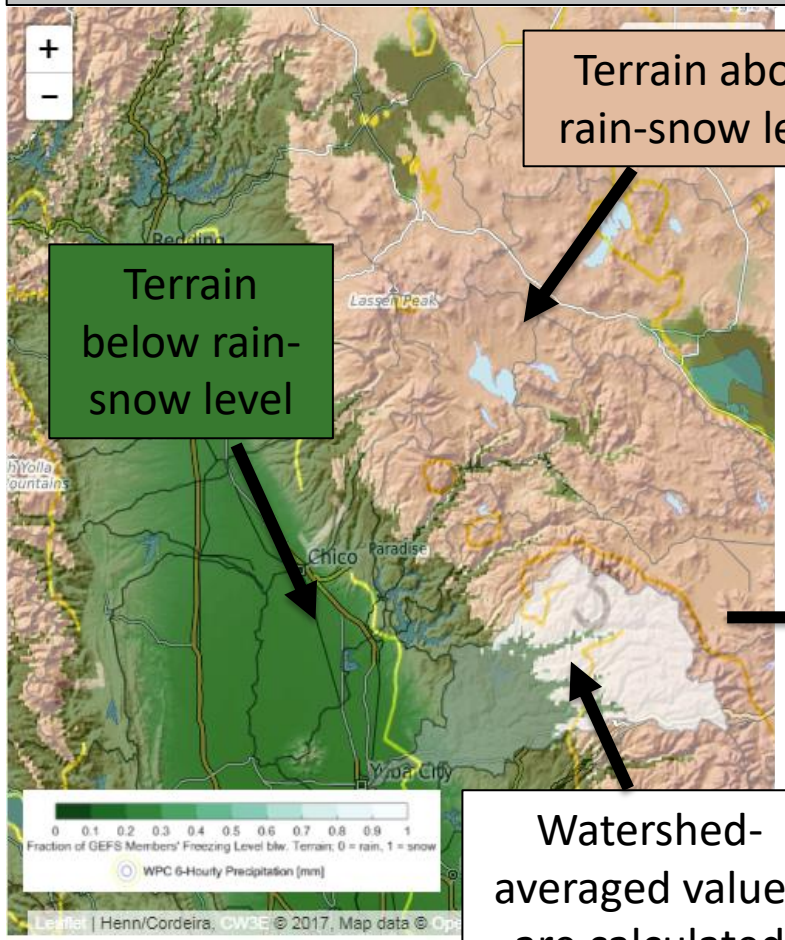


Interactive 21st century California Observing Network data portal (data provided by multiple sources, including NOAA)



Interactive watershed-by-watershed GFS precipitation forecasts and NWS/CNRFC hydrologic analyses

AR Rain-Snow Forecast Tool



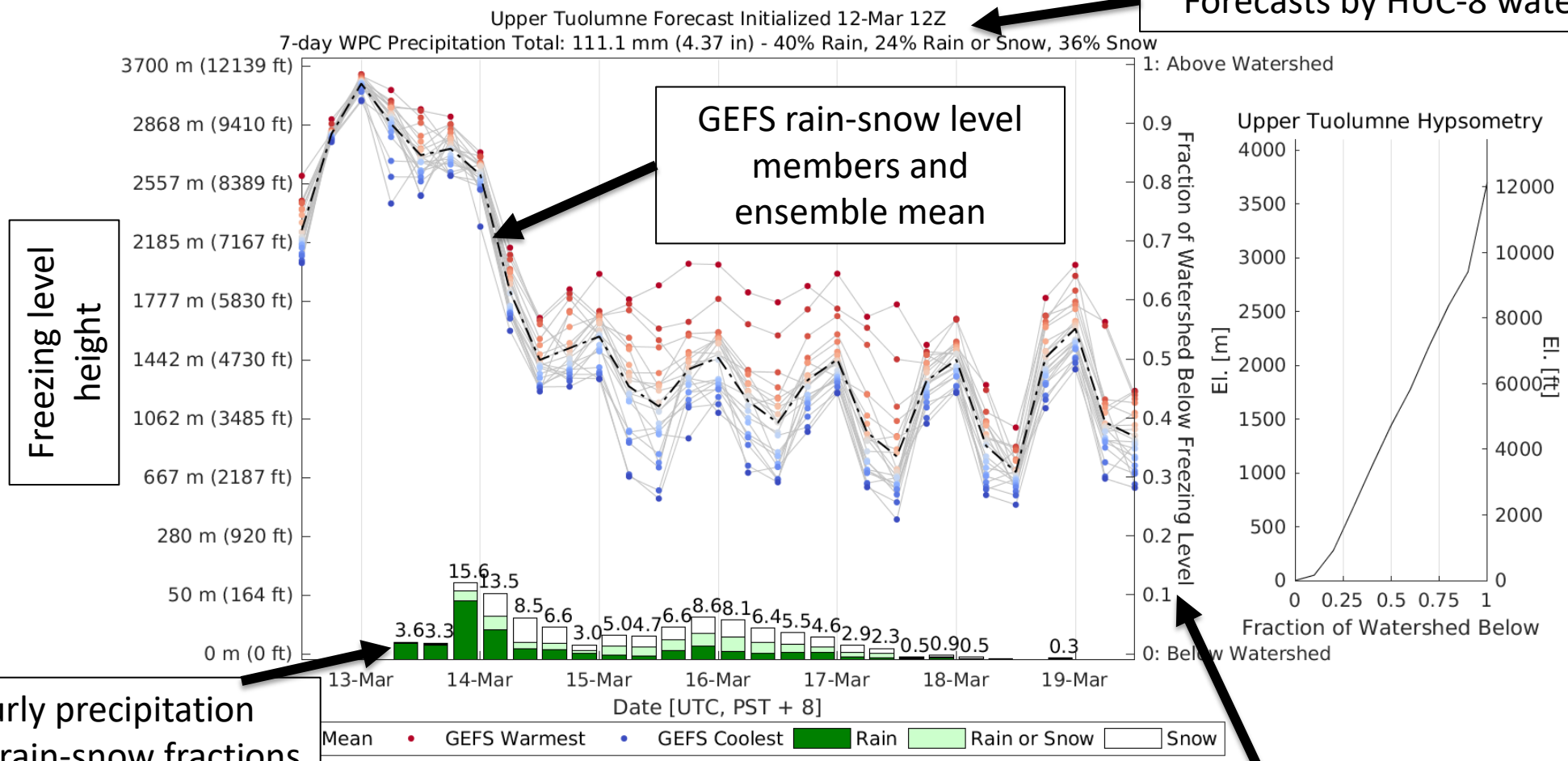
Terrain above rain-snow level

Terrain below rain-snow level

Watershed-averaged values are calculated

AR Rain-Snow Forecast Tool

Forecasts by HUC-8 watershed



Freezing level height

GEFS rain-snow level members and ensemble mean

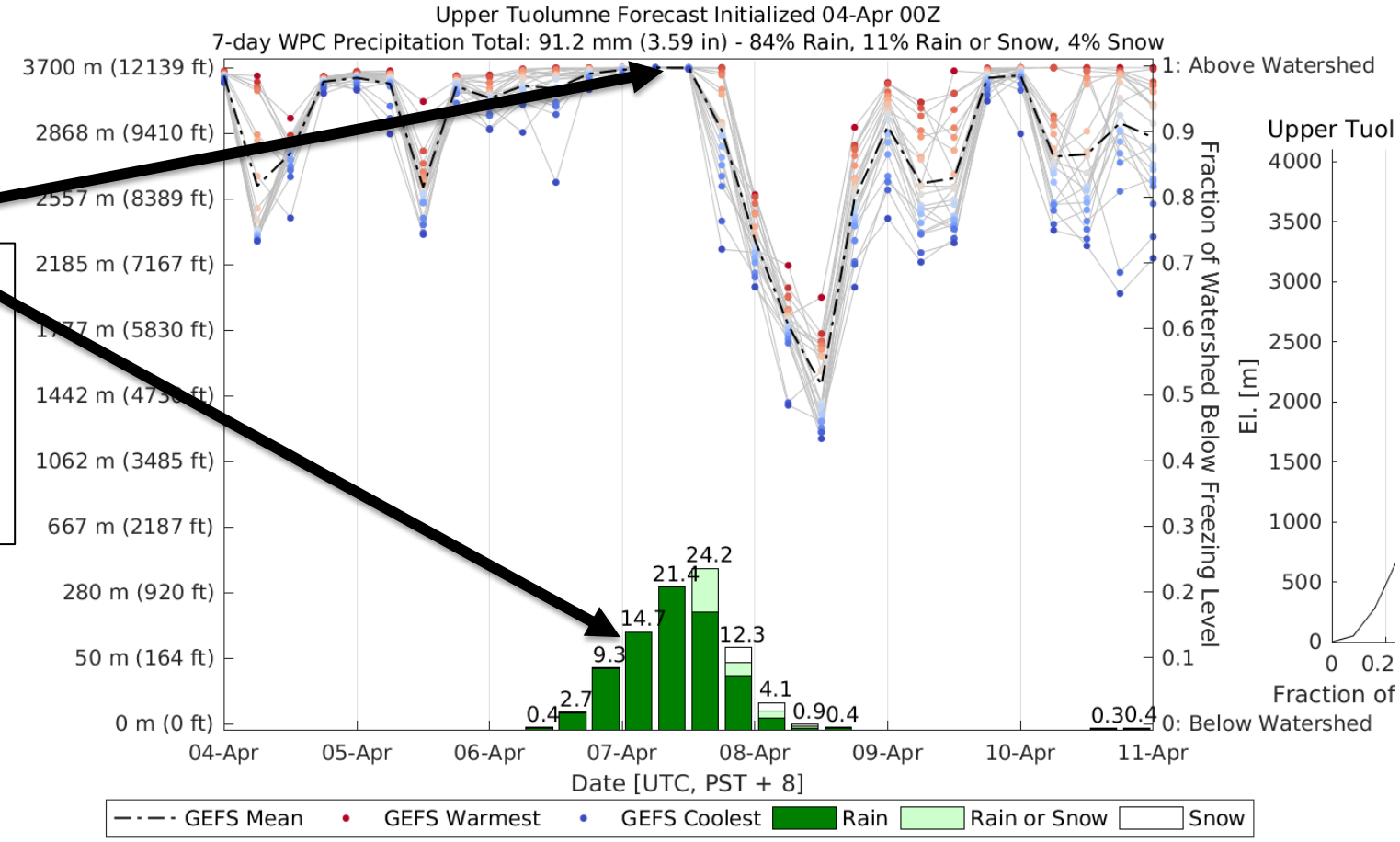
WPC 6-hourly precipitation amounts and rain-snow fractions

Freezing level height expressed as fraction of watershed below rain-snow level

April 6-7 Atmospheric River Forecast

Forecast for warm AR with 4” precipitation in Sierra Nevada and >12kft rain-snow level

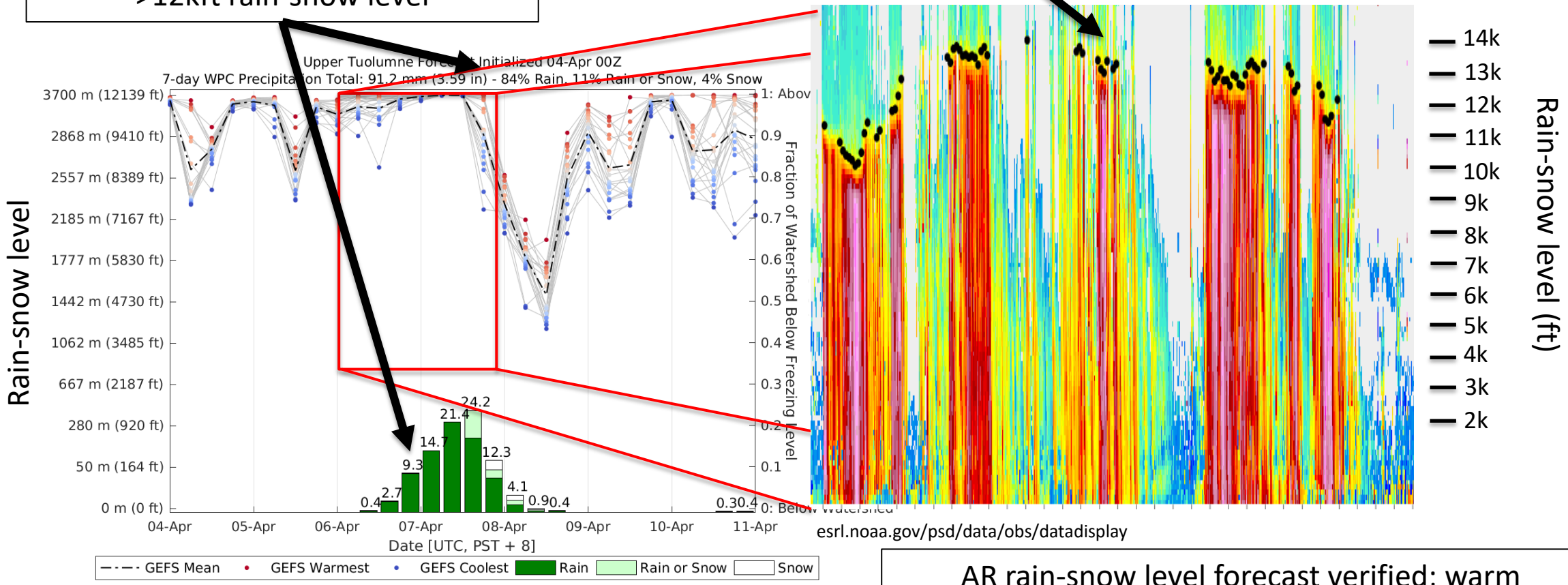
Rain-snow level



April 6-7 Atmospheric River Forecast

Forecast for warm AR with 4” precipitation in Sierra Nevada and >12kft rain-snow level

Observed rain-snow level nearly 13kft at New Exchequer radar



esrl.noaa.gov/psd/data/obs/datadisplay

AR rain-snow level forecast verified; warm temperatures associated with heavy precipitation, snowmelt, and flooding in Sierra Nevada

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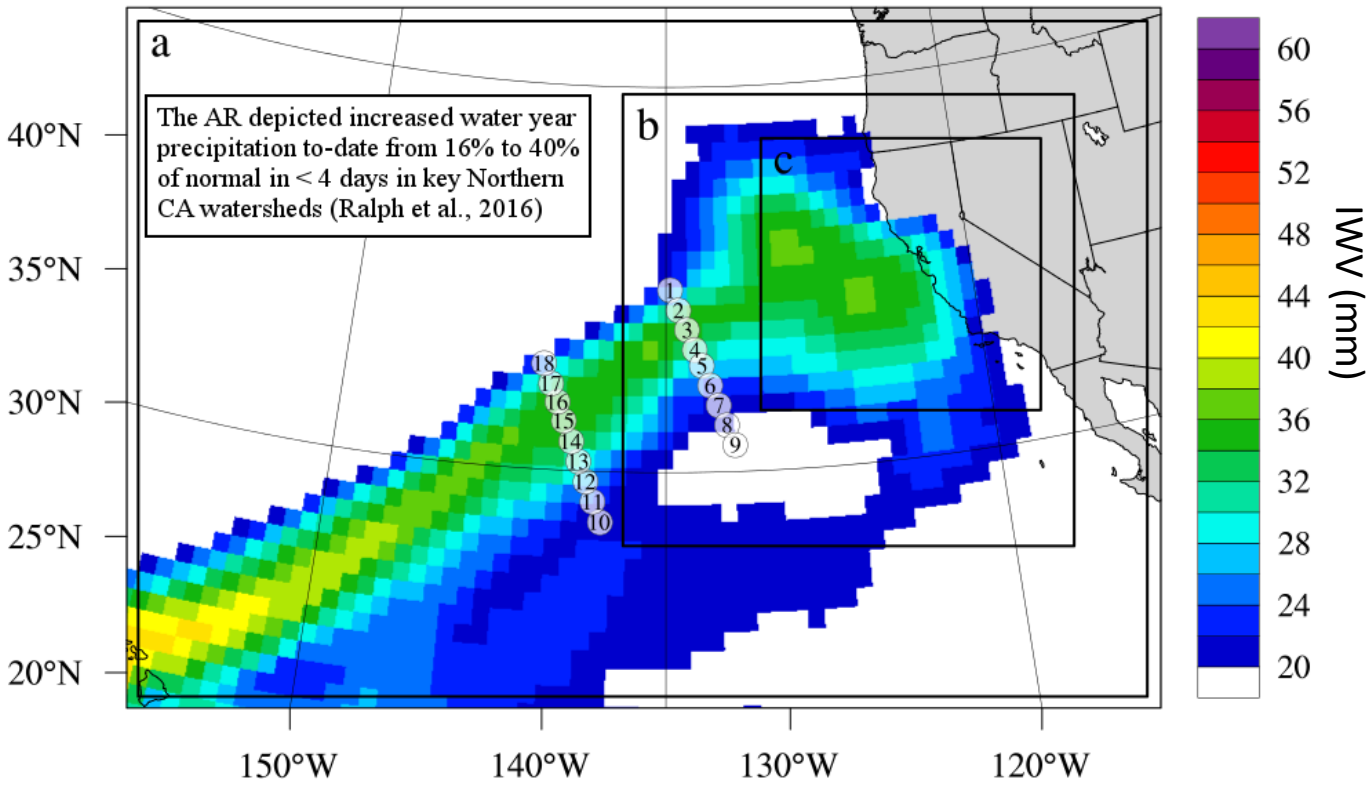
Provided by Brian Henn

Evaluation of Atmospheric River Predictions by the WRF Model Using Aircraft and Regional Mesonet Observations of Orographic Precipitation and Its Forcing

Andrew Martin, F Martin Ralph, Reuben Demirdjian, Laurel DeHaan, Rachel Weihs, John Helly, David Reynolds, Sam Iacobellis. *Journal of Hydrometeorology,* https://doi.org/10.1175/JHM-D-17-0098.1

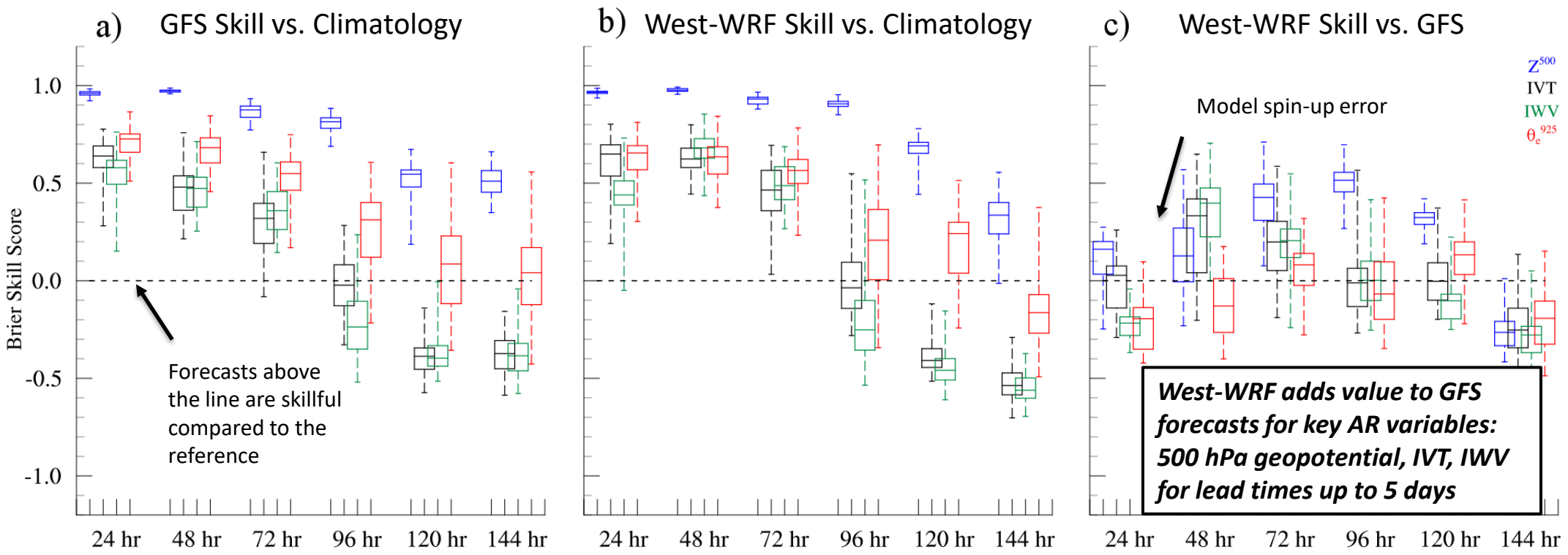


15 aircraft transects of AR were used to measure skill in West-WRF and GFS forecasts.

The data, comprising 191 dropsondes in total, were provided by the CalWater experiments of 2014-2015
(Ralph et al. 2016 *Bull. Amer. Meteor. Soc.)*

Evaluation of Atmospheric River Predictions by the WRF Model Using Aircraft and Regional Mesonet Observations of Orographic Precipitation and Its Forcing

Andrew Martin, F Martin Ralph, Reuben Demirdjian, Laurel DeHaan, Rachel Weihs, John Helly, David Reynolds, Sam Iacobellis. *Journal of Hydrometeorology,* https://doi.org/10.1175/JHM-D-17-0098.1



West-WRF adds value to GFS forecasts for key AR variables: 500 hPa geopotential, IVT, IWV for lead times up to 5 days

From 15 dropsonde cross sections offshore using 191 dropsondes from aircraft during CalWater -2014 and -2015

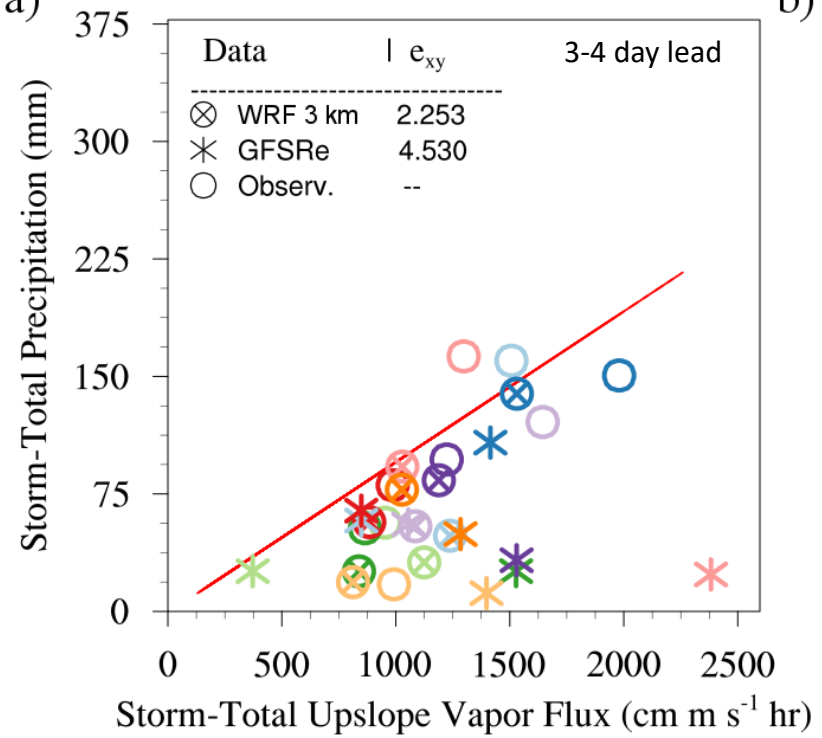
Evaluation of Atmospheric River Predictions by the WRF Model Using Aircraft and Regional Mesonet Observations of Orographic Precipitation and Its Forcing

The simulated relationship between AR upslope-directed vapor flux and precipitation was compared to the observed relationship for 10 moderate AR between 2014-2016. GFS and West-WRF were evaluated.

This same evaluation has been made for other high-res models (e.g. NAM 3km and 12 km) for select recent AR. West-WRF consistently performs best at preserving this first-order driver of orographic precip.

West-WRF Forecasts are more skillful in orographic precipitation during landfalling AR

a)



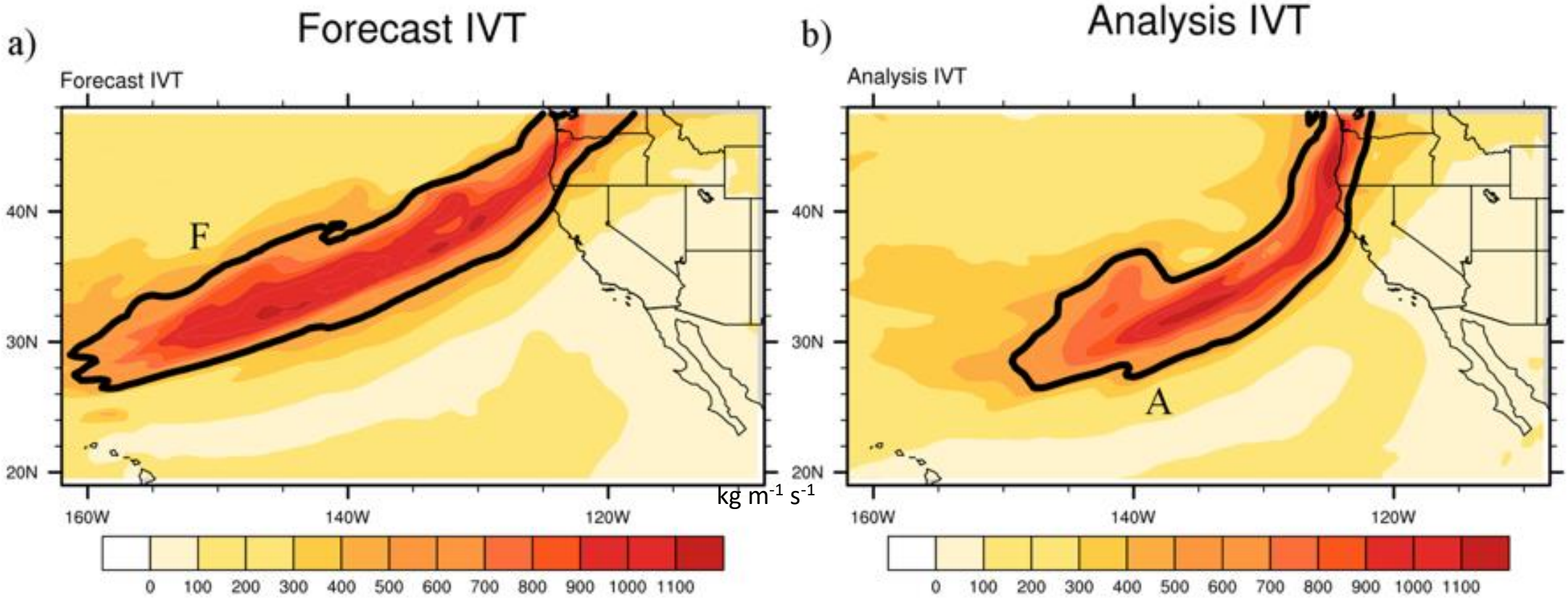
b)

Normalized Combined Error in Storm-Total Precipitation and Upslope Flux

Lead Time (days)	West-WRF	GFSRe
1 - 2	0.82	4.29
3 - 4	2.25	4.53
5 - 6	4.65	7.37

This, along with the previous finding, demonstrate that ***West-WRF better simulates AR properties offshore and the orographic component of precipitation onshore***.

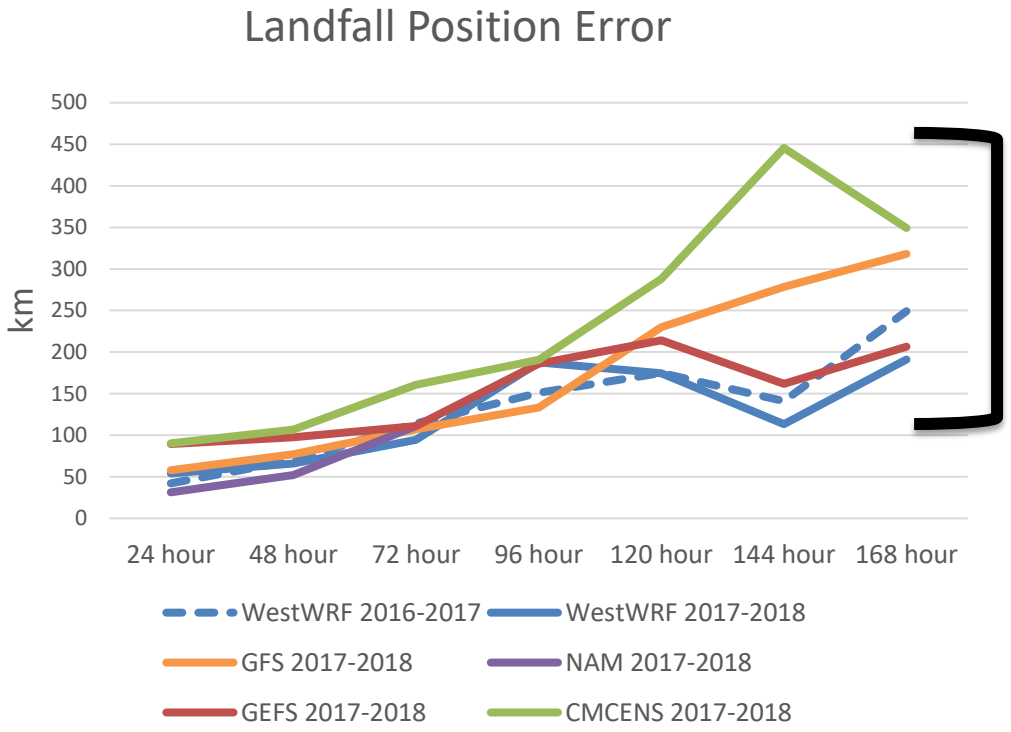
West-WRF Performance in AR Landfalls

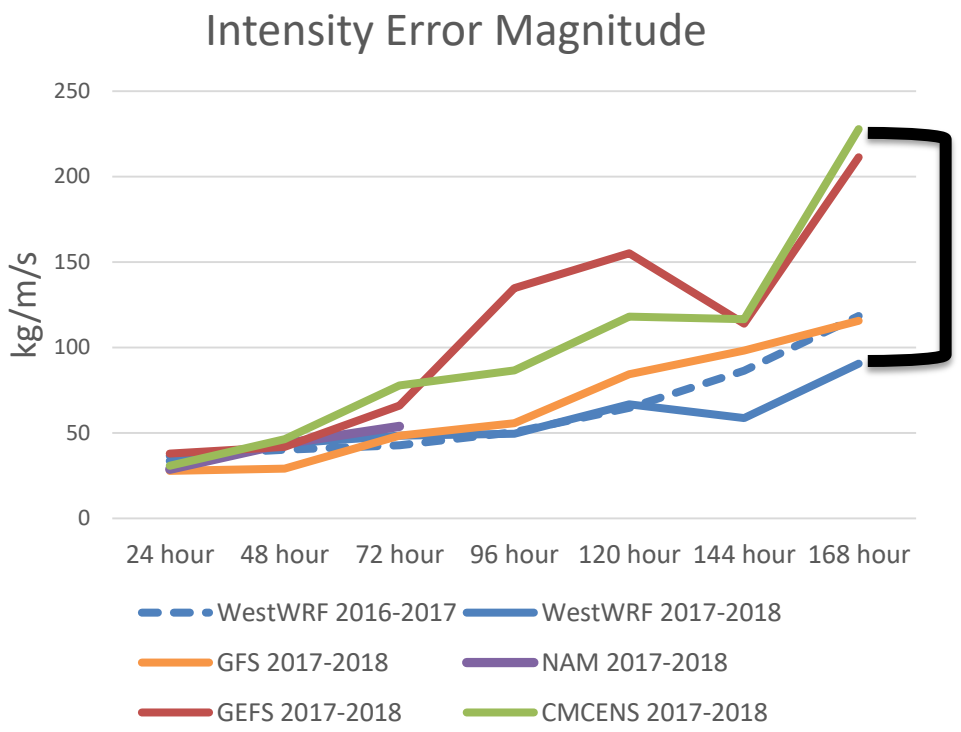


- CW3E has implemented NCAR's MODE software to detect ARs as objects in NWP forecasts and analyses. An example of paired AR objects from a GFS forecast and analysis is above.
- Landfalling AR Forecast skill can then be measured and compared across models.
- For select models and recent AR events, the results are displayed in near-real-time at cw3e.ucsd.edu

West-WRF Performance in AR Landfalls

By error in landfall position and intensity at landfall, West-WRF outperforms the other models shown up to 7 days lead time.

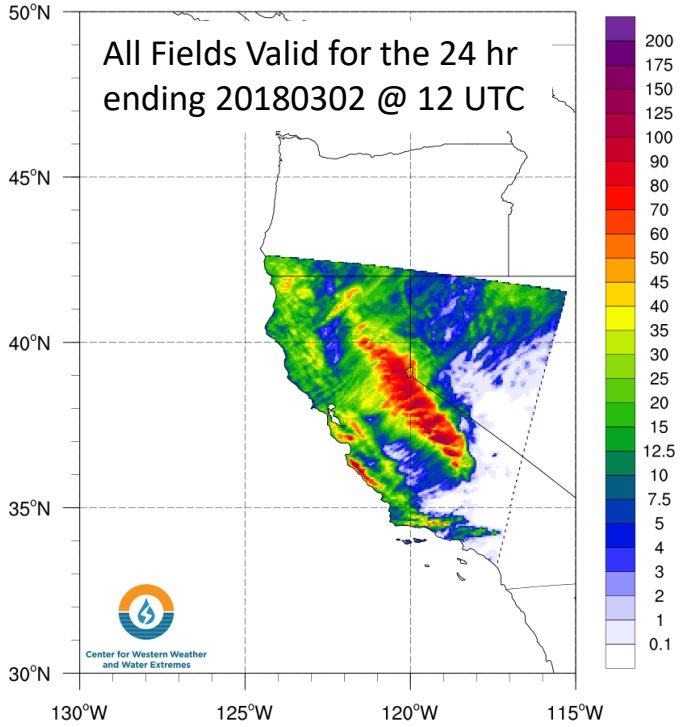




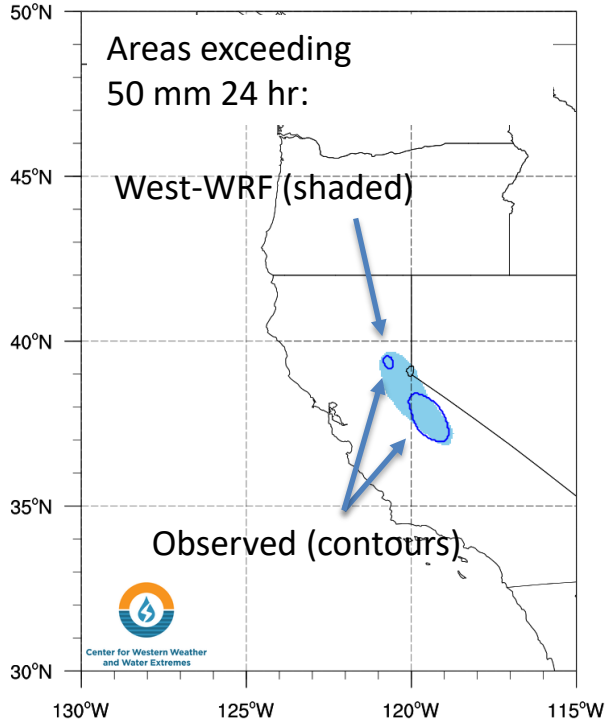
- The MODE methodology can separately evaluate the propagation and intensity of features like an AR.
- MODE object-based AR Landfall verification has been used to measure forecast skill in a suite of models during WY 2018.
- These results, though preliminary, suggest that object-based verification may alleviate the phase error penalty imposed on high res. models by traditional point or grid-to-grid verification.

Object-Based Precipitation Verification

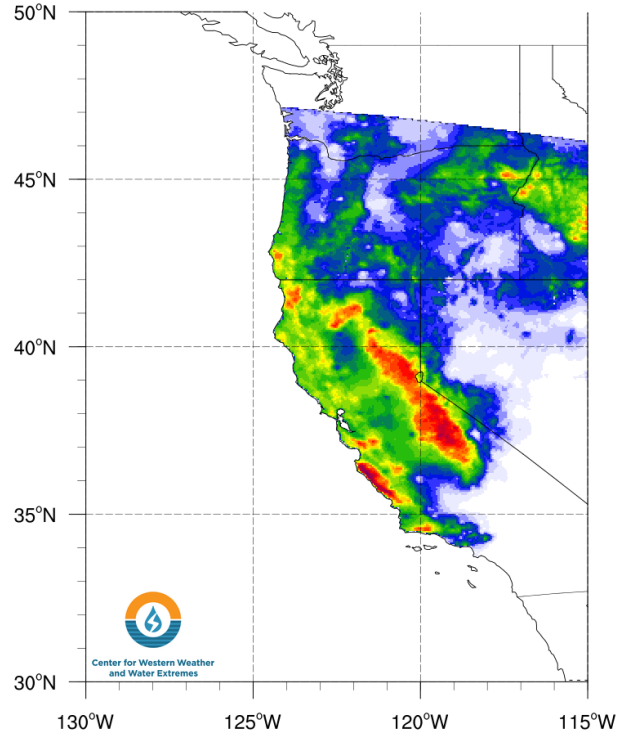
West-WRF QPF (mm)



Objects



Stage-IV QPE (mm)



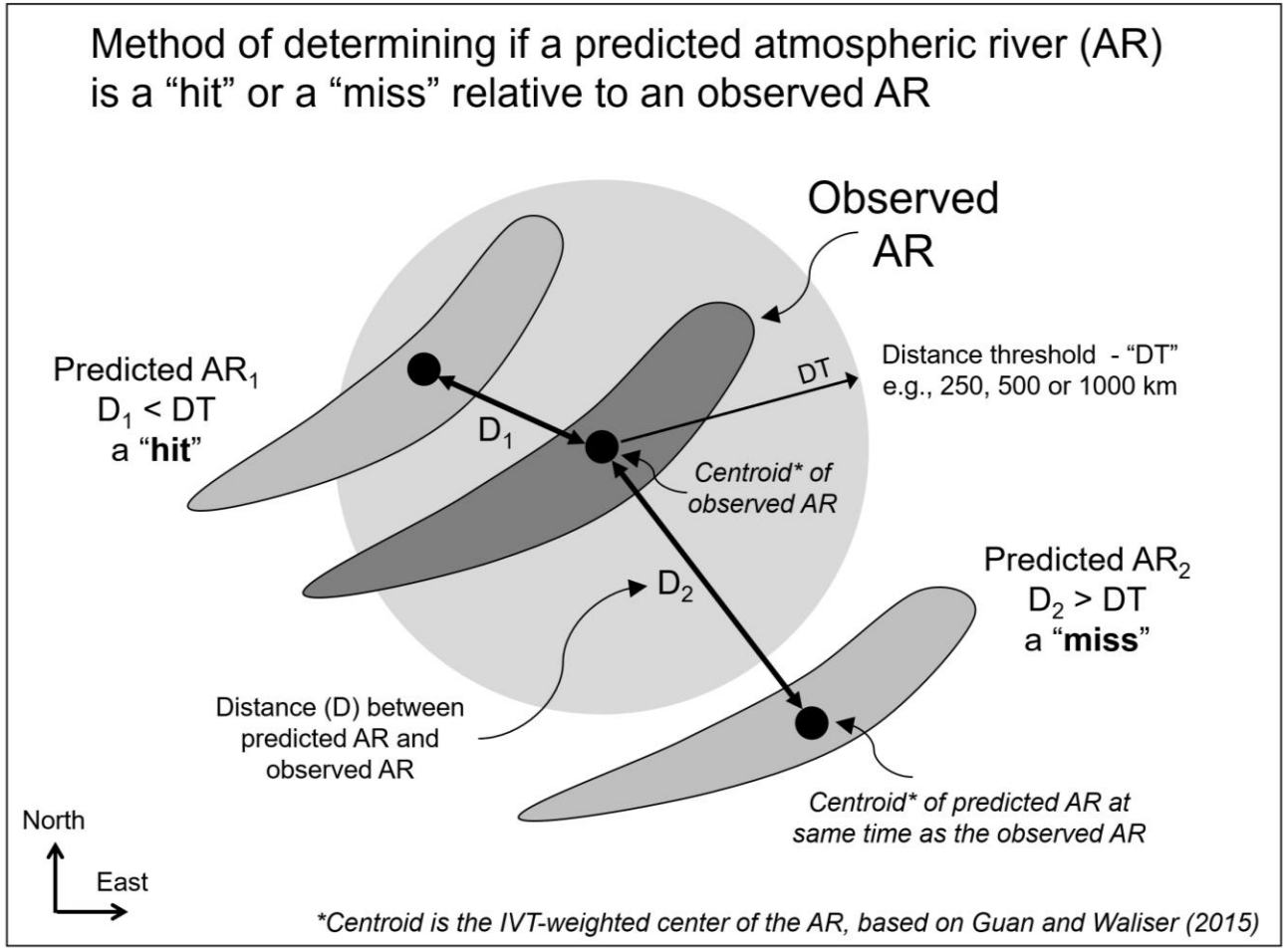
- CW3E is also using MODE to evaluate NWP precipitation forecasts during high-impact AR events.
- The above example shows the spatial relationship between 50 mm 24 hr^{-1} precipitation forecasted by West-WRF and analyzed by WPC Stage-IV.
- Similar analysis for recent events and for other NWP models can be found at cw3e.ucsd.edu

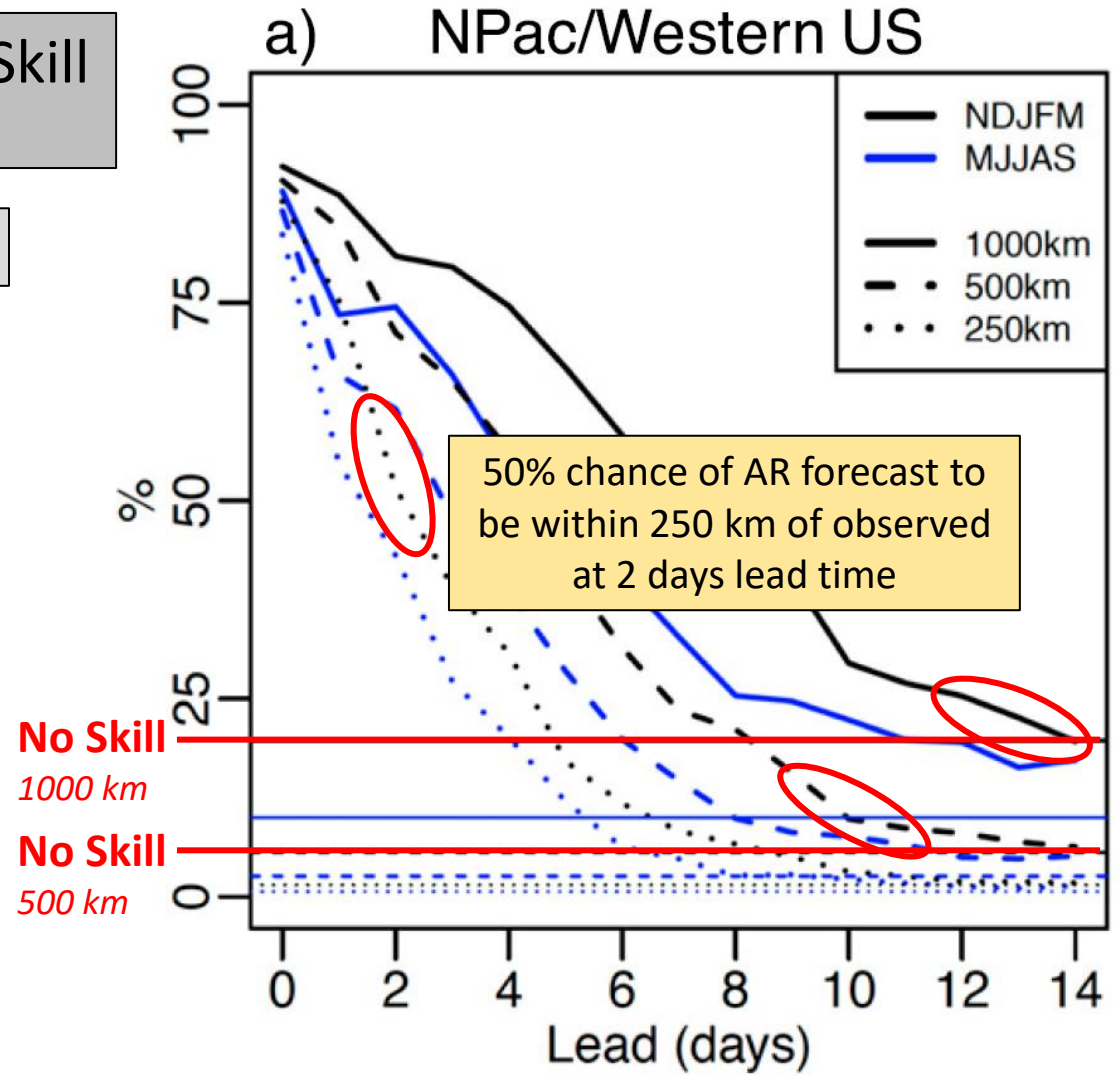
AR Forecast Challenges at Short Lead Times

Global Assessment of Atmospheric River Prediction Skill

DeFlorio, Waliser, Guan, Lavers and Ralph (*JHM 2018)*

Uses ECMWF forecasts and Guana and Waliser (2015) AR Catalog

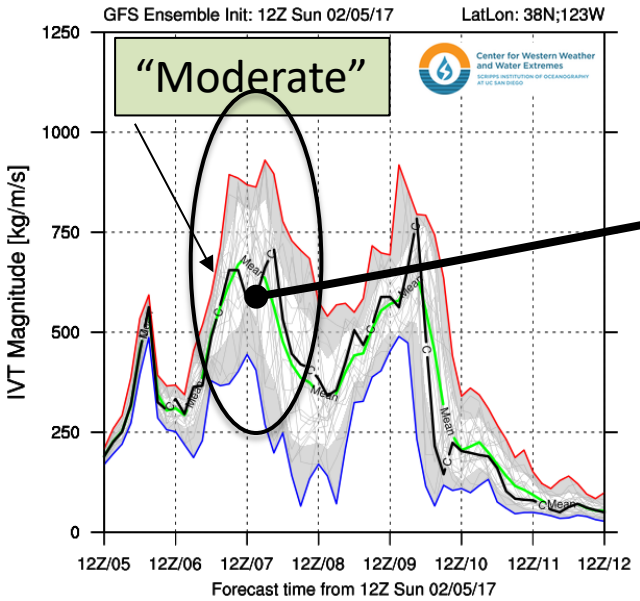




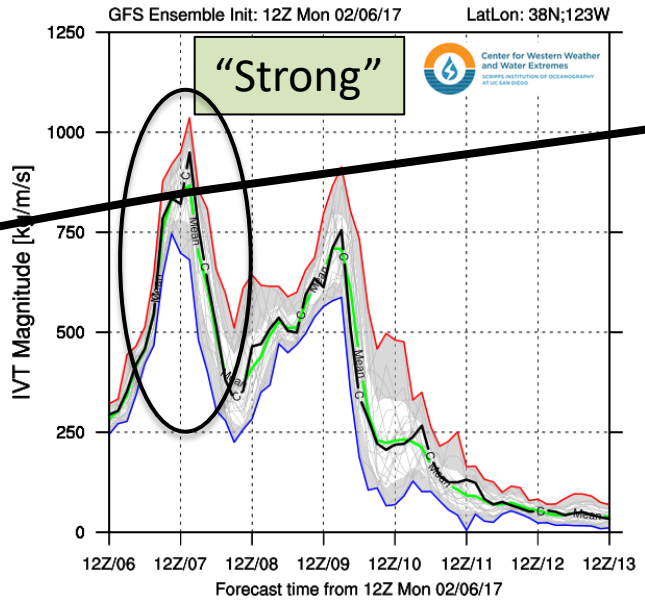
In Cool Season there is some AR forecast skill
for 500 km distance threshold out to 10 days
for 1000 km distance threshold out to 12 days

NCEP GEFS dProg/dt Example from February 2017 – "Oroville Case" (dam spillway issue)

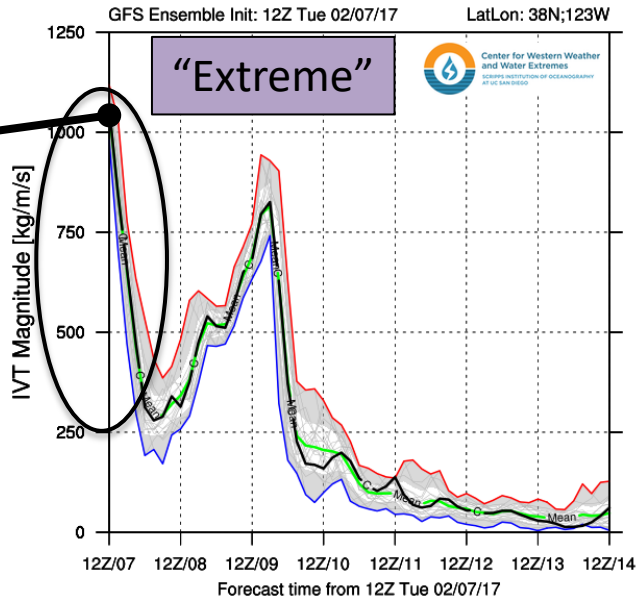
Oroville Dam Spillway Damaged



Init: 12Z/5 Feb



Init: 12Z/6 Feb



Init: 12Z/7 Feb

Image Description: 7-day forecasts of the NCEP GEFS IVT [kg m^{-1} s^{-1}] at 38N, 123W. The following is indicated at each forecast time: ensemble member maximum (red), ensemble member minimum (blue), ensemble mean (green), ensemble control (black), ensemble standard deviation (white shading), and each individual member (thin gray). Time advances from left to right.

Key: Variability in north-south shift of ARs result in increases or decreases in IVT magnitude at the coast. In this case the ARs ultimately ended up **stronger.**

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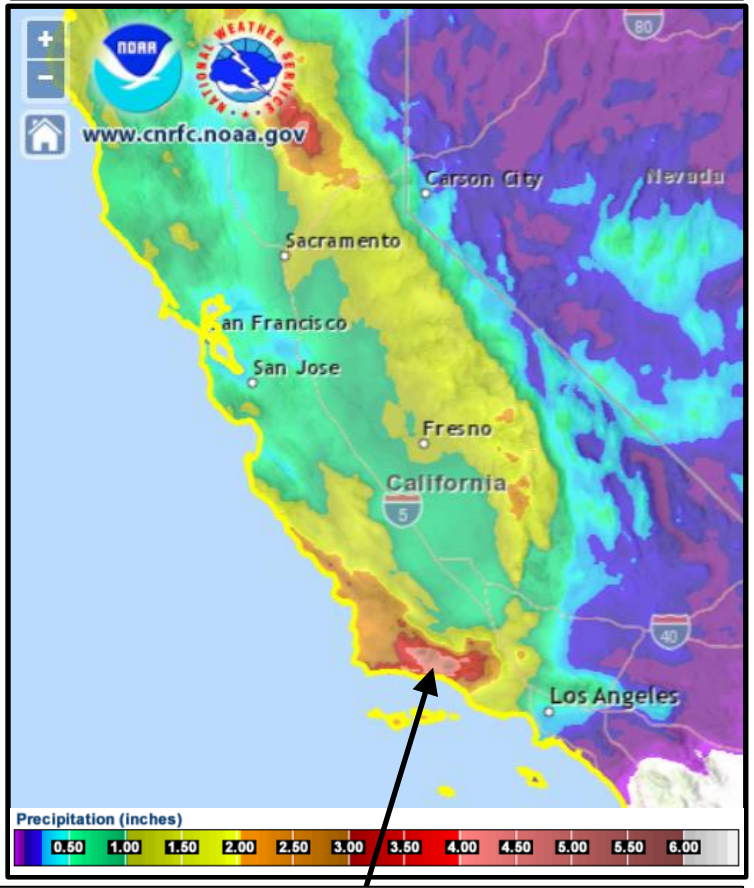
F. M. Ralph (mralph@ucsd.edu) and J. Cordeira

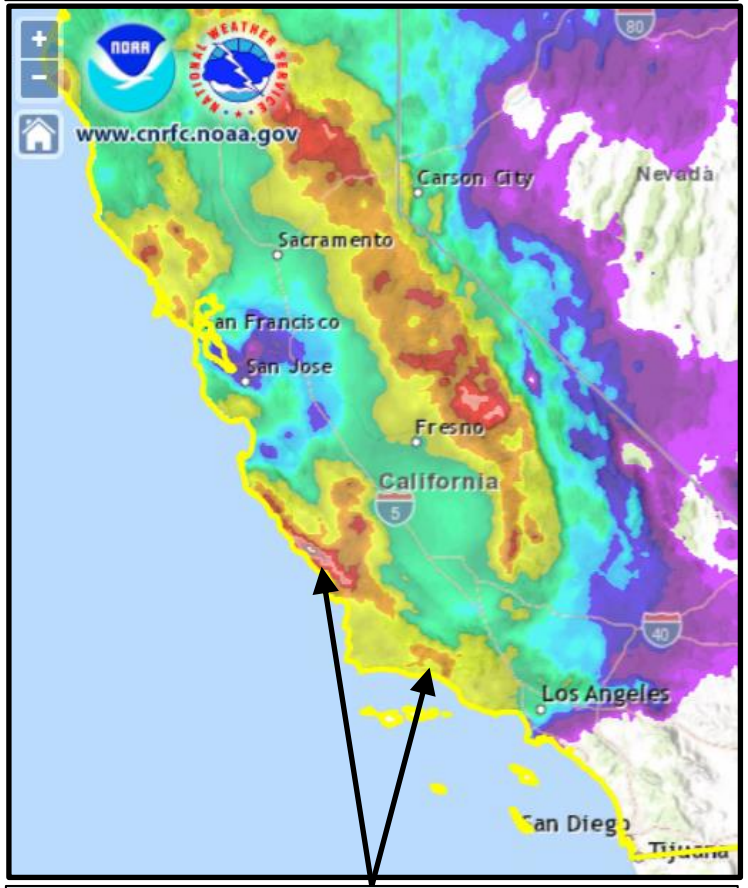
AR Outlook: 22 March 2018

CNRFC 24-hr QPF issued 20 March valid 5 AM PDT 21 to 5 AM 22 March 2018



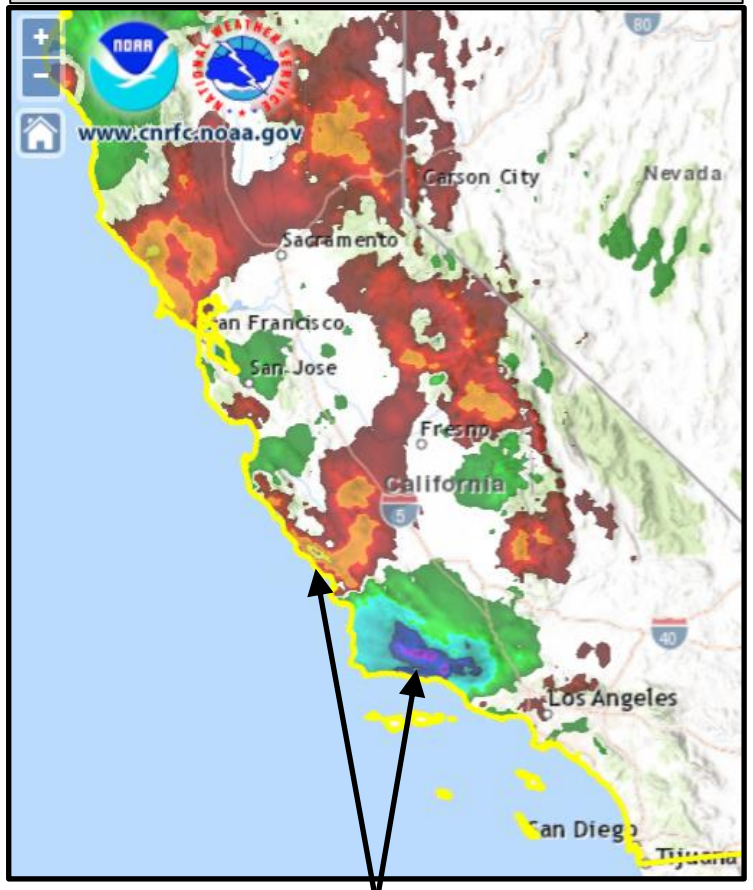
The 24-hr accumulated precipitation forecast for the period ending at 5 am PDT 22 March had a maximum accumulation of

CNRFC 24-hr QPE valid 5 AM PDT 21 to 5 AM 22 March 2018



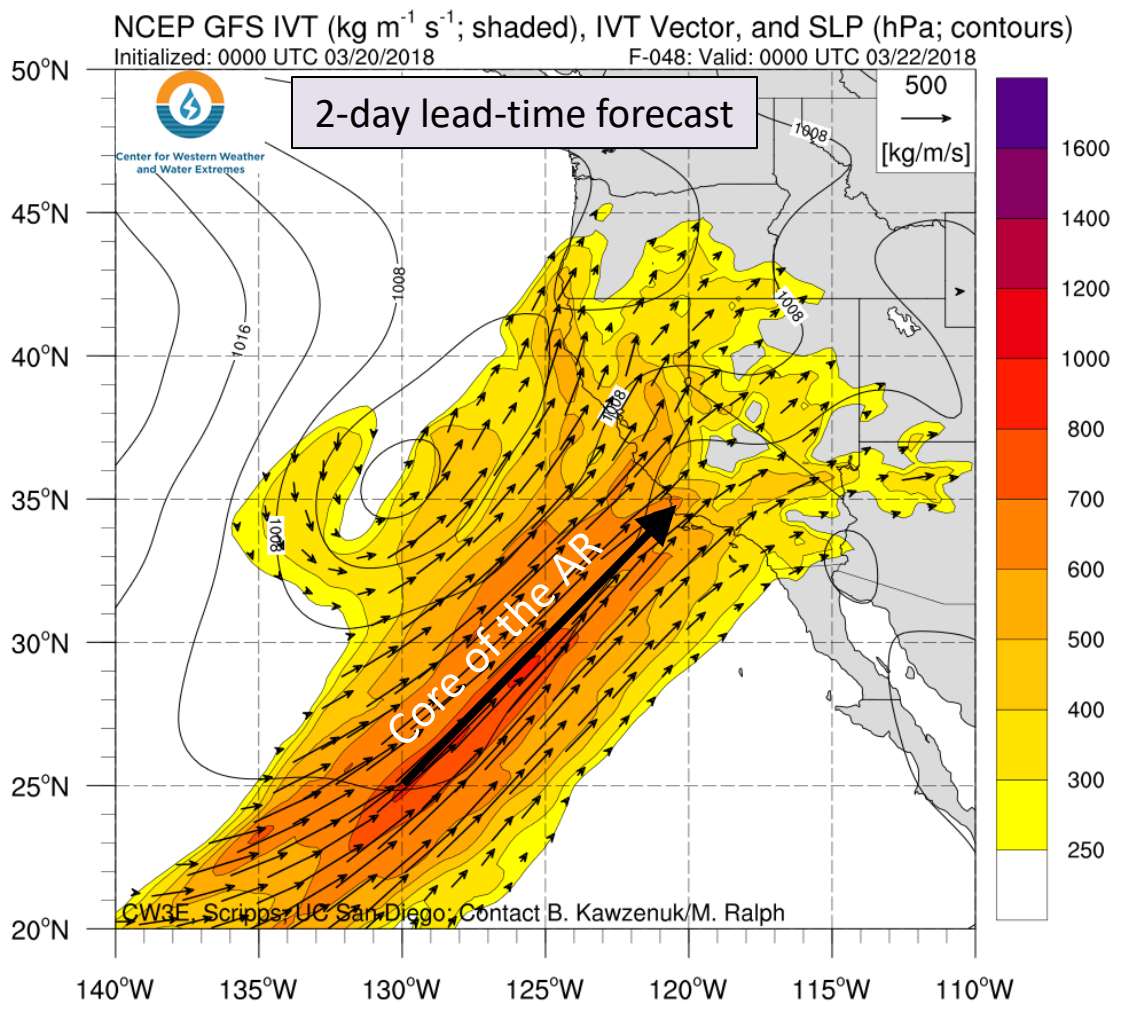
The 24-hr quantitative precipitation estimate (QPE) indicated that ~6 inches fell along the Coastal Mts. and ~2 inches fell over the Santa Ynez Mts.

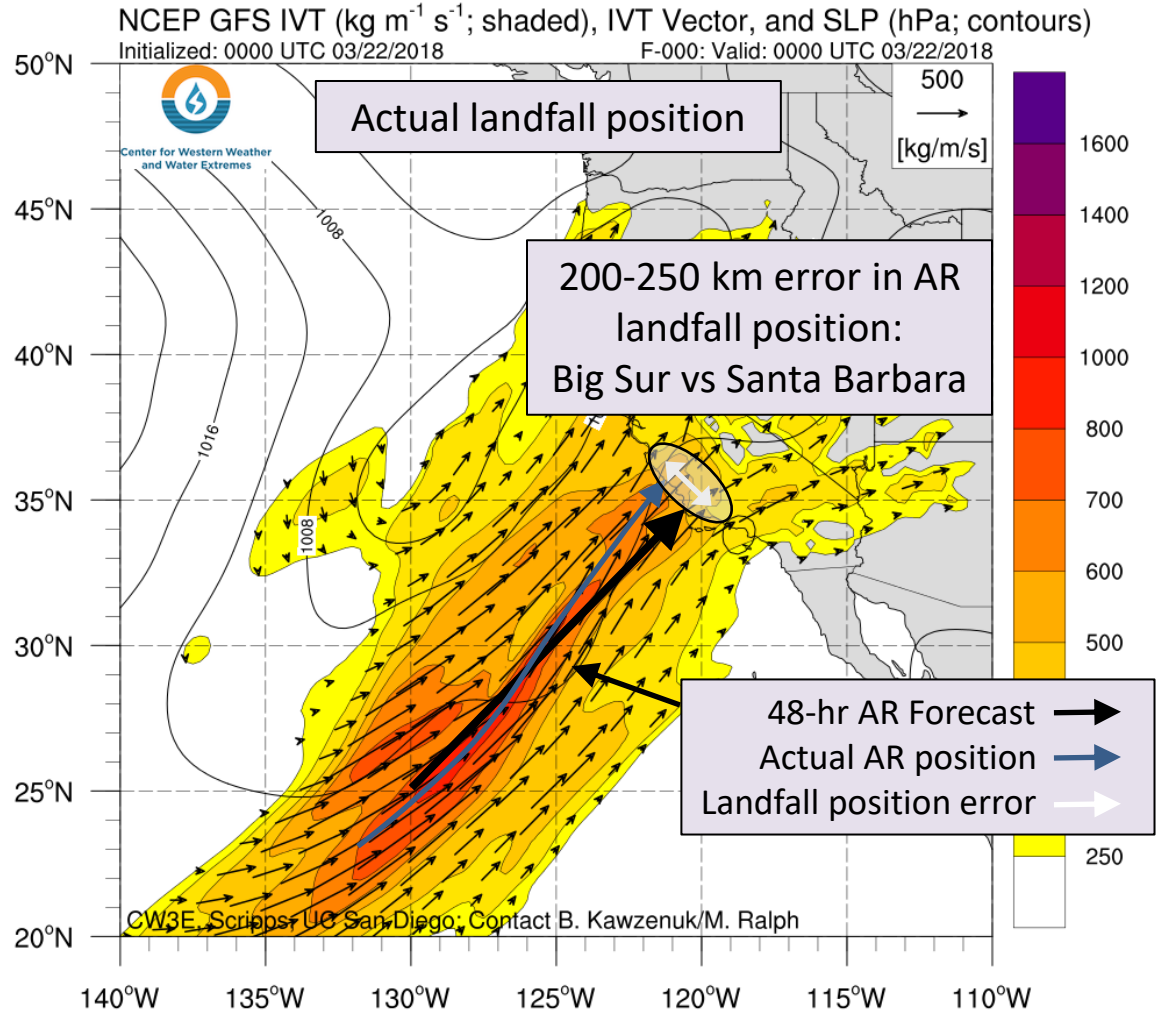
CNRFC 24-hr Verification (QPF–QPE) Valid 5 AM PDT 21 to 22 March 2018



The QPE accumulations resulted in a over forecast of ~3 in. over the Santa Ynez Mts. and an under forecast of ~3 in. over Big Sur

AR Outlook: 22 March 2018





- **The errors in the precipitation forecasts were partly driven by errors in weather model forecast of AR landfall location**
- **The forecast issued at 5 PM PT on Mon. 19 March predicted that the core of the AR 2 days later would be located just west of Santa Barbara at 5 PM PT Wed. 21 March, and would have produced up to 10 inches of rain in the mountains above Santa Barbara**
- **However, the observations (GFA analysis) showed that the core of the AR was instead over Big Sur (~200-250 km from the predicted position). Big Sur did receive up to 9-10 inches of rain, while mountains above Santa Barbara 4-5 inches**

AR Forecast Evaluation: 22 March 2018

Center for Western Weather and Water Extremes
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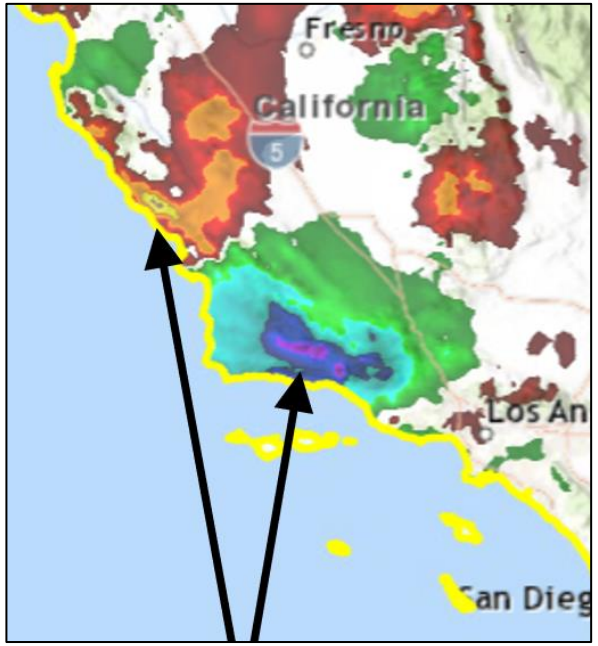
Big Sur
Observed
Max AR rainfall

200-250 km landfall position forecast error

Santa Barbara
Predicted Max AR rainfall

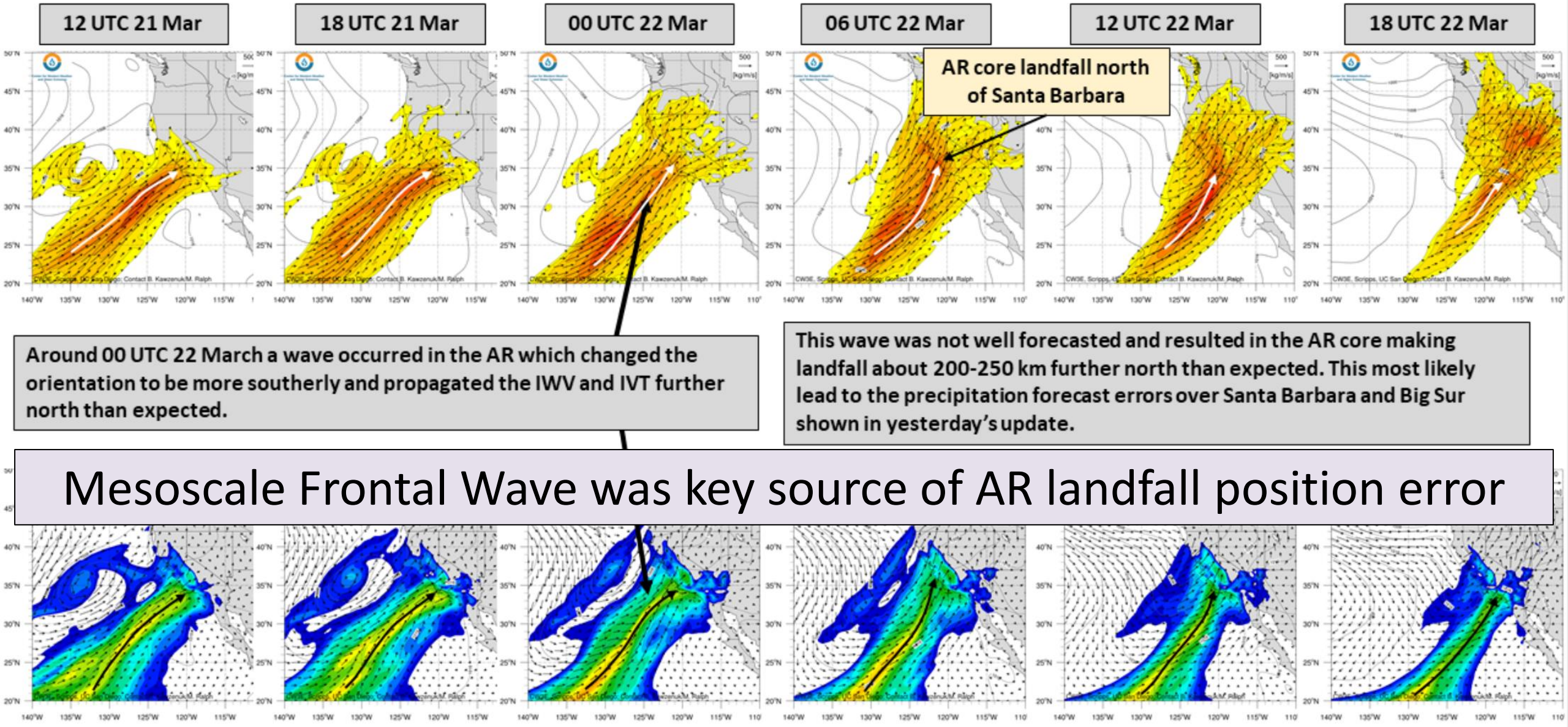


Precipitation forecast error pattern was a dipole, representing mostly a position error in the location of the heavy precipitation

AR Summary: 23 March 2018

F. M. Ralph, C. Hecht

GFS 0-hr Analysis (Top: IVT, bottom: IWV)



Around 00 UTC 22 March a wave occurred in the AR which changed the orientation to be more southerly and propagated the IWV and IVT further north than expected.

This wave was not well forecasted and resulted in the AR core making landfall about 200-250 km further north than expected. This most likely lead to the precipitation forecast errors over Santa Barbara and Big Sur shown in yesterday's update.

Mesoscale Frontal Wave was key source of AR landfall position error

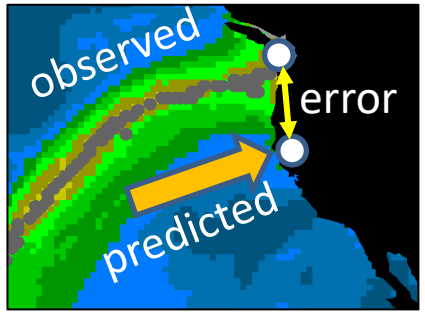
Airborne AR Recon

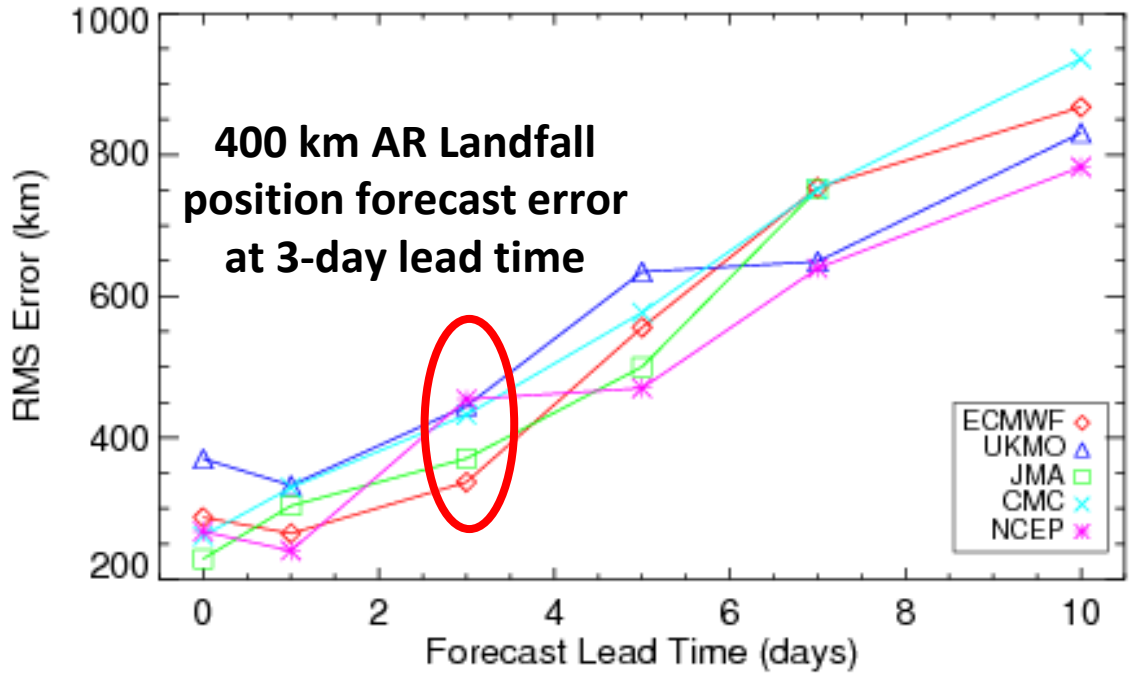
Atmospheric River Reconnaissance

FM Ralph (Scripps/CW3E), V Tallapragada (NWS/NCEP), J Doyle (NRL)

Water managers, transportation sector, agriculture, etc… require improved atmospheric river (AR) predictions

AR Forecast skill assessment establishes a performance baseline





Wick, G.A., P.J. Neiman, F.M. Ralph, and T.M. Hamill, 2013: Evaluation of forecasts of the water vapor signature of atmospheric rivers in operational numerical weather prediction models. *Wea. Forecasting*, **28**, 1337-1352.

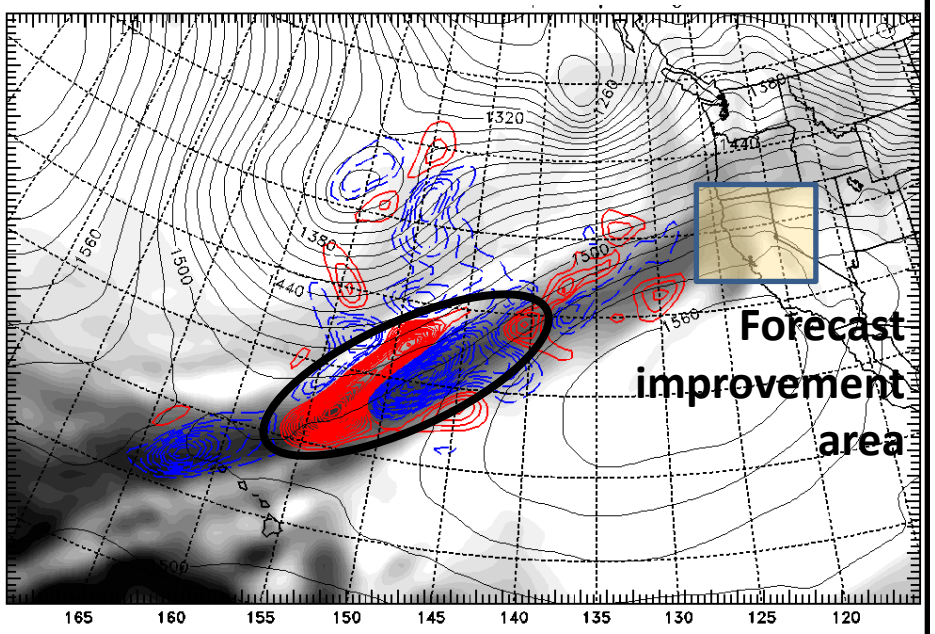
New Adjoint includes moisture – and finds AR is prime target

36-h Sensitivity (Analysis) 00Z 13 February (Final Time 12Z 14 February 2014)

J. Doyle, C. Reynolds, C. Amerault, F.M. Ralph

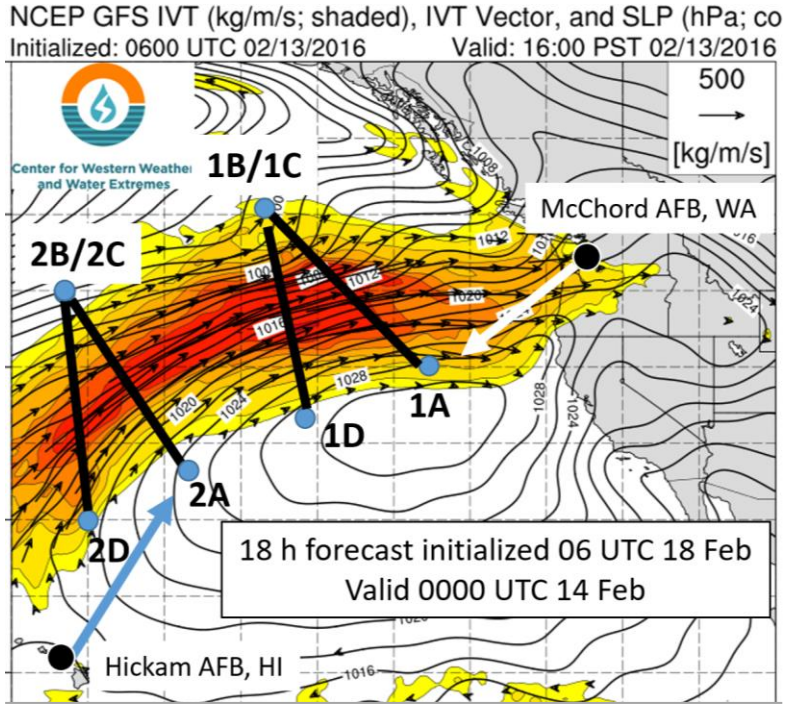
(International Atmospheric Rivers Conference 2016)

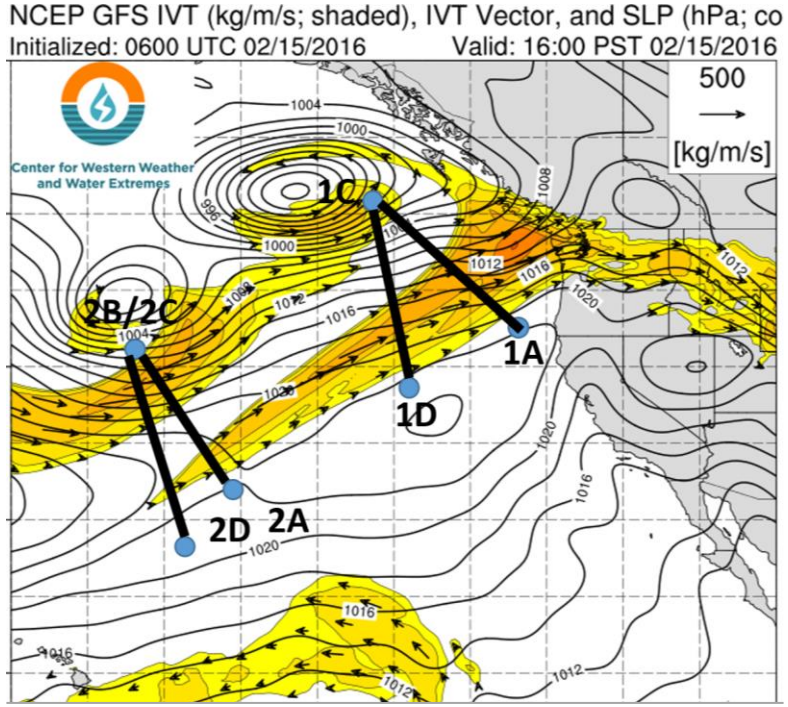
Color contours show the forecast sensitivity to 850 mb water vapor (grey shading) uncertainty at analysis time 00Z 13 Feb 2014 for a 36-h forecast over NorCal valid 12Z 14 Feb

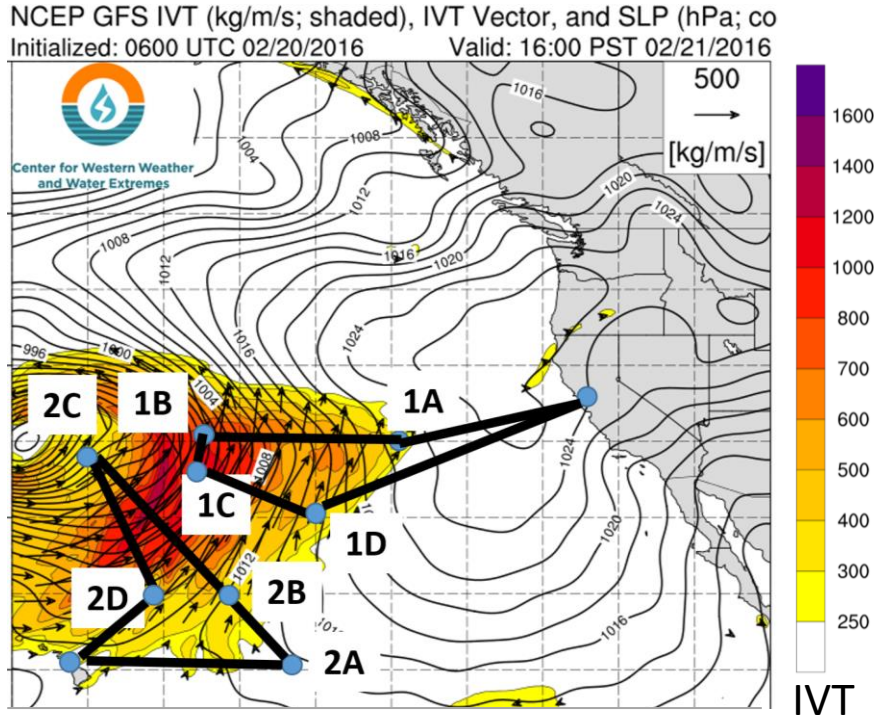


- Moisture sensitivity is strongest along AR axis; located > 2000 km upstream
- **Moisture sensitivity substantially larger than temp. or wind sensitivity.**

2016
Atmospheric River Reconnaissance Flights







2018
Atmospheric River Reconnaissance Flight Strategies

Center time: 0000 UTC
Dropsonde deployment window:
2100 – 0300 UTC

Each aircraft has a range of about 3500 nm

F.M. Ralph (AR Recon PI) and AR Recon Team

60N
55N
50N
45N
35N
160W
150W
140W
130W
120W
3.5 h
3.0 h
2.0 h
1.0 h
G-IV Ferry time from Seattle (black numbers)
Upper-level trough/PV anomaly
Example of a target for the NOAA G-IV
Example of Atmospheric River target for AF C-130s (color fill: IVT)
AF C-130
AF C-130
On-station time for G-IV (red text)
8 h
6 h
4 h
3 h

AR Recon – 2018 Flight Operations Planning and Execution

NWS Co-PI
V. Tallapragada (NCEP) – Co-PI
A. Edman (NWS WR) – Co-PI

AR Recon PI and Mission Director
F.M. Ralph (SIO/CIMEC & CW3E)
J. Doyle (NRL) – Alternate
Coordinators: A. Wilson, J. Kalansky, F. Cannon (CW3E)

Flight Execution
Major A. Lundry (AF C-130s)
J. Parrish (NOAA G-IV)
"Flight Directors"

C-130 & G-IV Crews; CARCAH

AR Core Target Planning
Two C-130s
J. Rutz (NWS WR) – Primary
J. Cordeira (Plym. St.)– Alternate
AR Core Target - Advisors
C. Reynolds (NRL) - backup
C. Smallcomb (NWS)
D. Lavers (ECMWF)
R. Demirdjian (SIO/CW3E)

iterate

Flight Track Assessment
Air Force Navigator
NOAA (Parrish/Cowan)
Coordinator: F. Cannon (CW3E)

iterate

Secondary Target Planning
NOAA G-IV
C. Davis (NCAR) – Primary
T. Galarneau (U.AZ) – Alternate
Secondary Target - Advisors
J. Doyle (NRL)
L. Bosart (SUNY Albany)
R. Demirdjian (SIO/CW3E)
TBD

Daily Forecasts, Flight Summaries and Planning 800 AM PT*

**Meetings led by either Cordeira, Rutz, Lavers, or alternate*

**Attended by "primary" and "alternate" from each group (not by all members of each group)*

Planning Data and Flight Summaries

Moist Adjoint Team
C. Reynolds (NRL) – Primary
J. Doyle (NRL) – Alternate
R. Demirdjian (SIO/CW3E) - Support

Flight Summaries
TBD - (SIO/CW3E) – PDocs/GrStud

AR Recon Forecasting Team
J. Cordeira (Plymouth St.) – Primary
D. Lavers (ECMWF) – Alternate
J. J. Rutz (NWS WR) – Alternate
C. Hecht (SIO/CW3E) - Alternate
B. Kawzenuk (SIO/CW3E)
K. Howard (NCEP), Other TBD

Modeling and Data Assimilation Team
A. Subramanian (SIO/CW3E) – Primary
V. Tallapragada (NCEP) – Alternate
J. Doyle (NRL), TBD (ECMWF),
C. Davis (NCAR), N. Baker (NAVGEM)
Zheng, Murphy, Haase, Co (SIO/CW3E)
Chen (UC Davis), Galarneau (UA)

Key dates

19 January: commit where to deploy the 2nd C-130

25 Jan - 10 Feb: G-IV is available for 3 storm flights from Seattle

25 Jan - 27 Feb: two C-130s available for 6 storm flts from Hawaii, Seattle, Travis AFB or San Diego

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AR Recon – 2018: IOP 1 on 26-27 Jan 2018

Key sponsors include US Army Corps of Engineers, NOAA and California Dept. of Water Resources

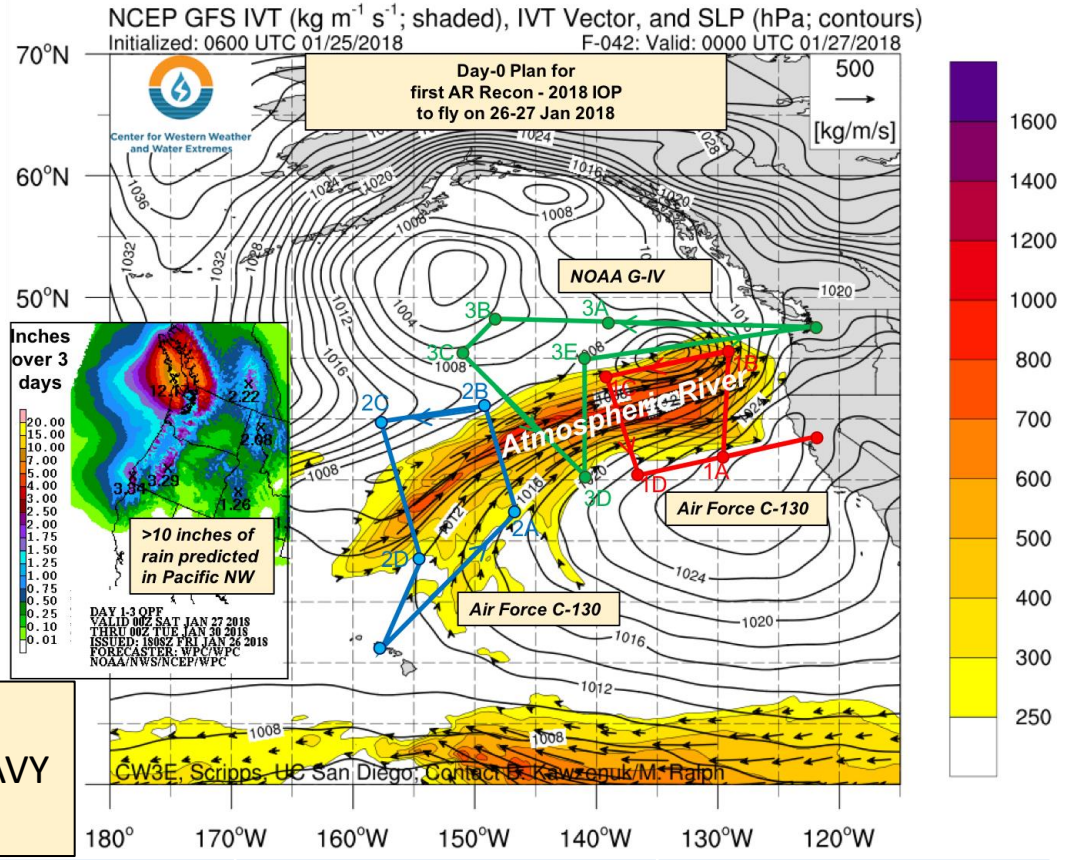
Center time for dropsondes: 0000 UTC 27 Jan 2018

Number of dropsondes planned: 27, 26, 36 (C-130 H, C-130 C, G-IV)

- Mission Director: F. Martin Ralph (PI; Scripps/CW3E)
- Co-PIs: Vijay Tallapragada (NWS/NCEP), Andy Edman (NWS/Western Region)
- C-130 Flight Planning lead: Jon Rutz (NWS)
- G-IV Flight Planning Lead: Chris Davis (NCAR)
- Forecasting Lead: Jay Cordeira (Plymouth St. Univ.)
- Moist Adjoint Lead: Jim Doyle/Carolyn Reynolds (NRL)
- GPS sensor lead: Jennifer Haase (Scripps/IGPP and CW3E)
- AR Recon Coordinator: Anna Wilson (Scripps/CW3E)
- Flight Track Coordinator: Forest Cannon (Scripps/CW3E)
- Air Force C-130 Flight Director: Ashley Lundry (AF/53rd Weather Recon)
- NOAA G-IV Flight Director: Jack Parrish (NOAA/AOC)


Air Force C-130 Aircraft – Weather Recon' Squadron

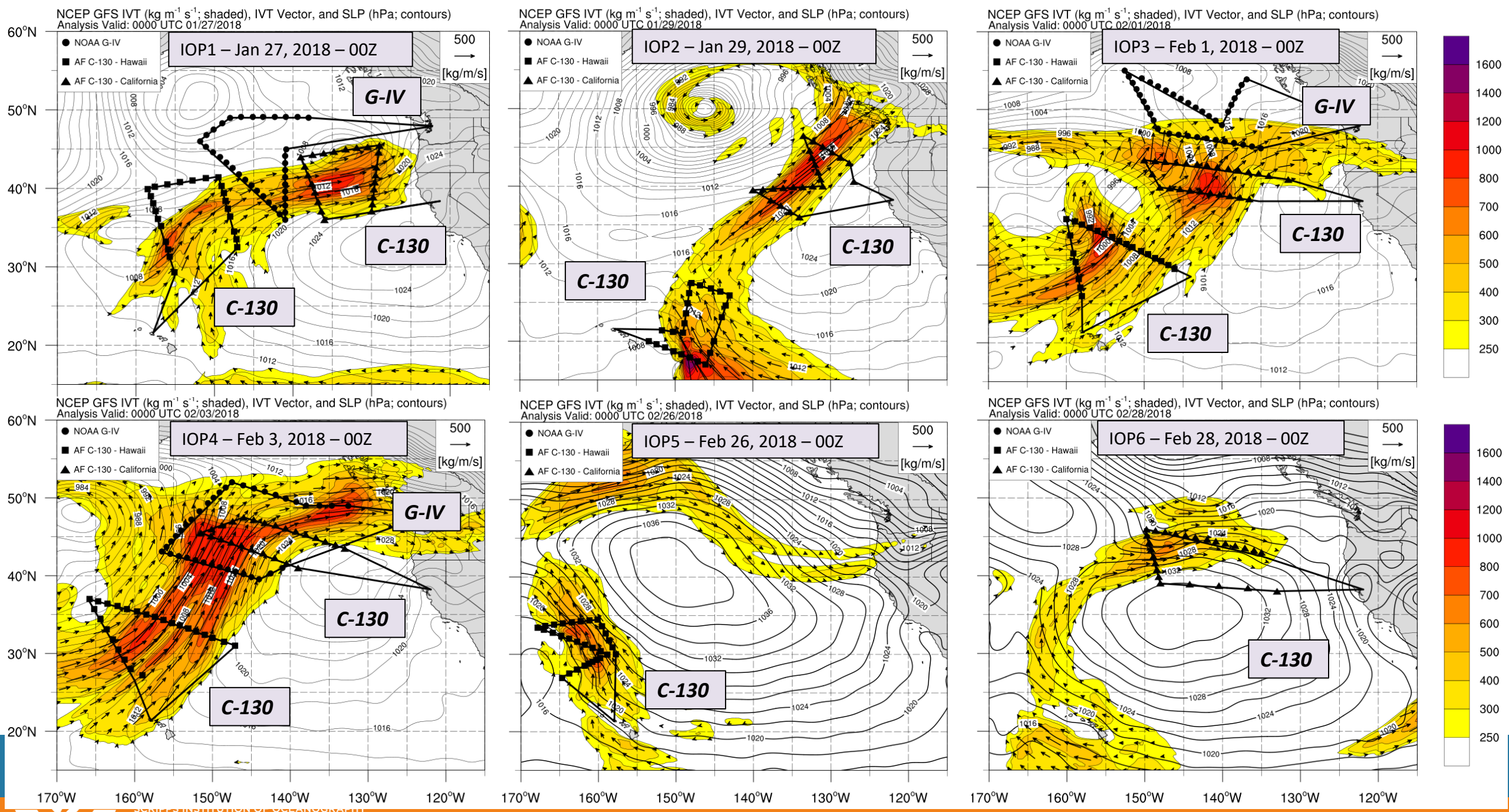

NOAA G-IV



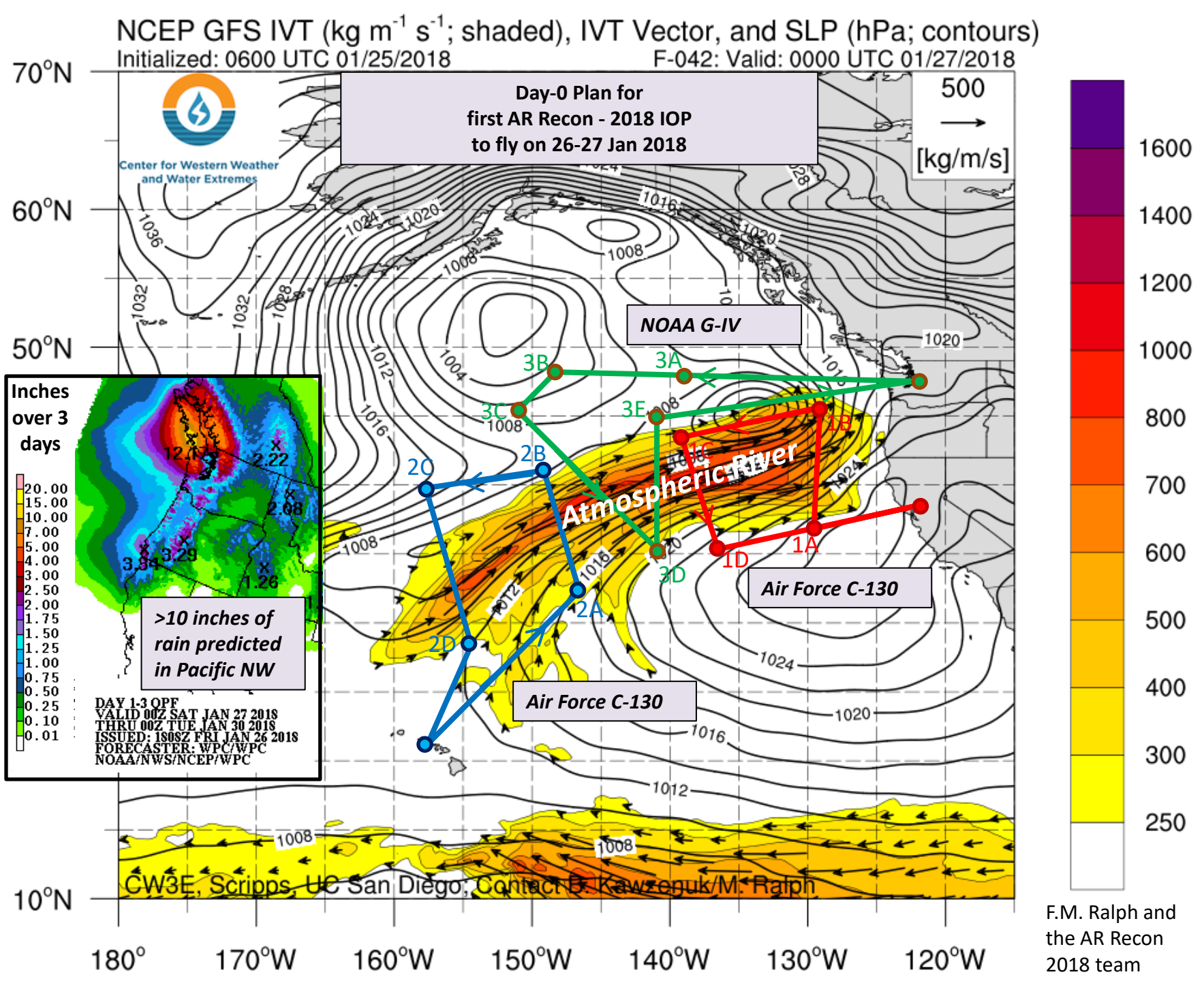
Modeling Partners

NWS/NCEP	US NAVY
ECMWF	NCAR

Forecaster	Chad Hecht (Scripps/CW3E)	Moist Adjoint support	Reuben Demirdjian (CW3E)
Forecaster	David Lavers (ECMWF)	Flight Planning ("alternate")	Tom Galarneau (Univ. AZ)
Forecaster	Philippe Papin (NRL)	Onboard Scientist	Jon Rutz (NWS)
Forecaster	Aneesh Subramanian (Scripps/CW3E)	Onboard Scientist	Reuben Demirdjian (CW3E)
		Onboard Scientist (GPS)	Bing Cao (Scripps/IGPP)


NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 01/27/2018
IOP1 – Jan 27, 2018 – 00Z
NOAA G-IV
AF C-130 - Hawaii
AF C-130 - California
500 [kg/m/s]
G-IV
C-130
C-130
NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 01/29/2018
IOP2 – Jan 29, 2018 – 00Z
C-130
C-130
NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/01/2018
IOP3 – Feb 1, 2018 – 00Z
G-IV
C-130
C-130
NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/03/2018
IOP4 – Feb 3, 2018 – 00Z
G-IV
C-130
C-130
NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/26/2018
IOP5 – Feb 26, 2018 – 00Z
C-130
C-130
NCEP GFS IVT (kg m-1 s-1; shaded), IVT Vector, and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/28/2018
IOP6 – Feb 28, 2018 – 00Z
C-130
C-130
1600
1400
1200
1000
800
700
600
500
400
300
250
60°N
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W

C-130 CA	Lat	Lon
Travis AFB	38.37	-121.3
1A	37	-130
1B	45.5	-129
1C	44	-139
1D	36	-136
C-130 HI	**Lat**	**Lon**
HI. AFB	21.59	-157.8
2A	32.5	-147
2B	41.5	-149.5
2C	40	-158.5
2D	29	-155
G-IV	**Lat**	**Lon**
SEA	47.91	-122.28
3A	50	-128
3B	49	-148
3C	46	-152
3D	36	-141
3E	45	-141



F.M. Ralph and the AR Recon 2018 team

C-130 CA	Lat	Lon
Travis AFB	38.37	-121.3
1A	37	-130
1B	45.5	-129
1C	44	-139
1D	36	-136
C-130 HI	**Lat**	**Lon**
HI. AFB	21.59	-157.8
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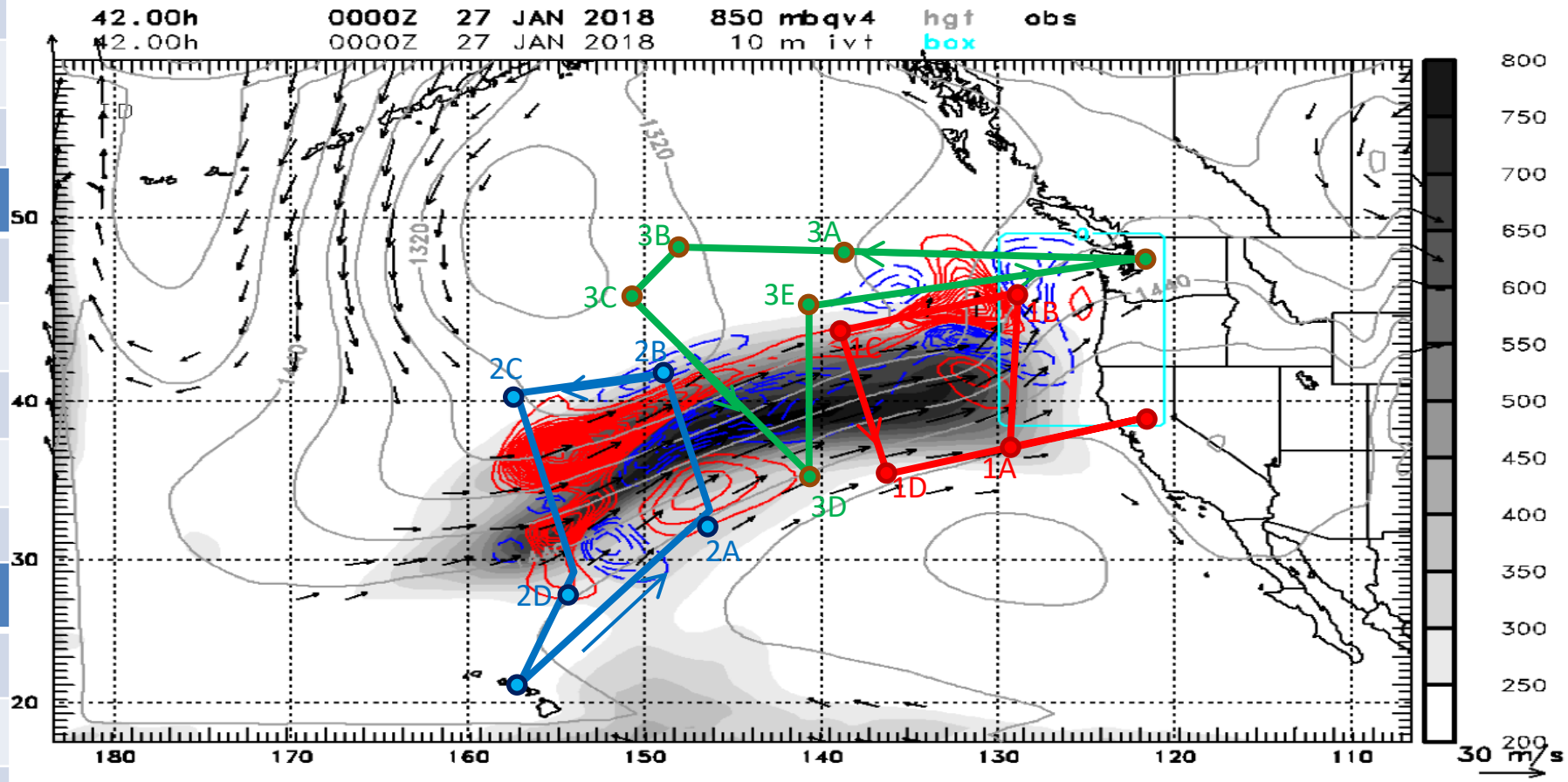
3A	50	-128
3B	49	-148
3C	46	-152
3D	36	-141
3E	45	-141

provided by
J. Doyle and C. Reynolds

COAMPS Adjoint Sensitivity
Valid at 00Z 27 January (42h)



IVT (gray fill)

850 hPa Heights (gray contour) and Winds (vectors)

850 hPa Water Vapor Sensitivity (blue/red)

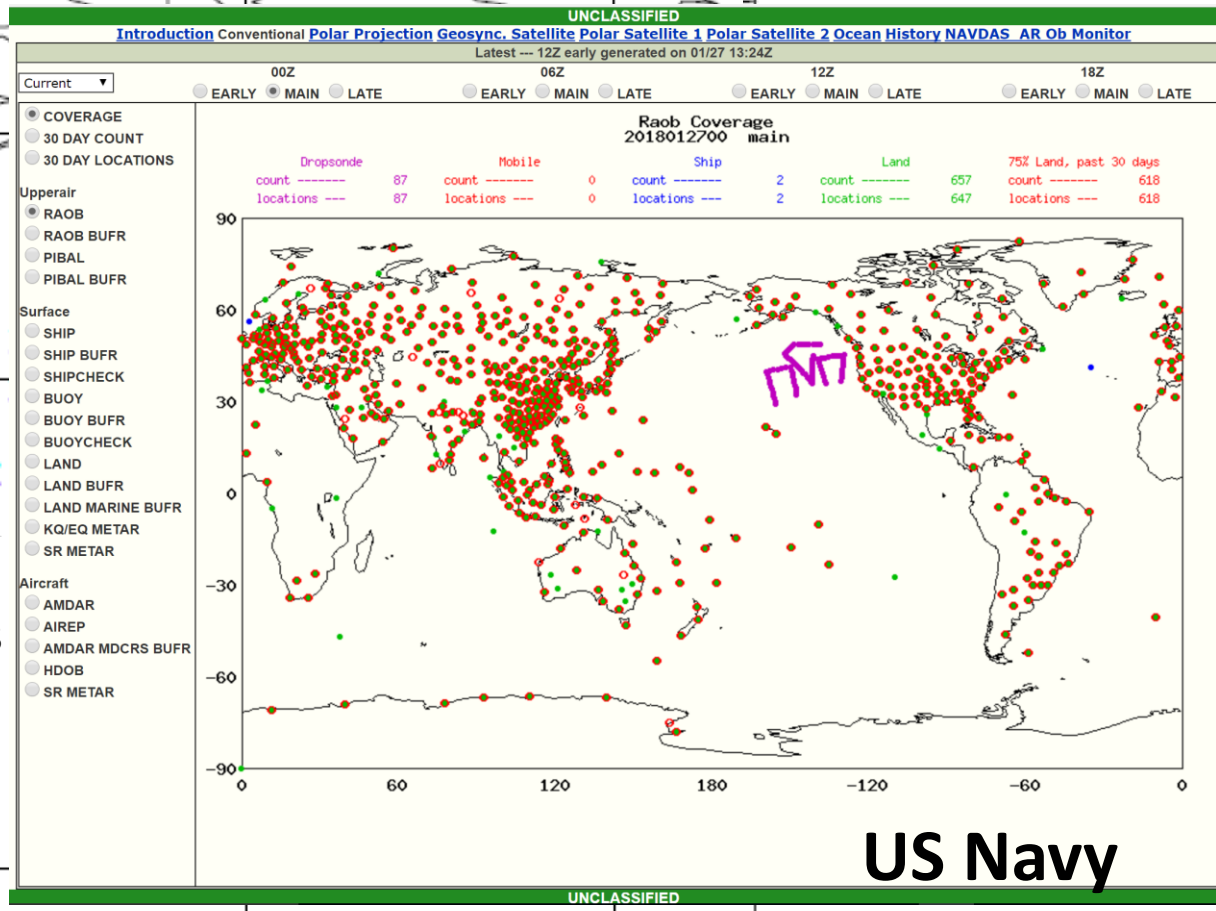
Response Function is 12-h Accumulated Precipitation (114 to 126h)

ECMWF Soundings Assimilated from AR Recon 2018 IOP 1 centered on 0000 UTC 27 Jan 2018

80 AR Recon dropsondes assimilated
10% of all radiosondes or dropsondes globally

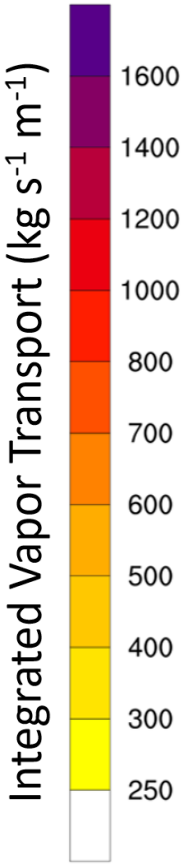
150°W 120°W 90°W 60°W
80°N 60°N 40°N 20°N 0°N

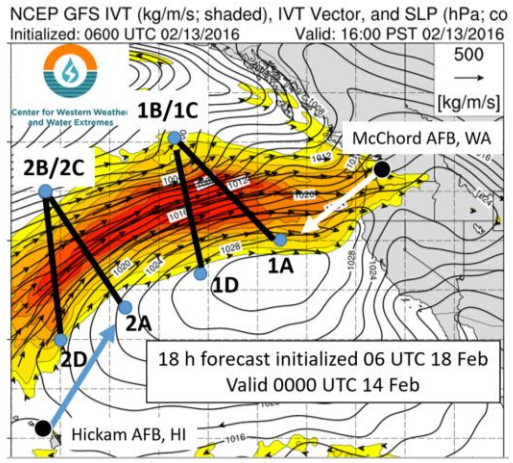
AR Recon dropsondes
From 2 Air Force C-130s
and the NOAA G-IV

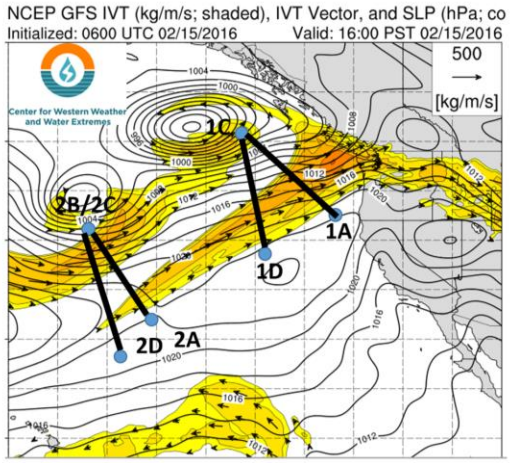


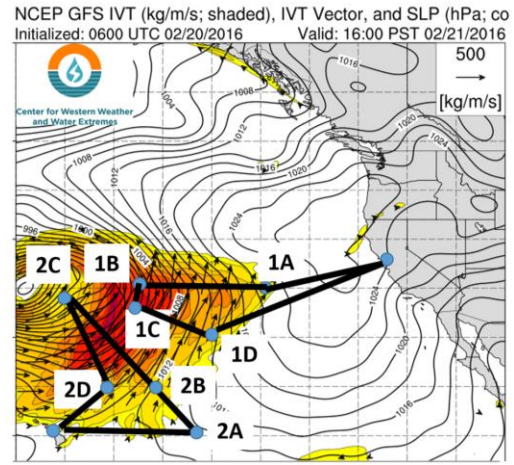
US Navy

Atmospheric River Reconnaissance

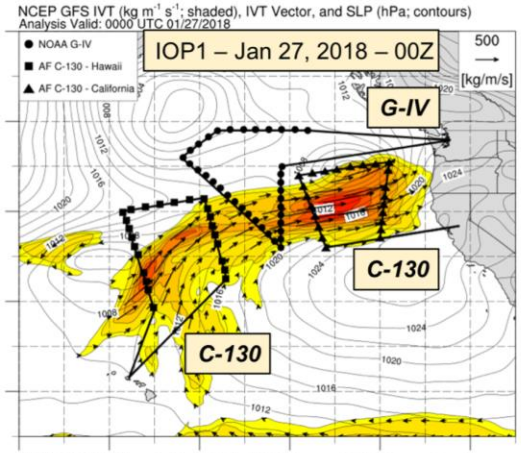


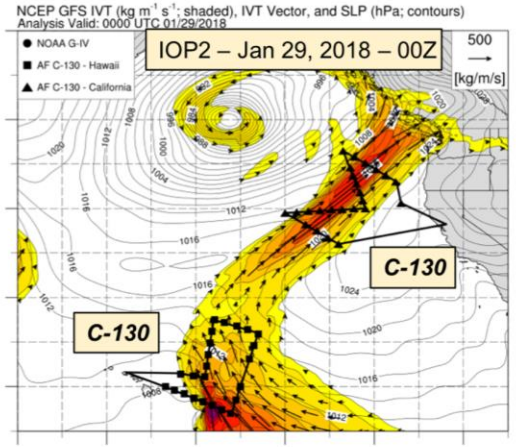


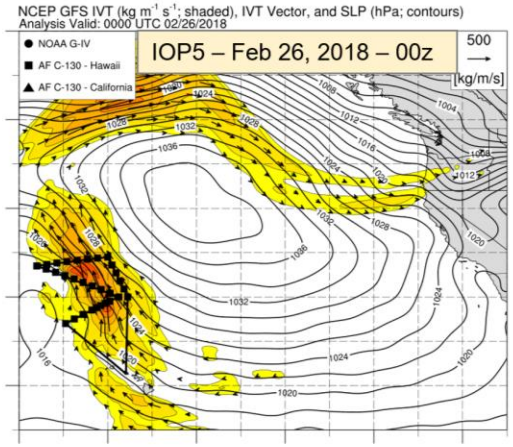




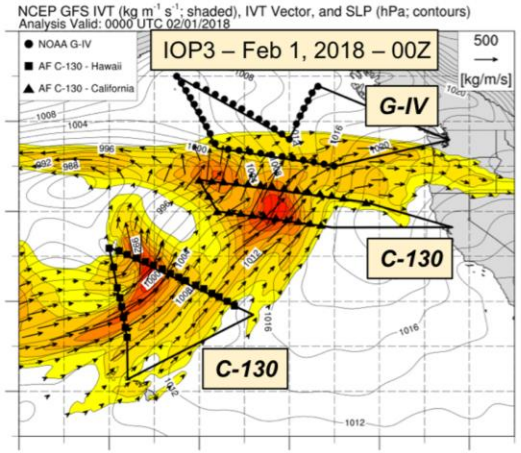
2016

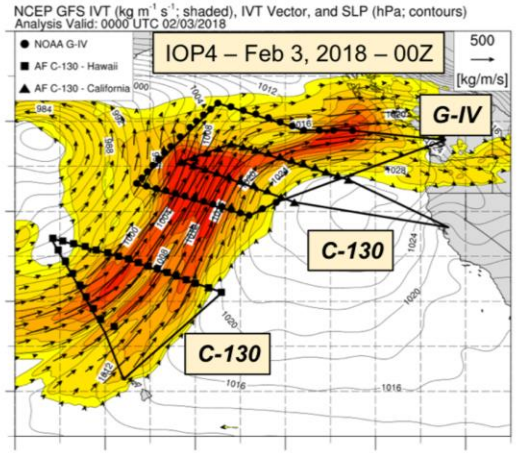


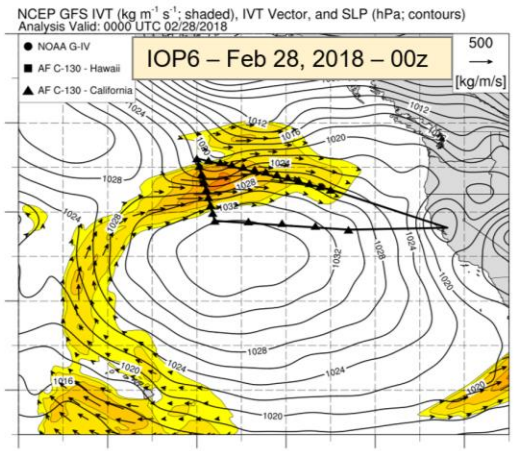




2018







2018

Contacts:
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V. Tallapragada (NCEP)
J. Doyle (NRL)
C. Davis (NCAR)
F. Pappenberger (ECMWF)
A. Subramanian (UCSD)

AR Recon – 2019: Requesting 3 Aircraft to Sample 9 Storms

Two Air Force C-130s and NOAA's G-IV

- ✓ Feb 2016: 3 Storms (2 aircraft per storm)
- ✓ Jan-Feb 2018: 6 Storms (3 aircraft per storm in 3 storms; 2 aircraft in 1 storm; 1 aircraft in 2 storms)
- ○ Jan-Mar 2019 (Requested): 9 storms (3 aircraft per storm)
- ○ **Target total number of cases: 18 storms, with 1, 2 or 3 aircraft sampling each storm**
- ✓ Interagency, International Steering Committee in place
  - Carry out assessments
  - Refine data assimilation methods
  - Create appropriate evaluation metrics
  - Provide impact results in peer-reviewed publications

Contacts
F. M. Ralph (mralph@ucsd.edu)
V. Tallapragada (vijay.tallapragada@noaa.gov)

AR Forecast Tools

Extreme Event Summaries

Unique Observations

Are available at

CW3E.UCSD.EDU

Contact: mralph@ucsd.edu

S2S Outlooks Supporting Water

Goal: Develop week-2 and week-3 outlooks for AR activity on the US West Coast. Evaluate and improve understanding of outlooks on these timescales.

Scripps Institution of Oceanography: F.M. Ralph (PI), A. Subramanian
JPL : Duane Waliser, Mike DeFlorio, Bin Guan, Alex Goodman
PSU : Jay Cordeira
CSU : Elizabeth Barnes
Data : WCRP / WWRP S2S Project

Supported by CA Dept. of Water Resources
Proposed working with NWS/NCEP/CPC

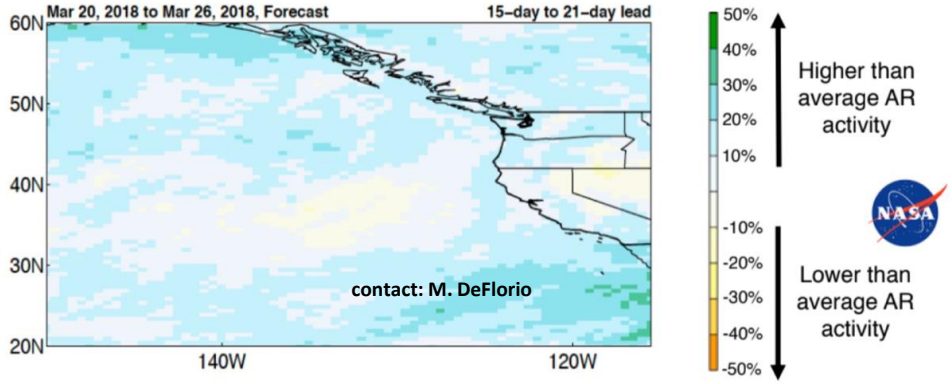
Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

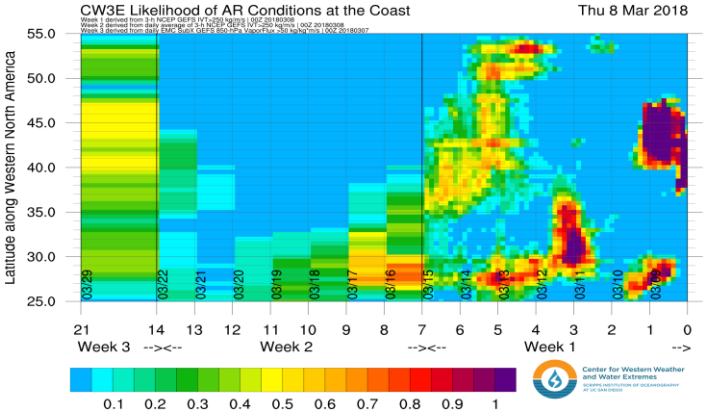
Jet Propulsion Laboratory
California Institute of Technology

Plymouth State University

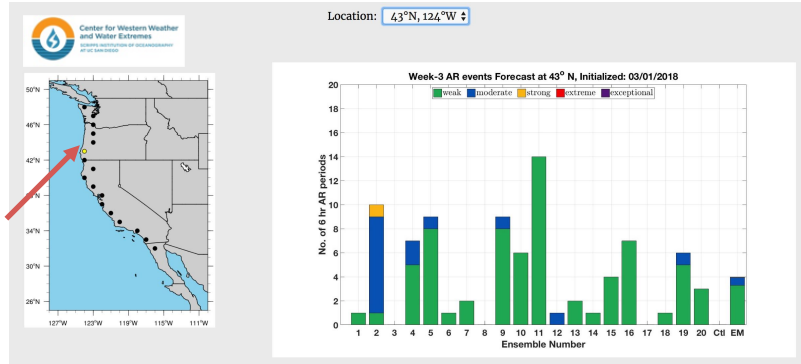
Colorado State University

AR probability maps (DeFlorio & Waliser)

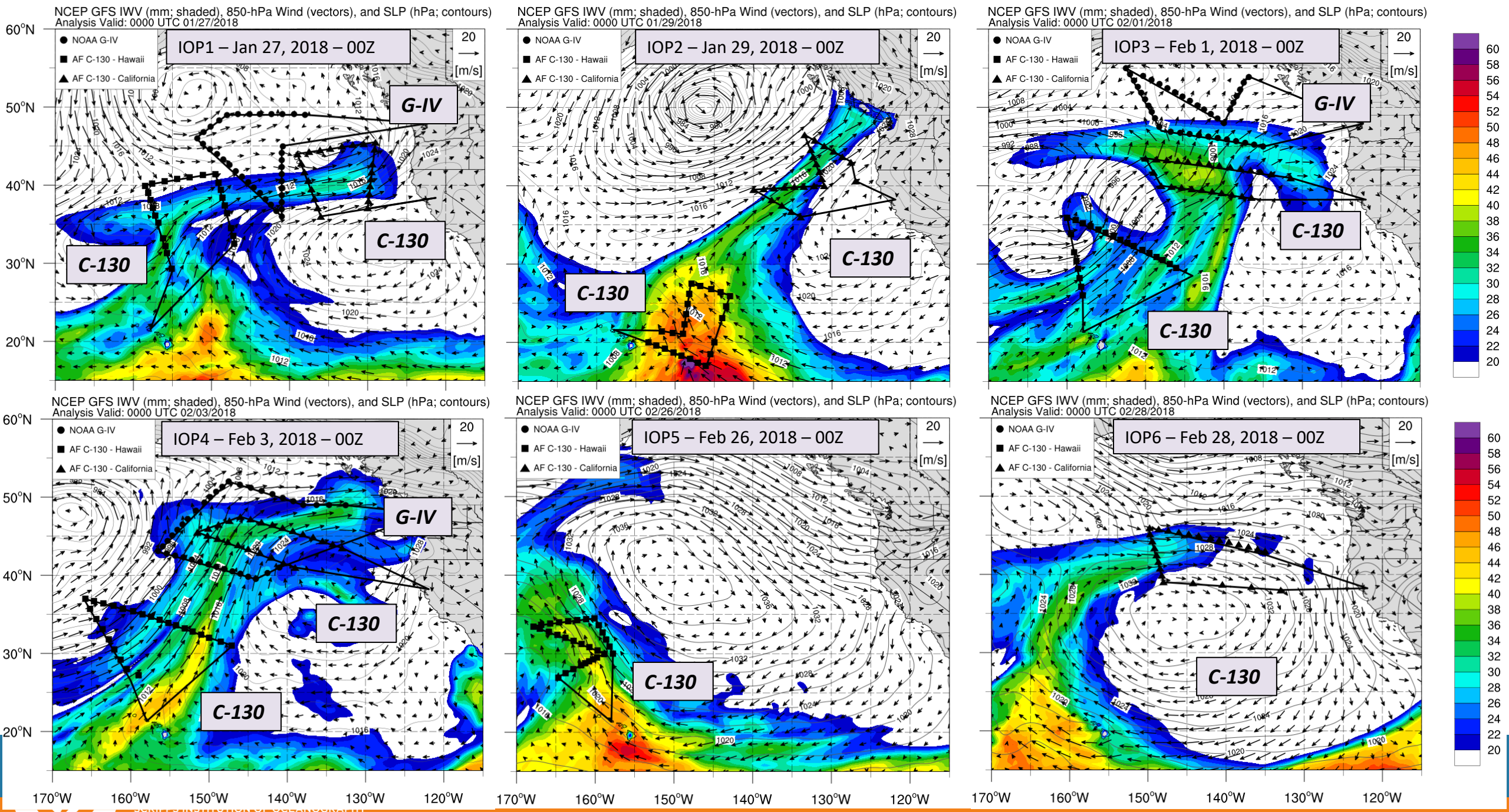




Landfall tool extended to week-2 and week-3 (Cordeira & Ralph)



AR scale probabilities for coastal locations (Subramanian & Ralph)


NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 01/27/2018
IOP1 – Jan 27, 2018 – 00Z
NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 01/29/2018
IOP2 – Jan 29, 2018 – 00Z
NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/01/2018
IOP3 – Feb 1, 2018 – 00Z
NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/03/2018
IOP4 – Feb 3, 2018 – 00Z
NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/26/2018
IOP5 – Feb 26, 2018 – 00Z
NCEP GFS IWV (mm; shaded), 850-hPa Wind (vectors), and SLP (hPa; contours)
Analysis Valid: 0000 UTC 02/28/2018
IOP6 – Feb 28, 2018 – 00Z
NOAA G-IV
AF C-130 - Hawaii
AF C-130 - California
G-IV
C-130
20
[m/s]
60°N
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
60
58
56
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