Atmospheric River Reconnaissance: Needs, Approaches and Underlying Science

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

AR Recon Data Assimilation and Impacts Assessment Steering Committee:

F. Martin Ralph, Scripps Institution of Oceanography/CW3E

Vijay Tallapragada (presenter), NOAA/NWS/NCEP

James Doyle, Naval Research Lab.

Chris Davis, NCAR

Florian Pappenberger, ECMWF

Aneesh Subramanian, CU Boulder

ECMWF Workshop:
Observational Campaigns for Better Weather Forecasts
10-13 June 2019
Reading, UK

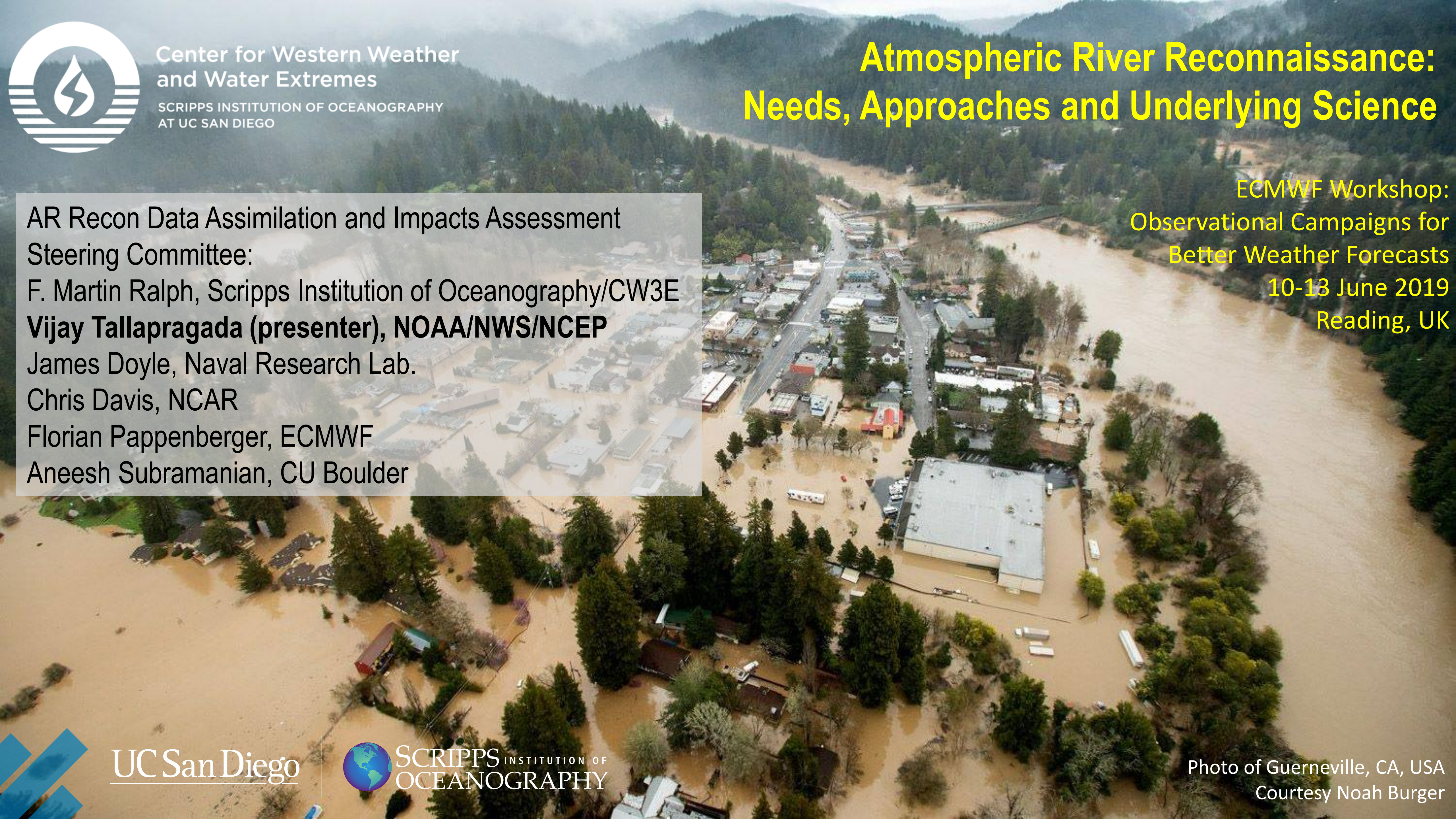


Photo of Guerneville, CA, USA
Courtesy Noah Burger

UC San Diego | SCRIPPS INSTITUTION OF OCEANOGRAPHY

Overarching concept for AR Recon

- Forecasts of landfalling storms on the U.S. West Coast in winter are impacted by limitations in the accuracy of initial conditions over the Eastern North Pacific used for numerical weather prediction.

- Impacts of landfalling storms in the cool-season include
  - Extreme precipitation and flooding
  - Coastal erosion and coastal flooding due to waves and high sea levels
  - Damaging high winds

- Extreme precipitation and flooding is mostly associated with landfalling atmospheric rivers, and landfall position errors are +/- 200-500 km at 1-5 days lead time (Wick et al. 2013)

- The initial condition errors that produced the greatest error in forecasts of a major landfalling storm in Europe at 2 days lead time were the offshore position and characteristics of an atmospheric river (Doyle et al. 2014)

- On average the greatest sensitivity coincides with the AR and its edges. (Reynolds et al. 2019)

Glossary of Meteorology

Added May 2017. Process described in Ralph, Dettinger, Cairns, Galarneau, Eylander, 2018, *Bull. Amer. Meteor. Soc.*, ***99***, pp 837-839.

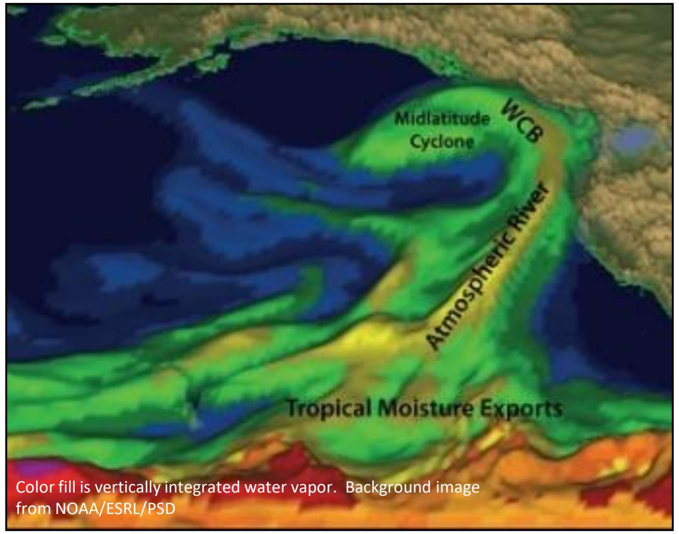
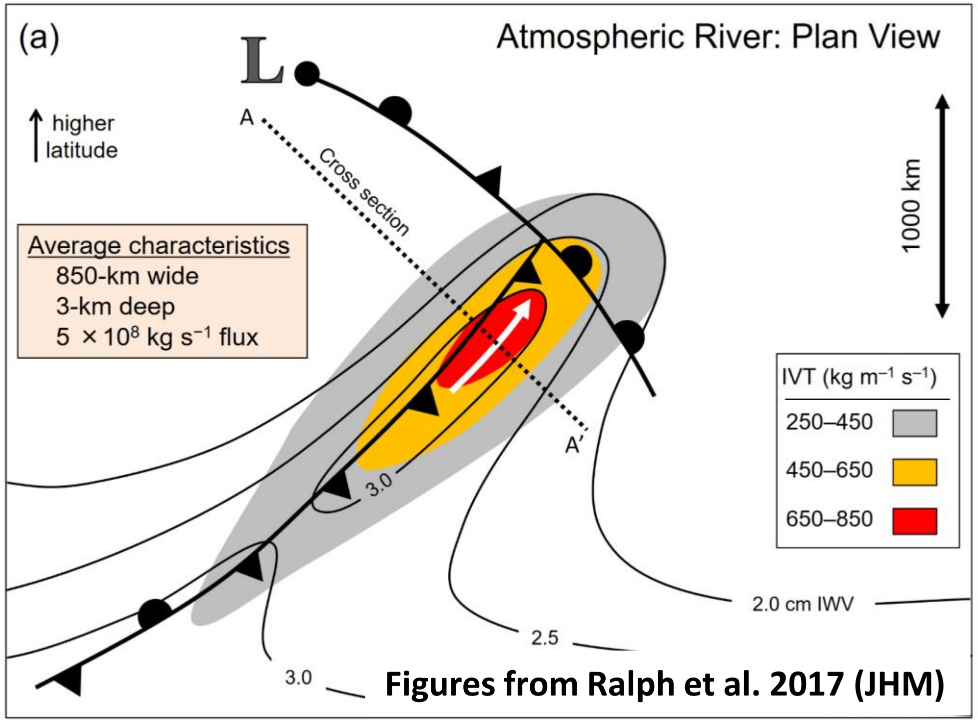


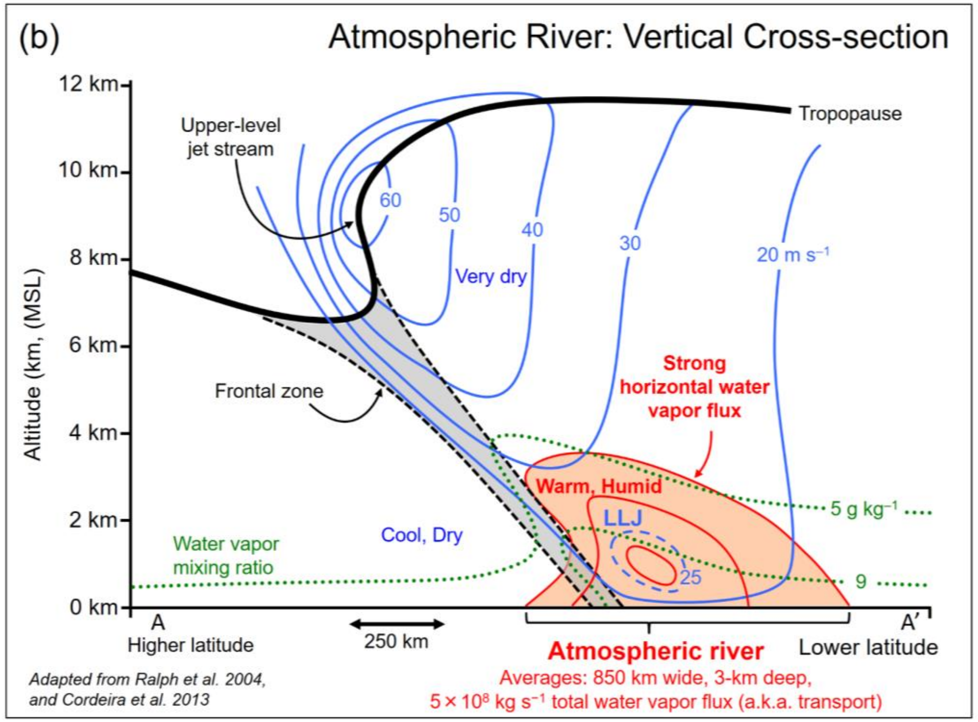
Fig. from Dettinger, Ralph, Lavers, EOS 2015

ATMOSPHERIC RIVER

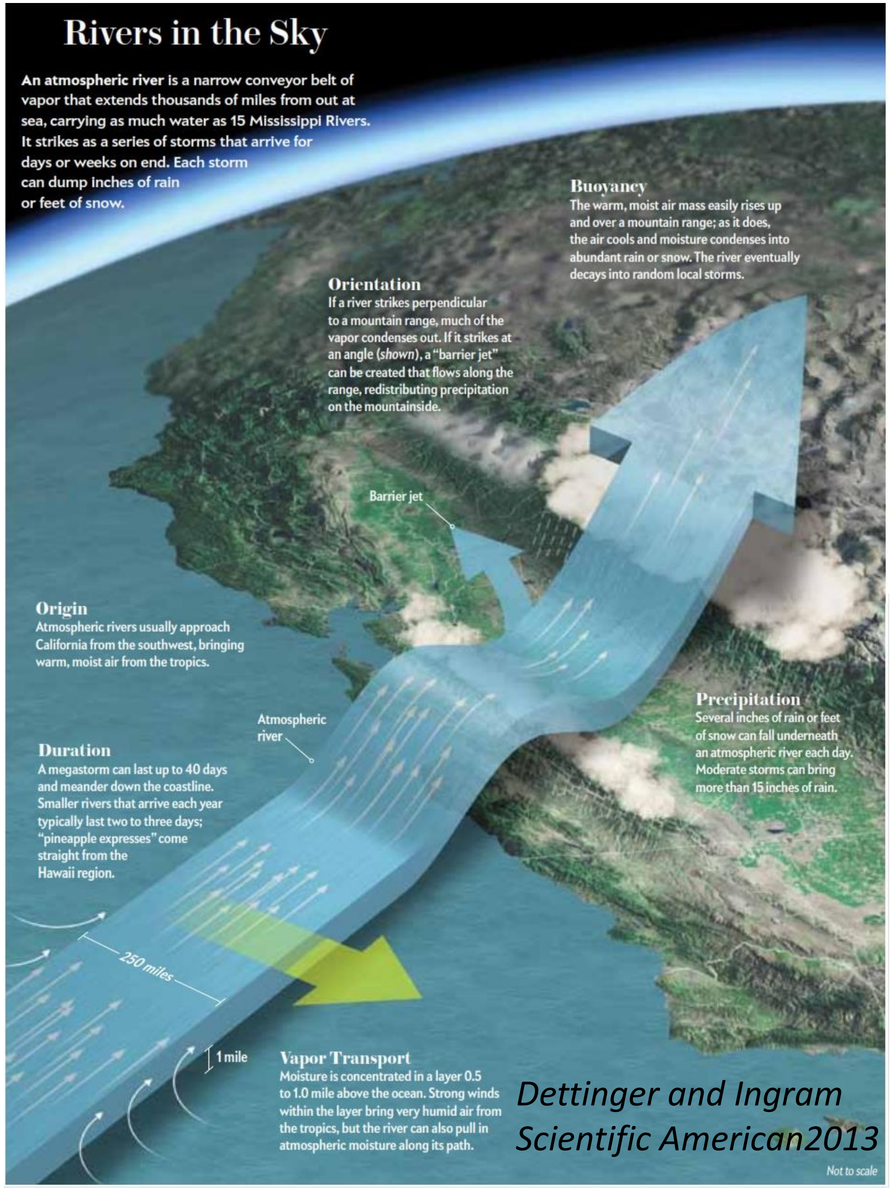
A long, narrow and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources. Atmospheric rivers frequently lead to heavy precipitation where they are forced upward, e.g., by mountains or by ascent in the warm-conveyor-belt. Horizontal water vapor transport in the mid-latitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere.



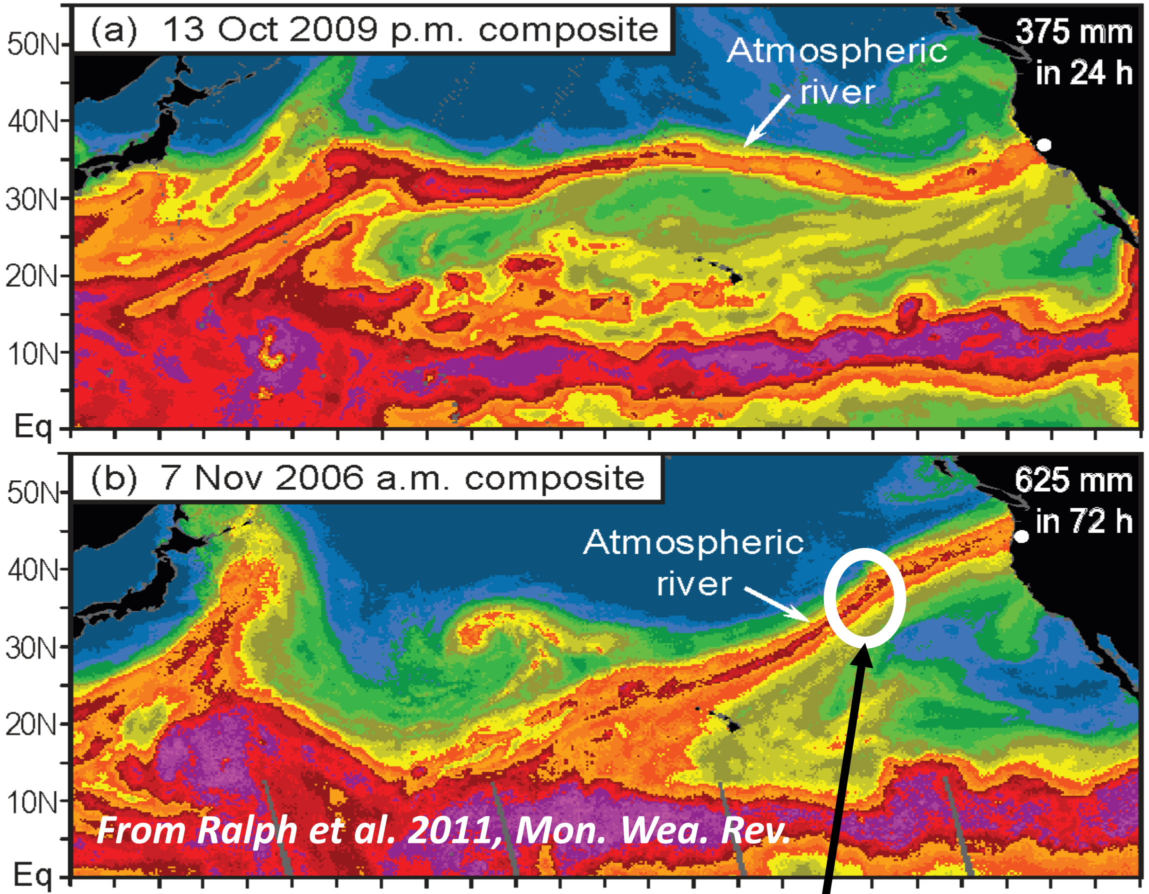
Figures from Ralph et al. 2017 (JHM)



Atmospheric Rivers are like rivers in the sky – Rivers of water vapor



Dettinger and Ingram Scientific American2013



From Ralph et al. 2011, Mon. Wea. Rev.

These color images represent satellite observations of atmospheric water vapor over the oceans.

Warm colors = moist air
Cool colors = dry air

ARs can be detected with these data due to their distinctive spatial pattern.

In the top panel, the AR hit central California and produced 18 inches of rain in 24 hours.

In the bottom panel, the AR hit the Pacific Northwest and stalled, creating over 25 inches of rain in 3 days.

One AR transports as much water as 25 Mississippi Rivers, but as vapor rather than liquid
(from Ralph et al. 2017)

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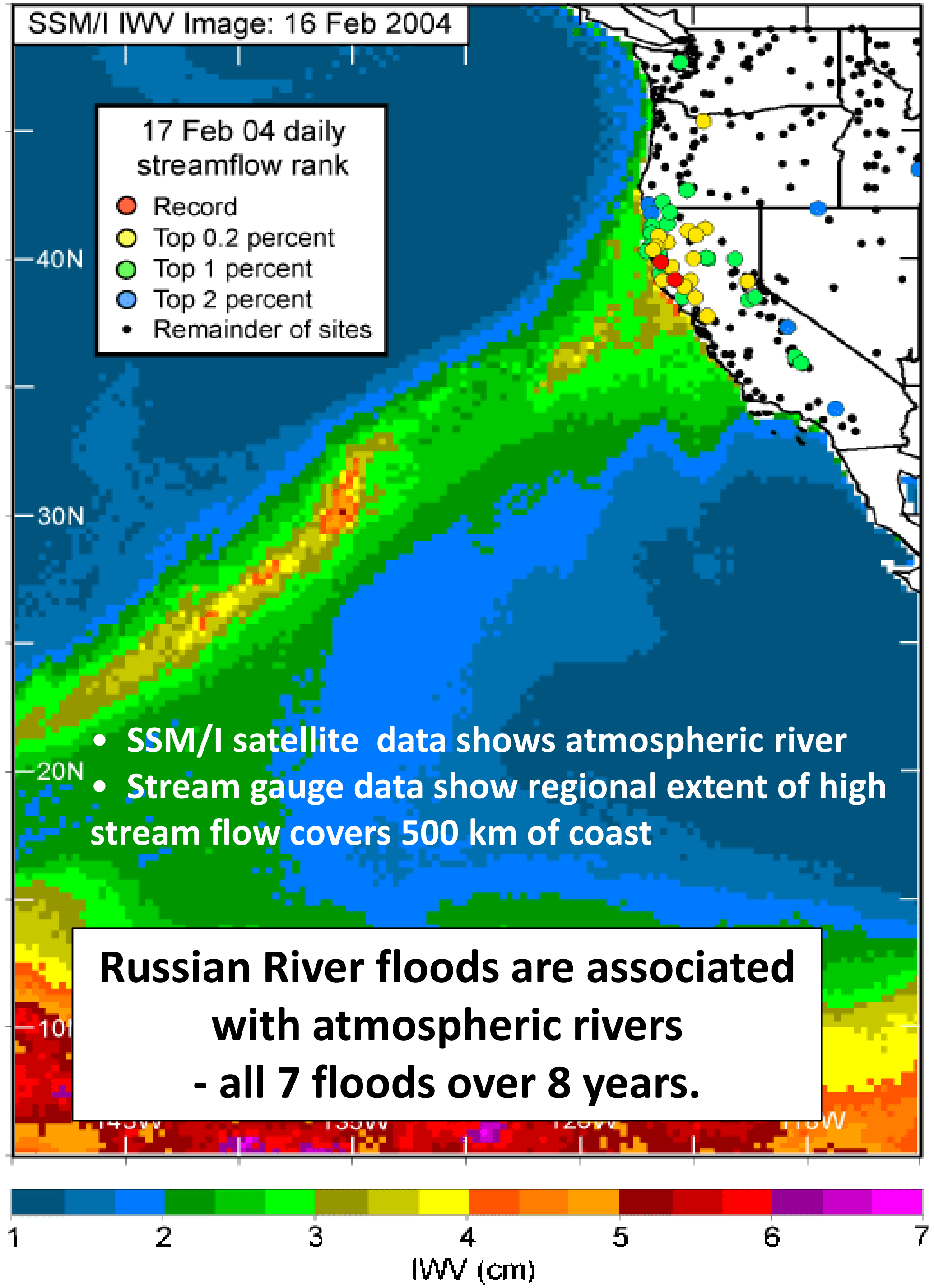
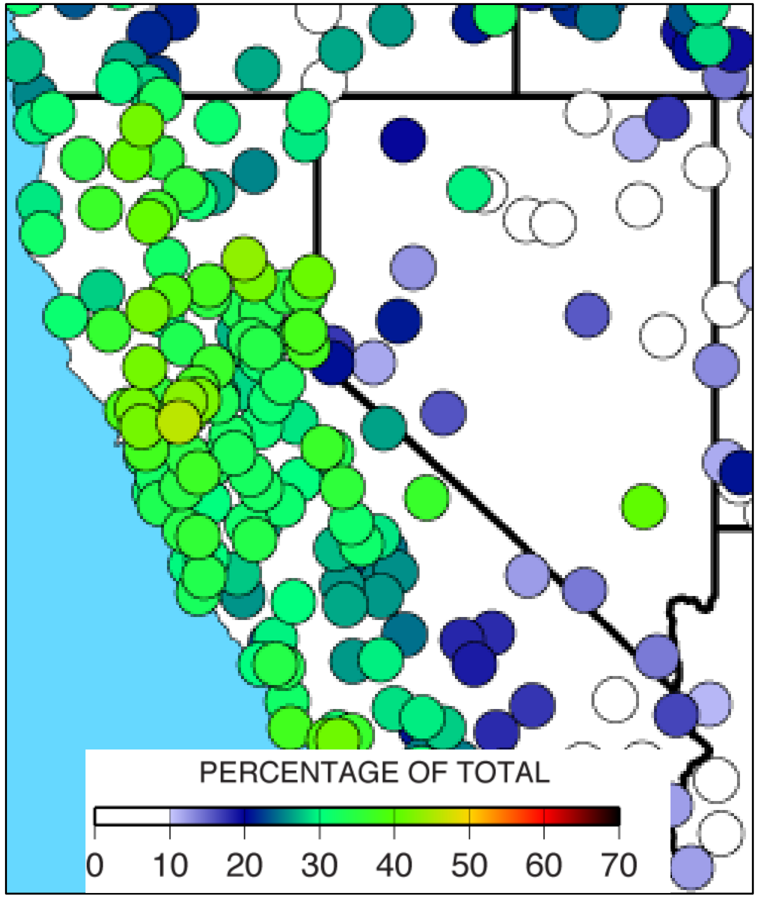
AR Impacts



Flooding on California's Russian River: Role of atmospheric rivers

Ralph, F.M., P. J. Neiman, G. A. Wick, S. I. Gutman, M. D. Dettinger, D. R. Cayan, A. White (*Geophys. Res. Lett., 2006)*

ARs can CAUSE FLOODS and PROVIDE WATER SUPPLY

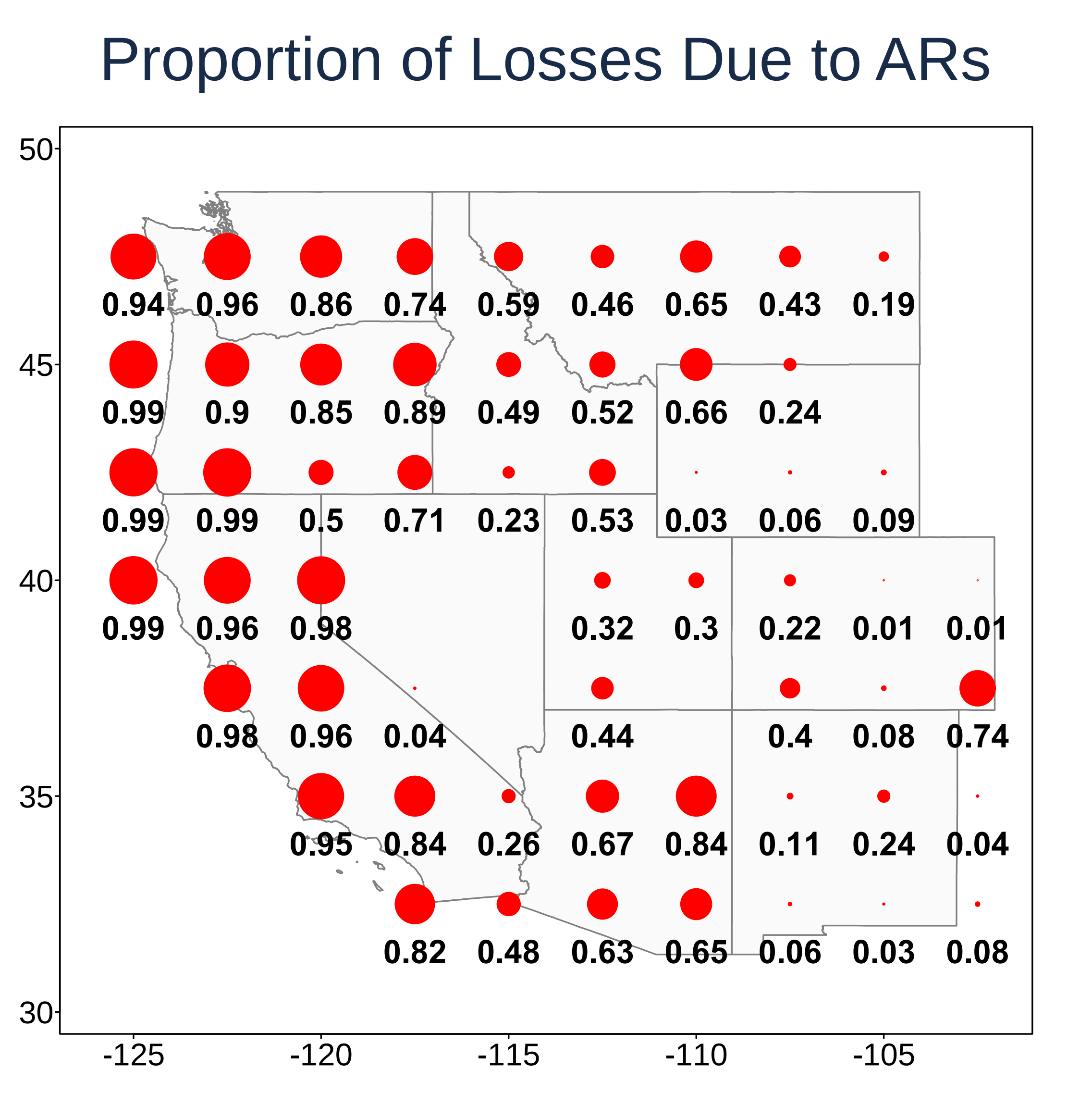


Atmospheric Rivers, Floods and the Water Resources of California

Mike Dettinger, M. Ralph, , T. Das, P. Neiman, D. Cayan (*Water, 2011*)

ARs drive flood losses

84% of insured losses in the 11 western states were caused by ARs



Cordeira et al., 2019 (BAMS, in press), "San Francisco Bay Area landslide days predominantly occur during December–March in Sonoma, Marin, San Mateo, and Santa Cruz counties where 82% of these days coincide with landfalling atmospheric rivers."

T. Corringham, 2018

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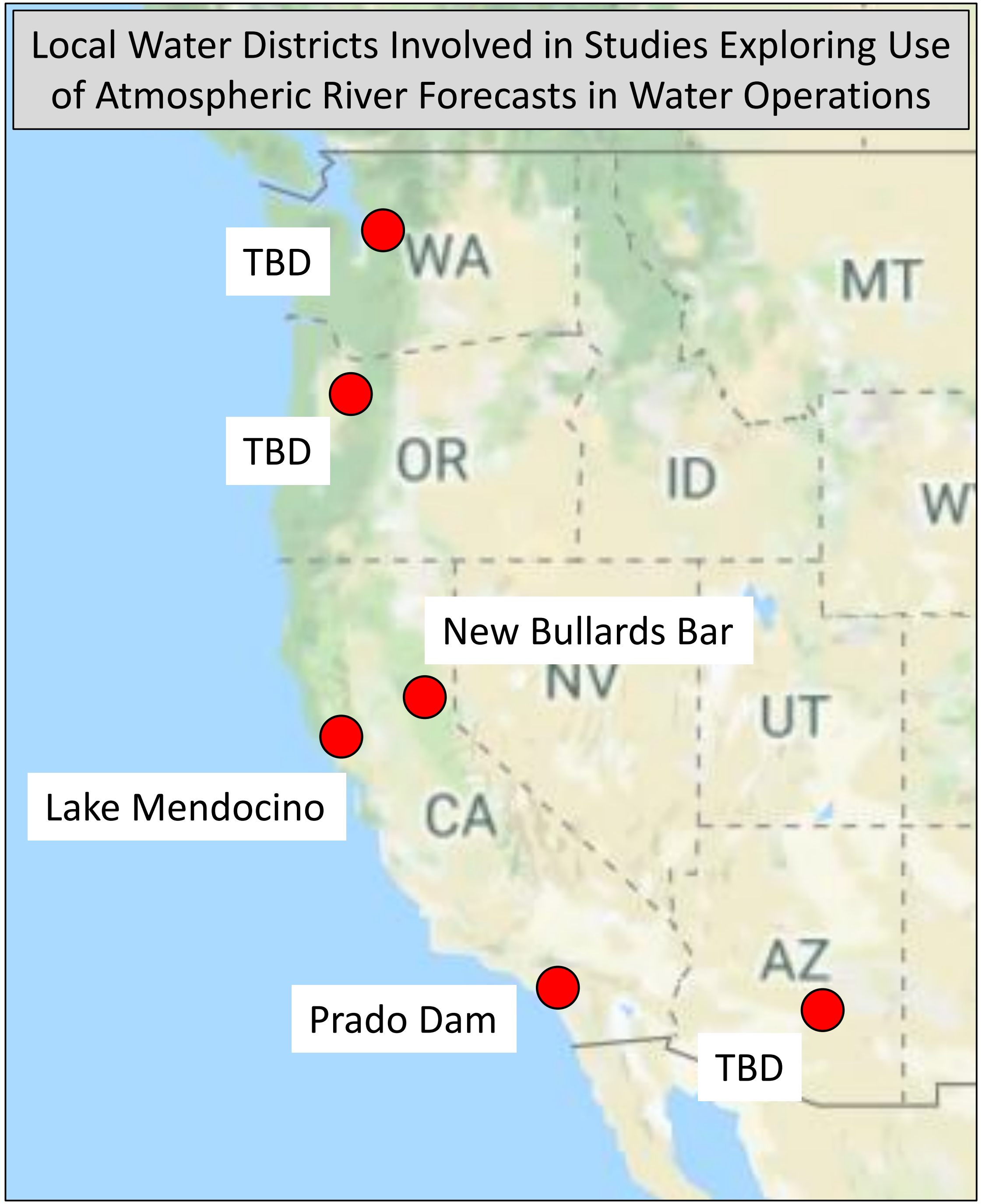
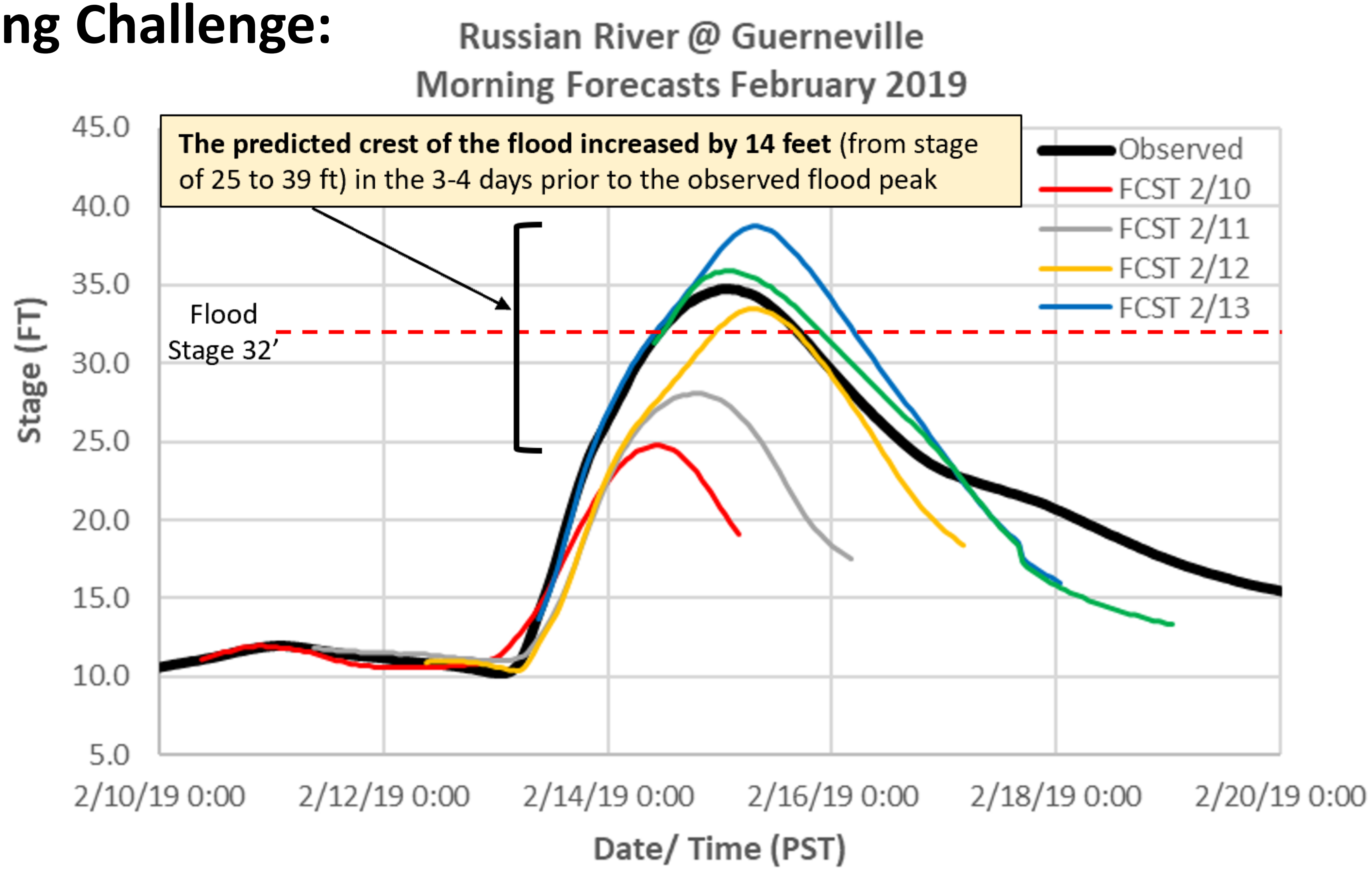


Water Supply hinges on ARs in this region.

Agencies responsible for providing water for the public, agriculture, and industry, while maintaining healthy (water-dependent) ecosystems, can improve their operations through use of better forecasts of ARs and their associated extreme precipitation and runoff.

Forecasting challenges associated with landfalling ARs

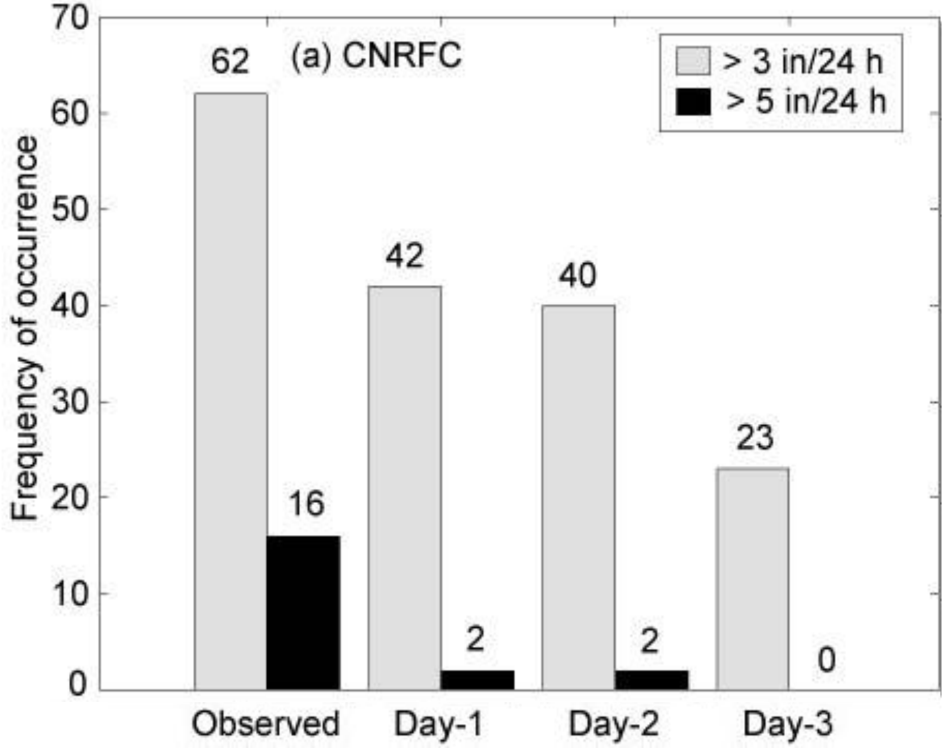
The Forecasting Challenge: Floods



Each line represents a different forecast (FCST) issued on either 10, 11, 12, 13 or 14 Feb, which were either 0, 1, 2, 3, or 4 days prior to when the flood crest was observed.

The Forecasting Challenge: QPF and ARs

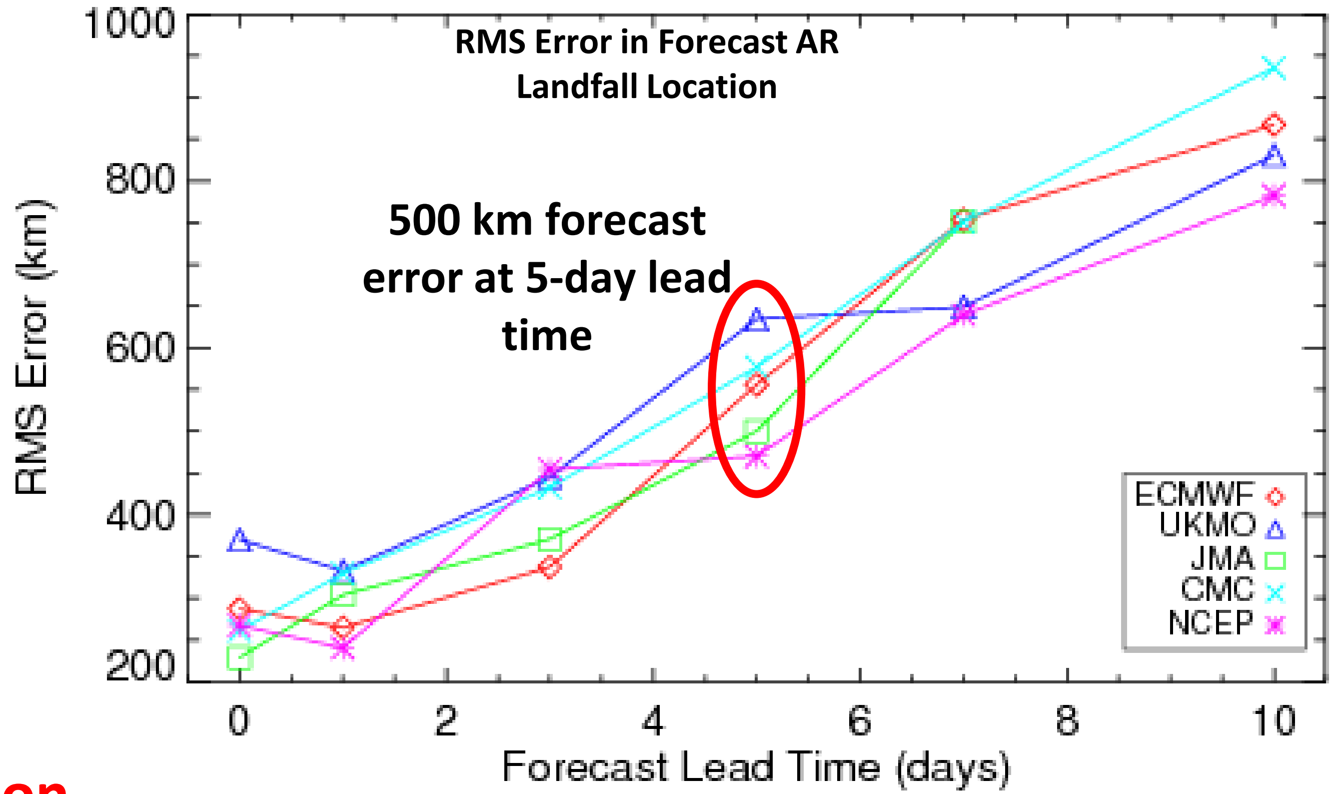
Forecasting large precipitation amounts is difficult (only 2 of 16 extreme precip. events were predicted to be that strong at just 1 day lead time)



Of the 20 dates with >3 inches of precipitation in 1 day, 18 were associated with ARs.

Ralph et al. 2010

Forecasting AR landfall includes position errors larger than watersheds



Wick et al. 2013

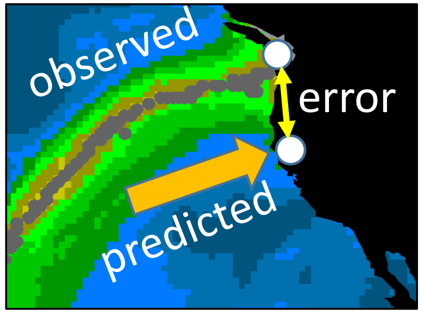
AR Reconnaissance (“AR Recon”) Targeting and Operations

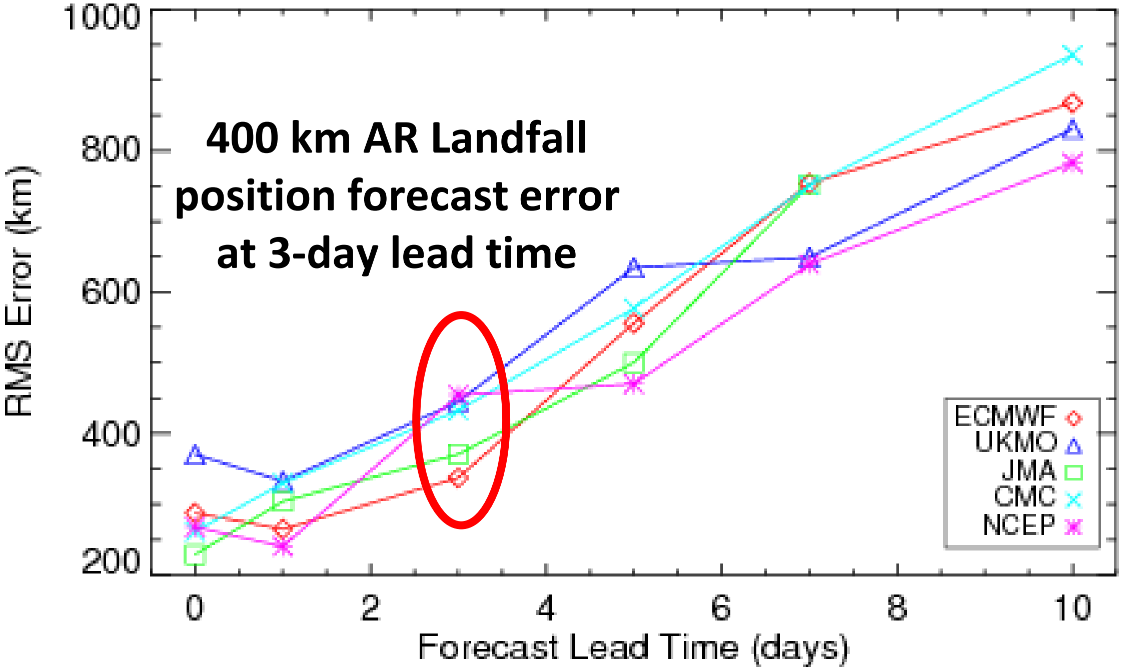
Atmospheric River Reconnaissance

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.

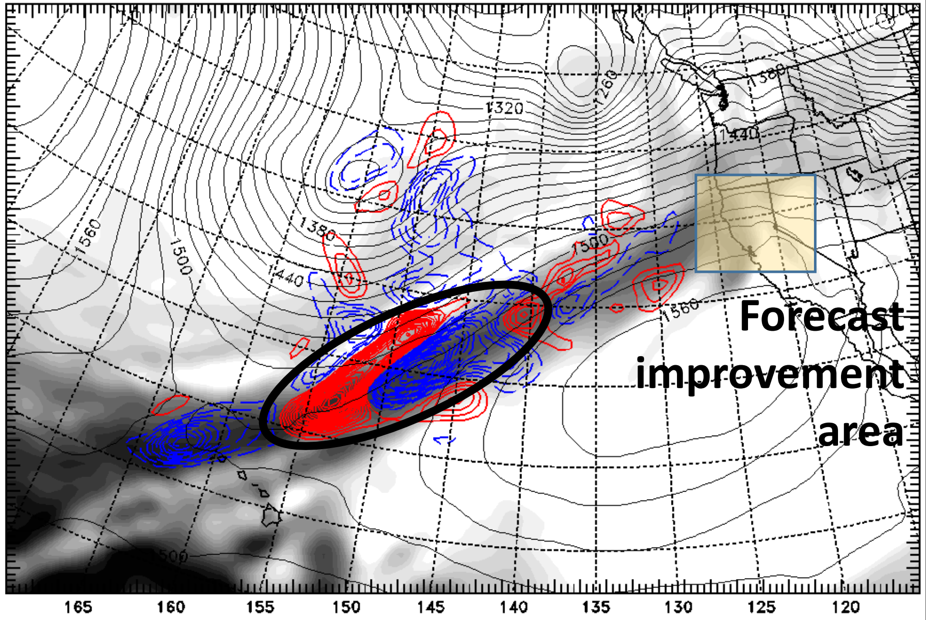
New Adjoint includes moisture – and finds AR is prime target

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

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

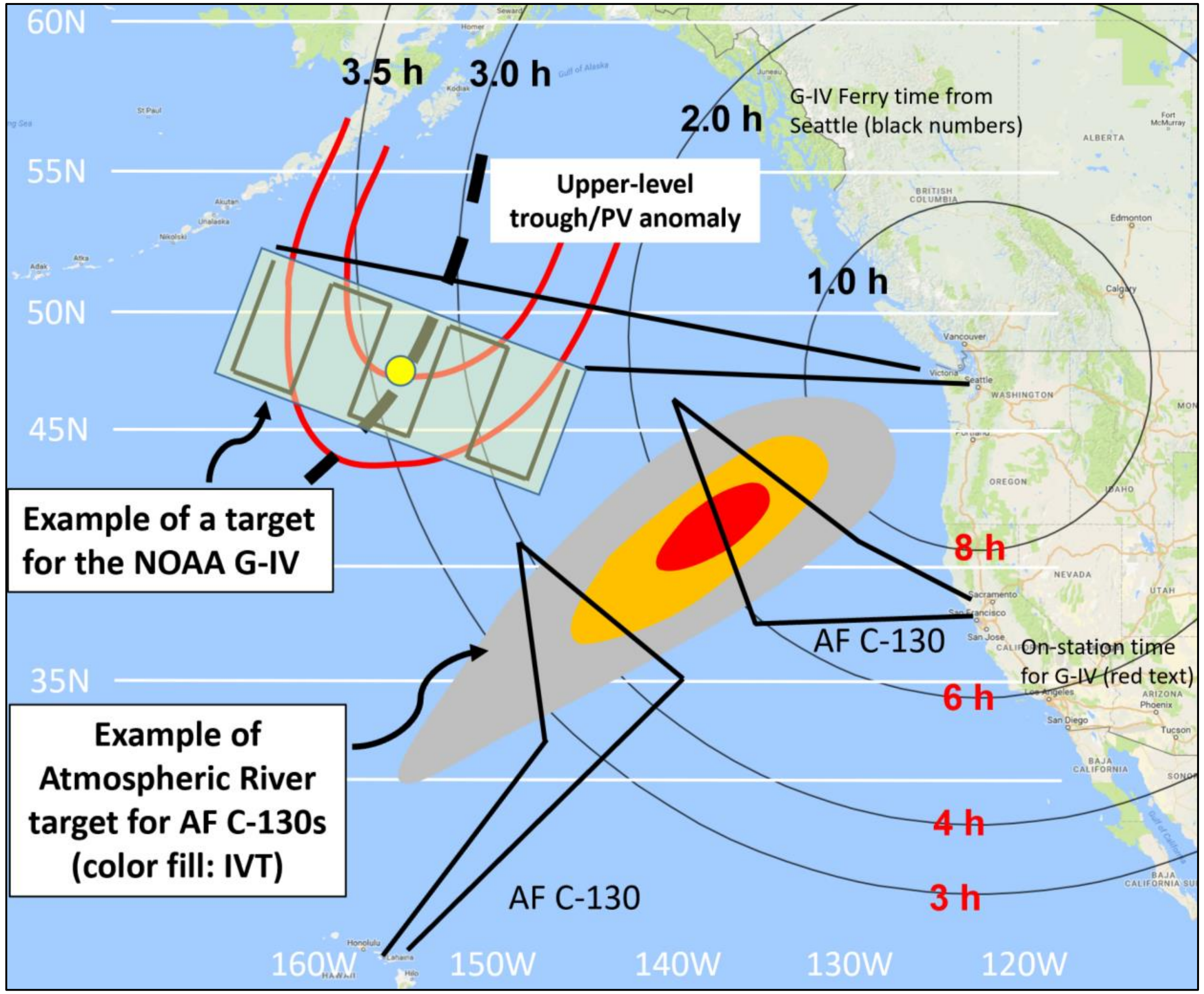
(International Atmospheric Rivers Conference 2016)

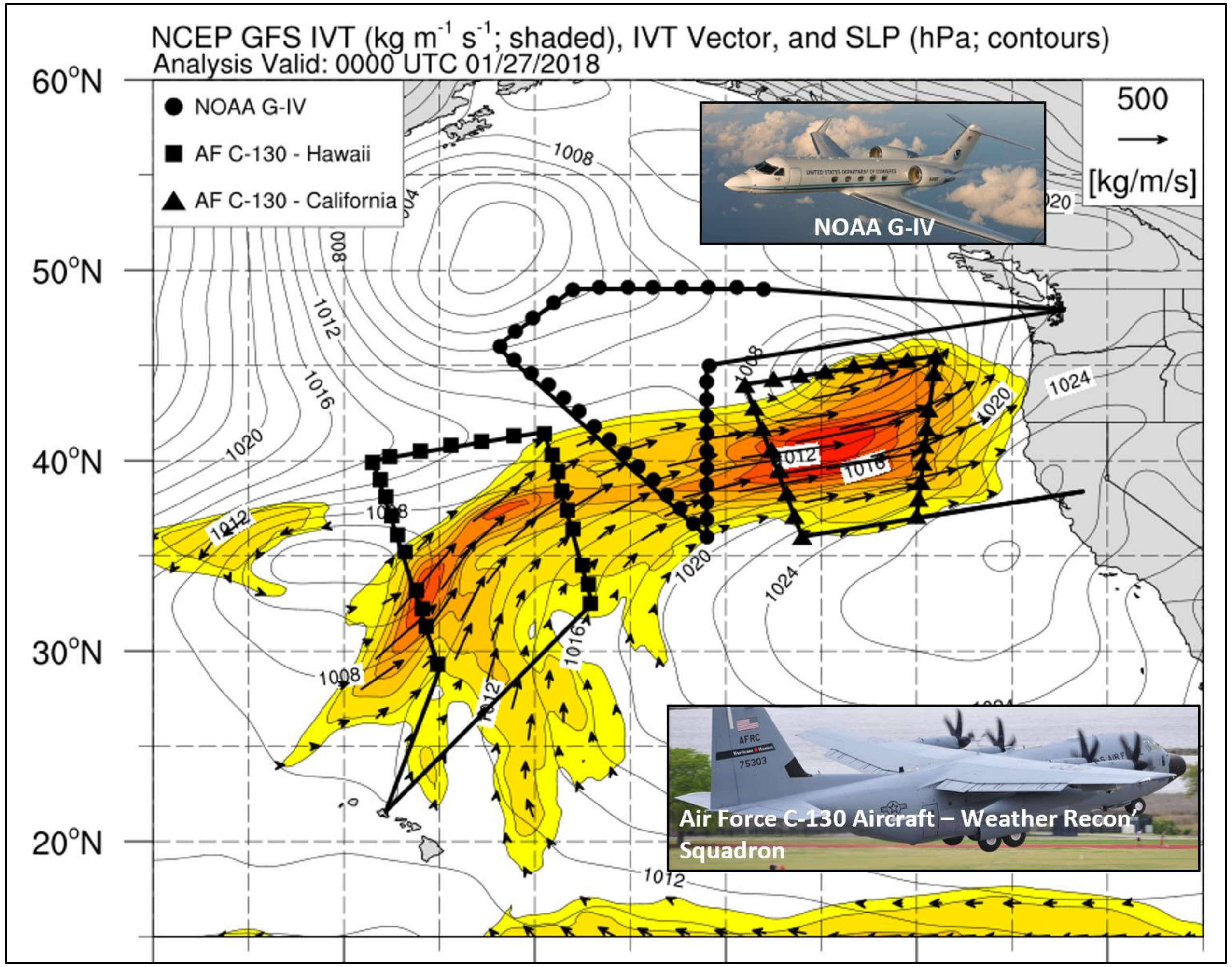
Color contours show the forecast sensitivity to 850 mb water vapor (grey shading) uncertainty at analysis time 00Z 13 Feb 2014 for a 36-h forecast over NorCal valid 12Z 14 Feb



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

Atmospheric River Reconnaissance Sampling Concept and Example from 27 Jan 2018





F. Martin Ralph (AR Recon PI; Scripps/CW3E), Vijay Tallaprgada (AR Recon Co-PI; NWS/NCEP) and AR Recon Team

AR Recon 2016 to 2020

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

✓ Feb 2016: 3 Storms (2 aircraft/storm; AF C-130s)

✓ Jan-Feb 2018: 6 Storms (3 aircraft/storm in 3 storms – 2 AF C-130s plus the NOAA G-IV (With Airborne GPS Radio Occultation, J. Haase); 2 C-130s in 1 storm; 1 C-130 in 2 storms)

✓ 1 Feb-14 Mar 2019:
  Core program: 6 storms (2 AF C-130s/storm; 25 dropsondes/aircraft/storm flight; 300 sondes)
  Addit'l data: 32 drifting buoys supplemented with barometers in AR Alley (L. Centurioni, B. Inglesby)

○ Jan-Mar 2020 (in planning): 9-12 storms (3 aircraft/storm)

○ 2021 and beyond: Long-term requirements captured in the US' National Winter Storm Operating Plan

○ **Target total number of cases: 27 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

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

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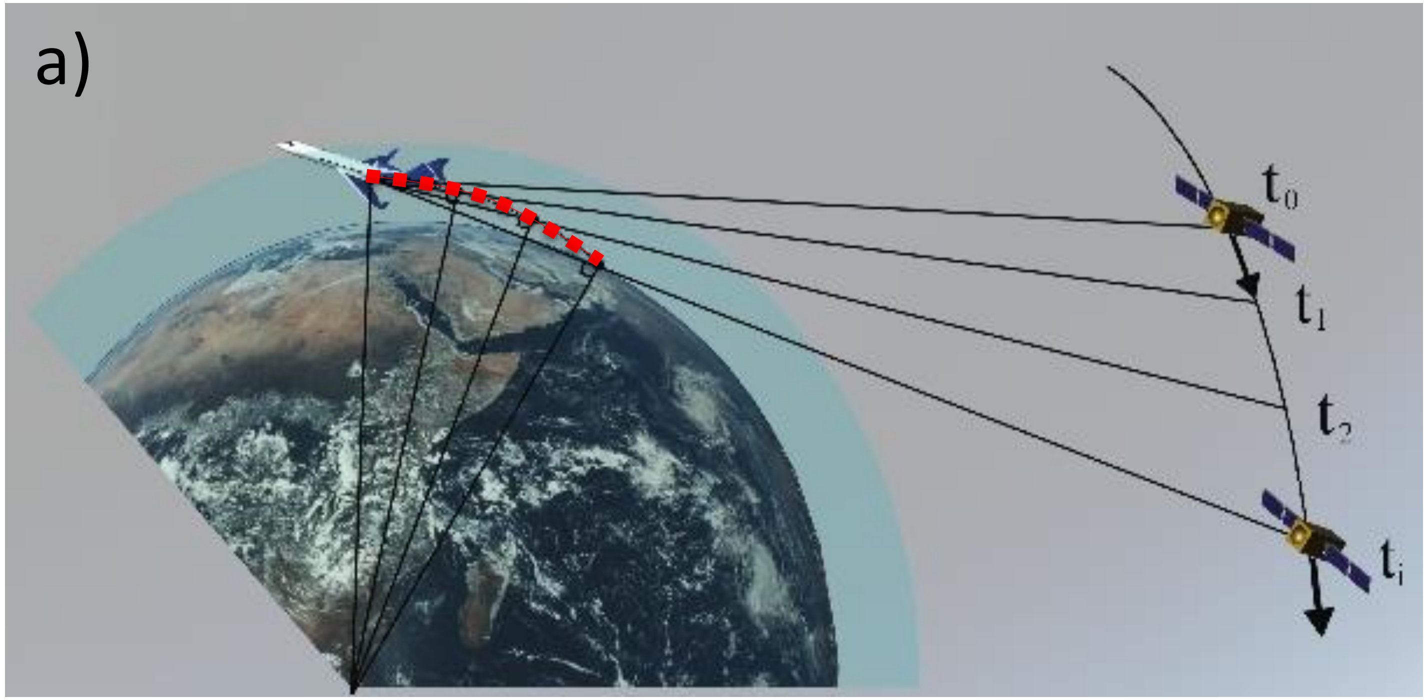
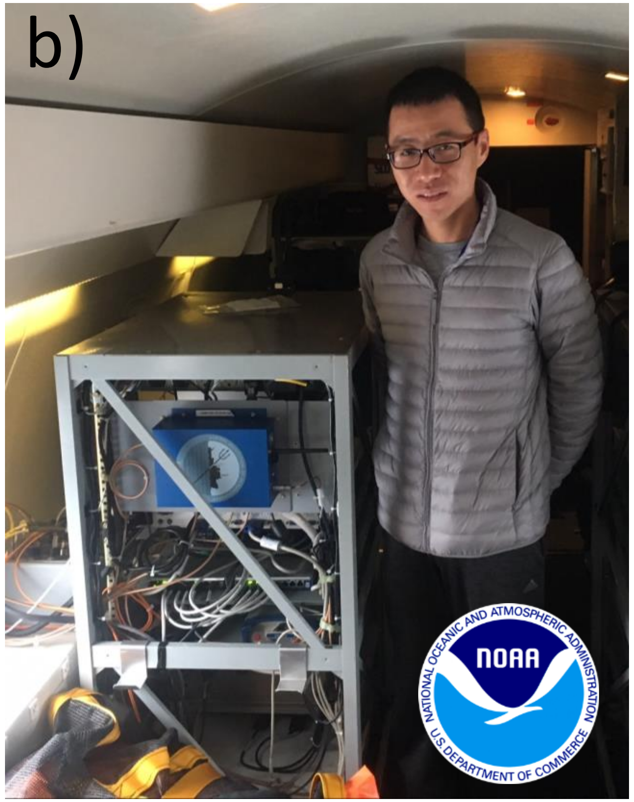
AR Recon 2018 Airborne Radio Occultation Instrument Provides Environmental Soundings Complementary to Dropsondes

See Poster by Haase et al.

PI: Dr. Jennifer Haase; jhaase@ucsd.edu



Airborne Radio Occultation (ARO) Concept
Delays in the travel time of low elevation GPS and Galileo signals as the satellites set are used to derive temperature and moisture of successively lower atmospheric layers.



NOAA GIV Installation
Small instrument profile for easy installation in any aircraft, uses existing GPS antenna.

CW3E

Research in collaboration with Marty Ralph (AR Recon PI) and the Center for Western Weather and Water Extremes

Drifting Buoys for AR Recon 2019

See Poster by Wilson et al.

Proposed Drop Locations *(no guarantee on residence time)*

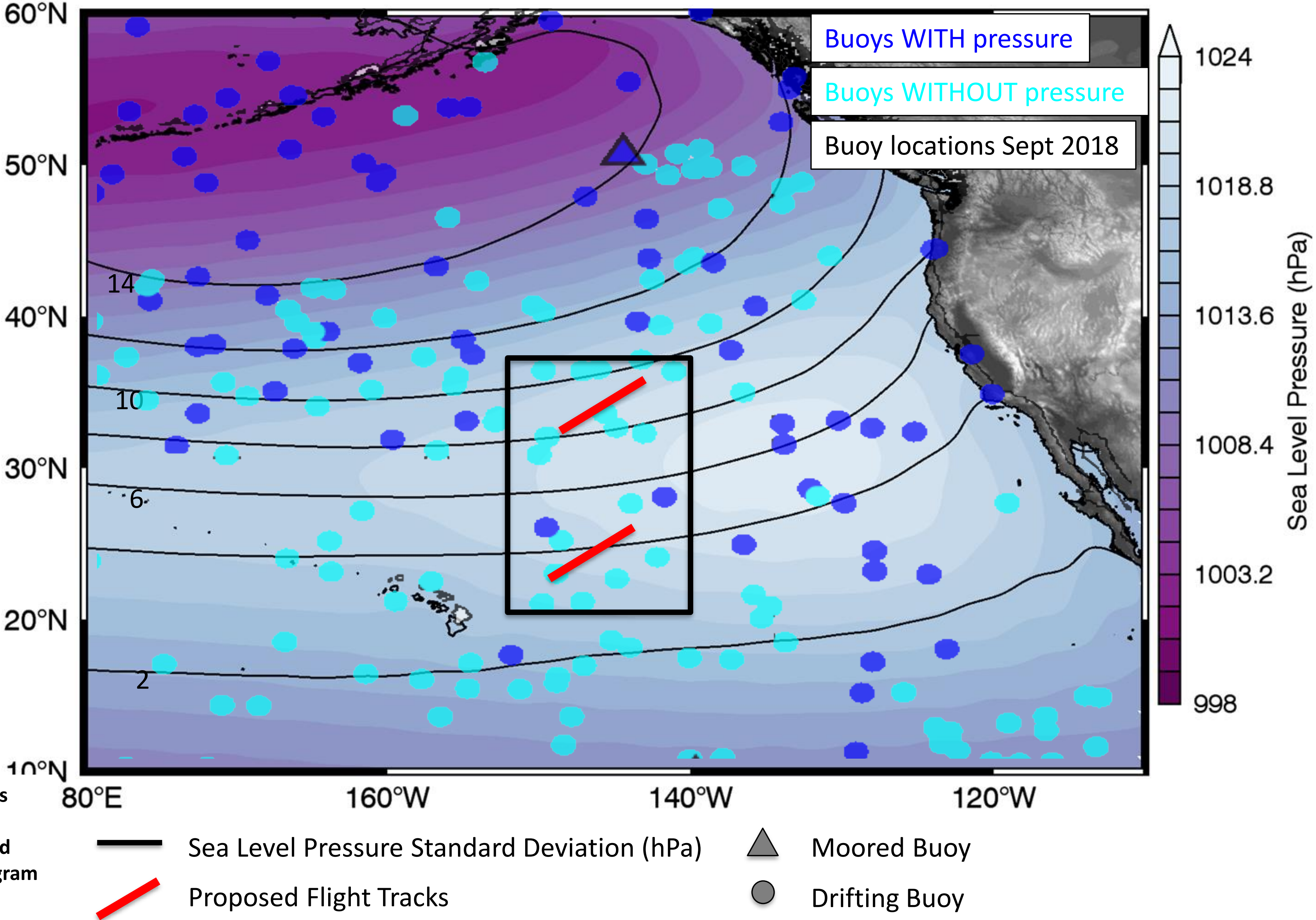
Air Force requirement: ***Starting point, direction, and spacing***
For Jan deployment, must be below 40N.

Figure provided by Forest Cannon, CW3E

PI: F. Martin Ralph

Sponsored by California's Atmospheric Rivers Research, Mitigation, and Climate Forecasting Program Managed by CA DWR

Climatology of Nov-Apr Mean Sea Level Pressure and Standard Deviation (1979-2017)

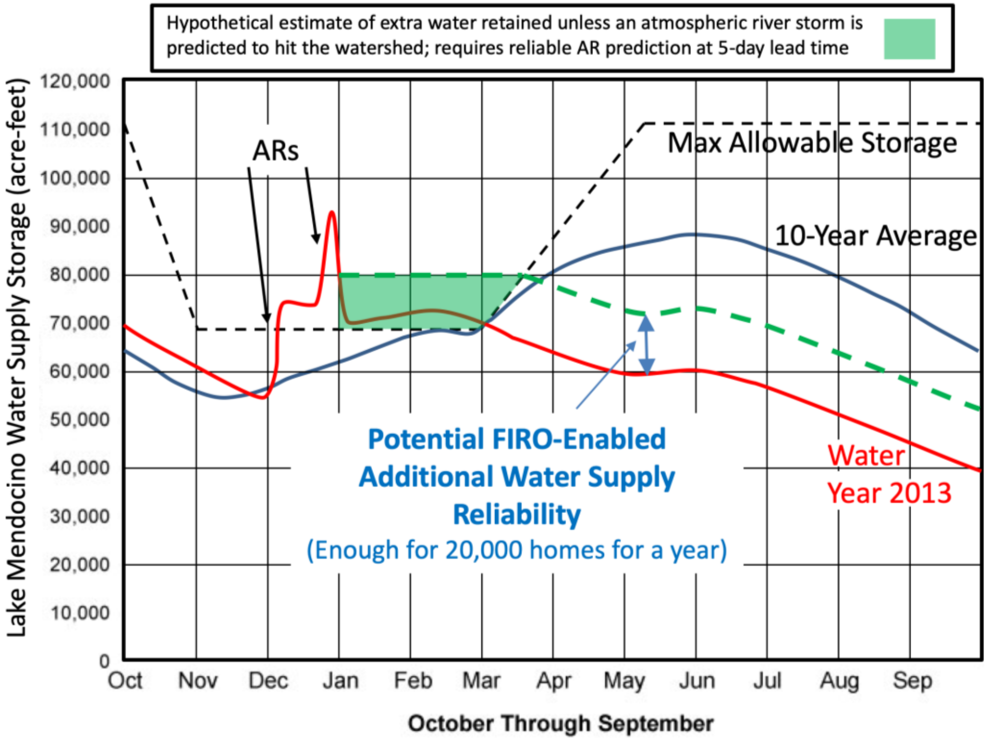


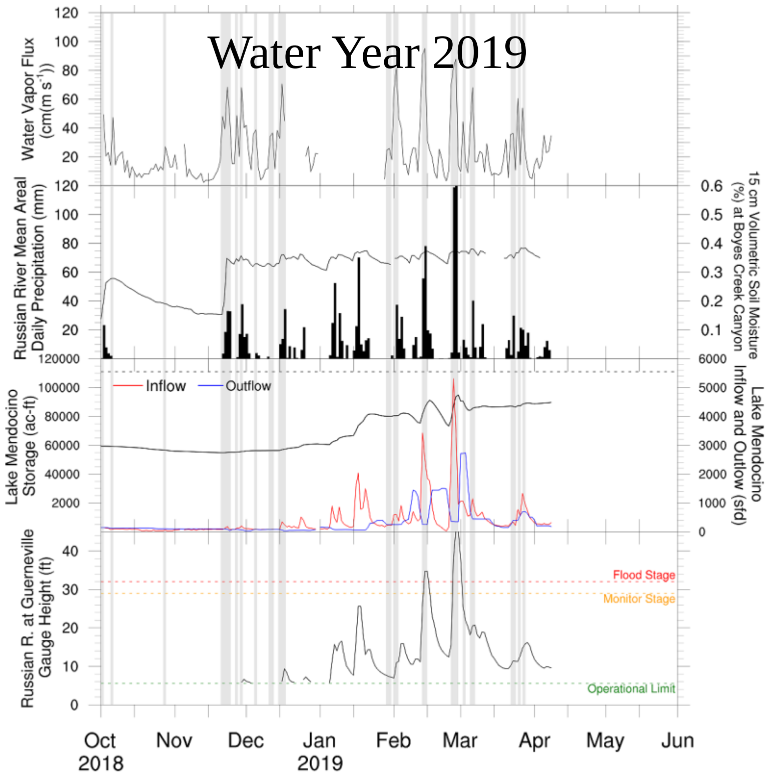
Forecast Informed Reservoir Operations (FIRO): Supporting Forecast Improvements through Targeted Data Collection

Anna M. Wilson[1], F. Martin Ralph[1], Jay Jasperse[2], Cary A. Talbot[3], Brian Kawzenuk[1], Carly Ellis[1], and Stephen Turnbull[3]

[1]*Center for Western Weather and Water Extremes*, [2]*Sonoma Water*, [3]*US Army Engineer Research and Development Center*

See Wilson et al Poster on hydrologic and hydrometeorological measurements onshore, which supports better physical understanding, model development and verification - critical components of improving forecasts.





- FIRO: How can we better use existing infrastructure to meet competing needs (flood mitigation, water supply, ecosystem services)?
- Test watershed: Lake Mendocino in northern California – ARs bring most significant precipitation and control storage regimes in soil and reservoirs
- Need better forecasts of AR landfall location, intensity, and duration, to accurately predict precipitation patterns

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 SC
F.M. Ralph (SIO/CW3E) – Co-Chair
V. Tallapragada (NCEP) – Co-Chair
J. Doyle (NRL),
C. Davis (NCAR)
F. Pappenberger (ECMWF),
A. Subramanian (SIO/CW3E)

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

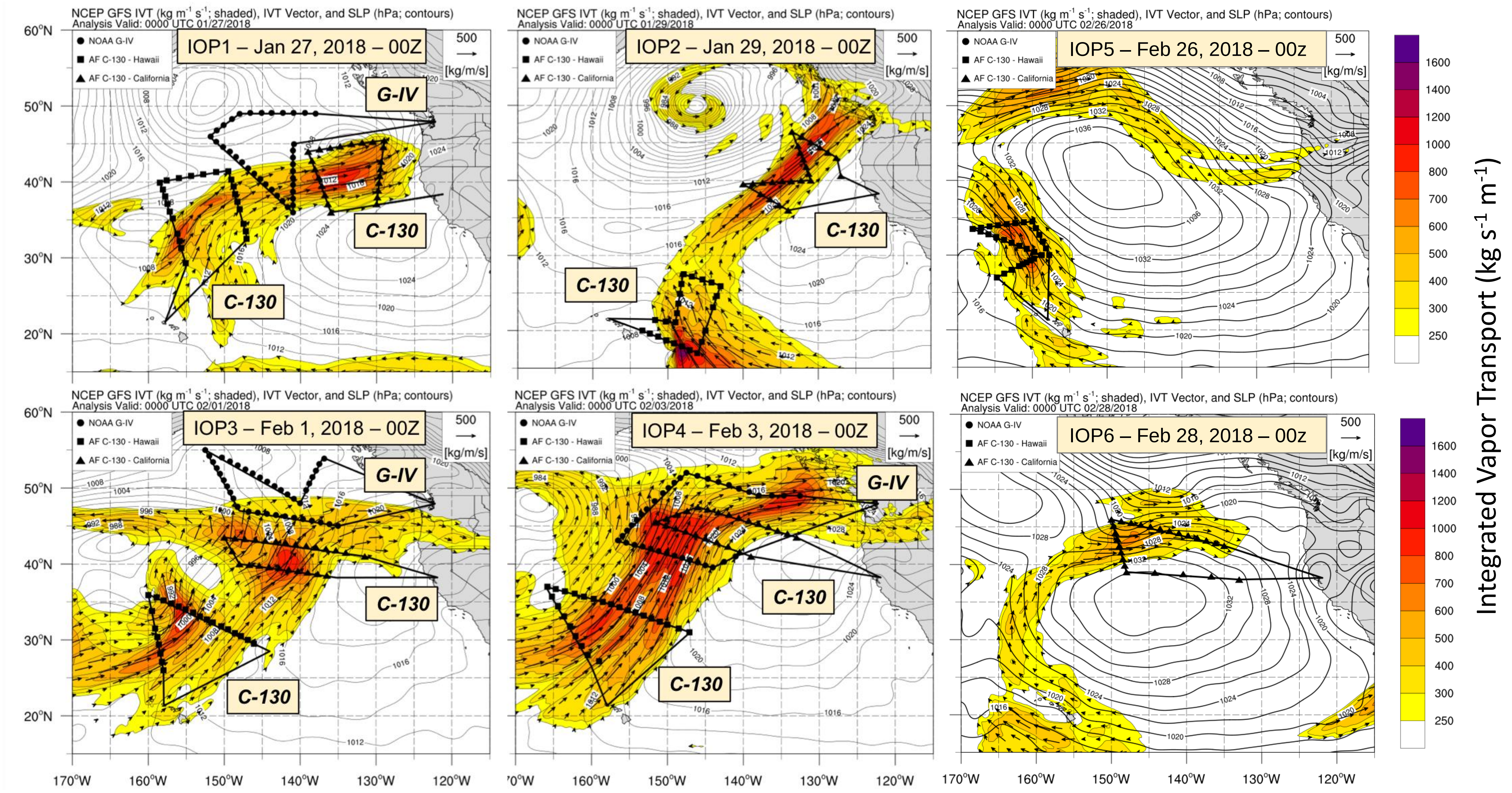
25 Jan - 27 Feb: two C-130s available for 6 storm flts from Hawaii, Seattle, Travis AFB or San Diego

Atmospheric River Reconnaissance 2018

Center for Western Weather and Water Extremes

Contacts: F. M. Ralph (PI; mralph@ucsd.edu); V. Tallapragada (Co-PI; vijay.tallapragada@noaa.gov)

U.S. AIR FORCE



Early analysis

The Gauging and Modeling of Rivers in the Sky

D. A. Lavers[1], M. J. Rodwell[1], D. S. Richardson[1], F. M. Ralph[2],J. D. Doyle[3], C. A. Reynolds[3], V. Tallapragada[4] , and F. Pappenberger[1]

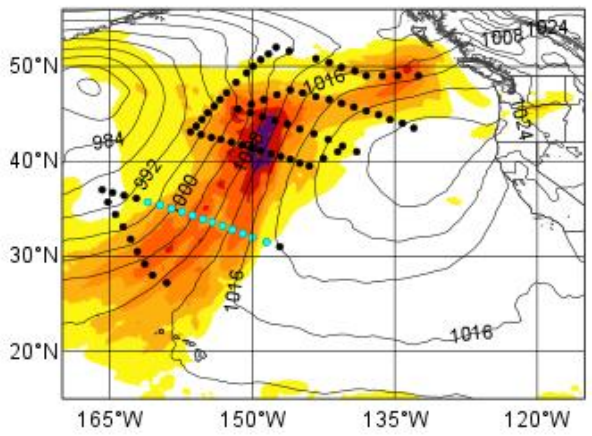
[1]European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK, [2]Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California, San Diego, CA, USA, [3]Naval Research Laboratory, Monterey, CA, USA, [4]NOAA/NWS/NCEP/Environmental Modeling Center, College Park, MD, USA

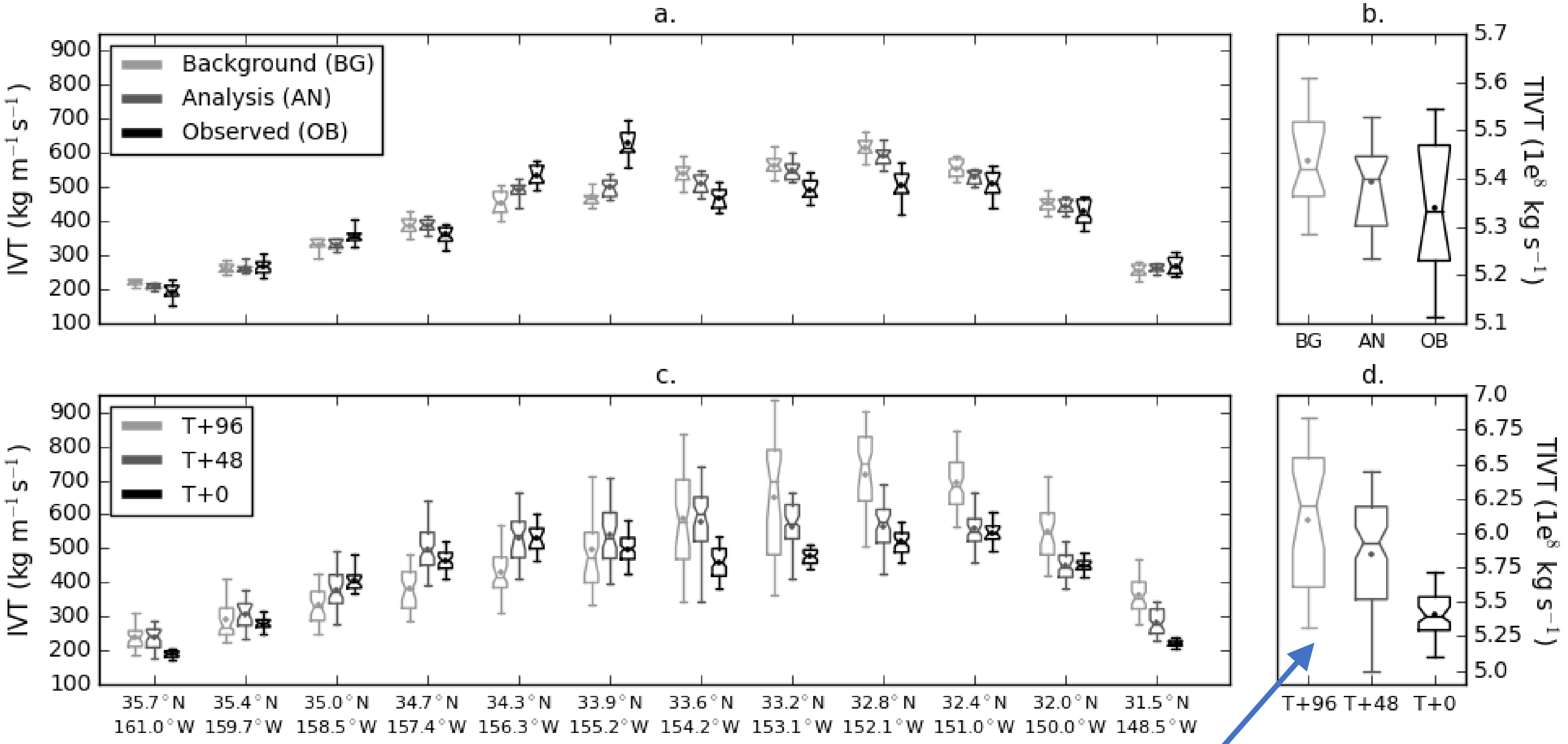
Geophysical Research Letters, 2018

Significant differences were found between the observed AR characteristics and the ECMWF first guess, especially near the MBL top.

An example comparison between observed and model initial condition in an AR transect

d. IOP4 00UTC 03 Feb. 2018

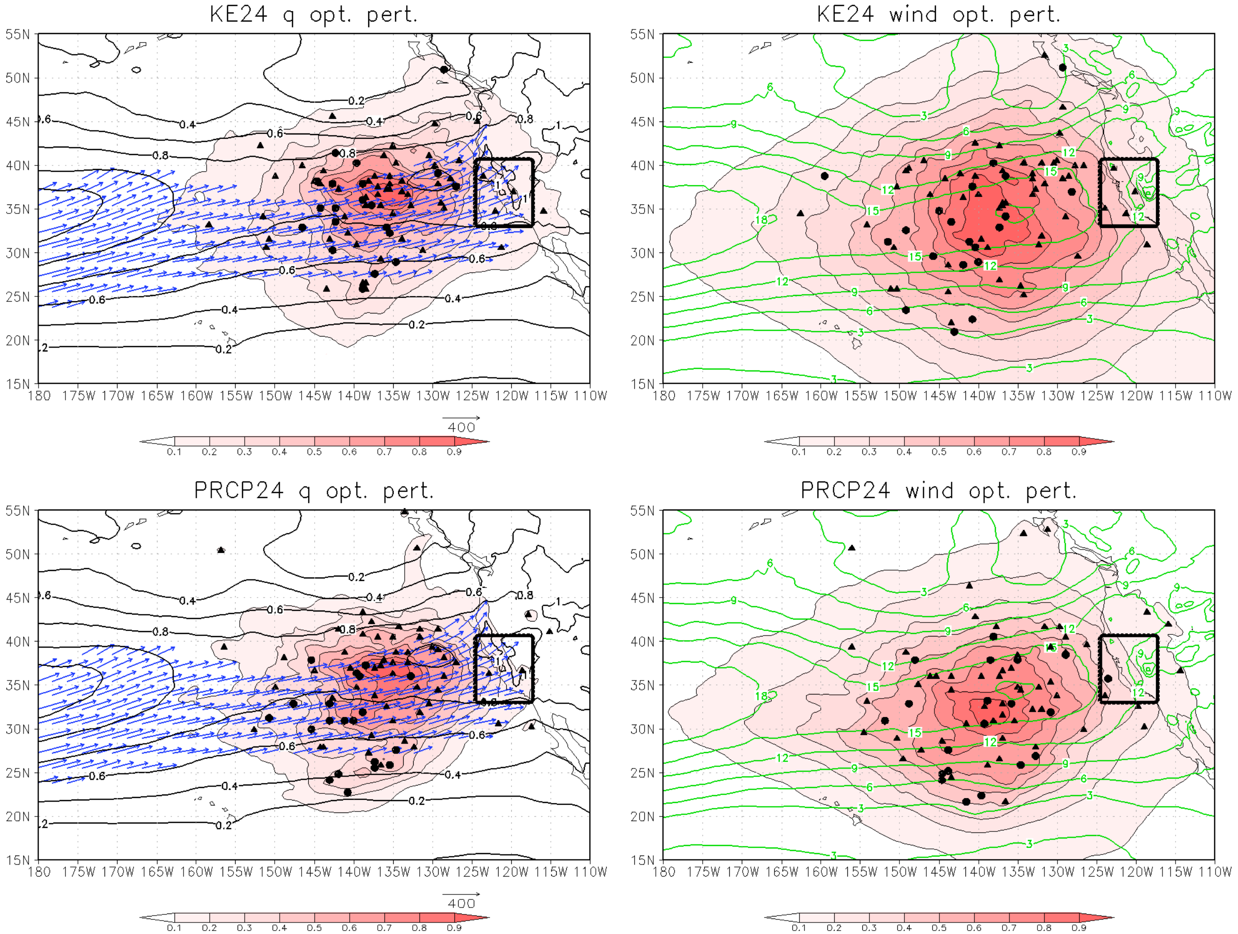




~20% difference in water vapor transport predicted at the location observed by AR Recon

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

Adjoint Sensitivity of North Pacific Atmospheric River Forecasts



Vertically averaged optimal perturbations for moisture (left panels) and wind (right panels) for wind forecasts (top) and precipitation forecasts (bottom). Moisture figures include IVT (blue vectors) and Eady growth rate (black contours, day^{-1}). Wind panels include 700-hPa wind speed (green contours, m s^{-1}). The locations of individual maxima are indicated by triangles and circles (circles represent the 20 largest sensitivity cases).

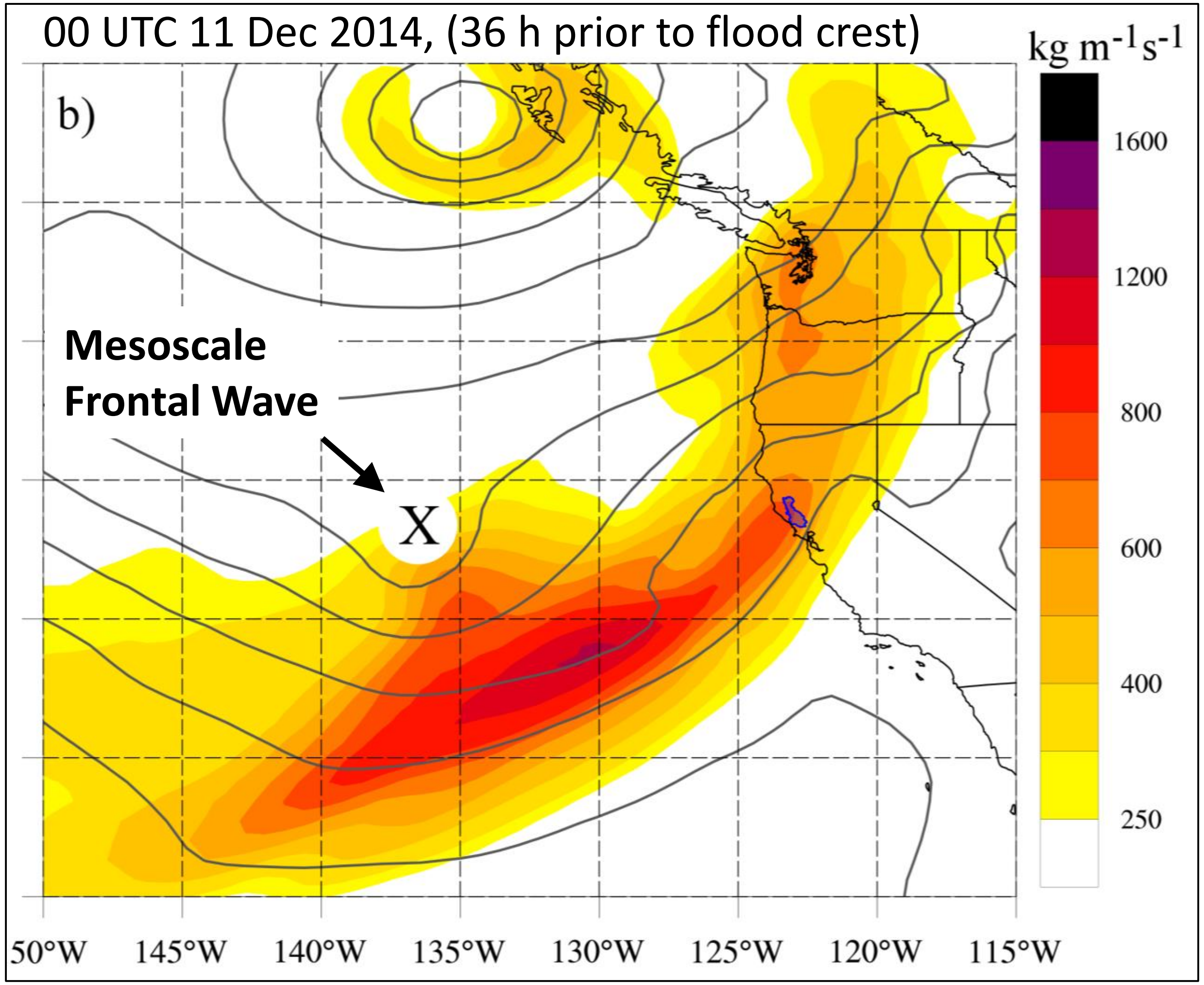
On average, sensitivity of the wind forecasts (top) and precipitation forecasts(bottom) are very similar, with maxima occurring on average north of the strongest IVT and near the latitudinal maximum in baroclinic instability.

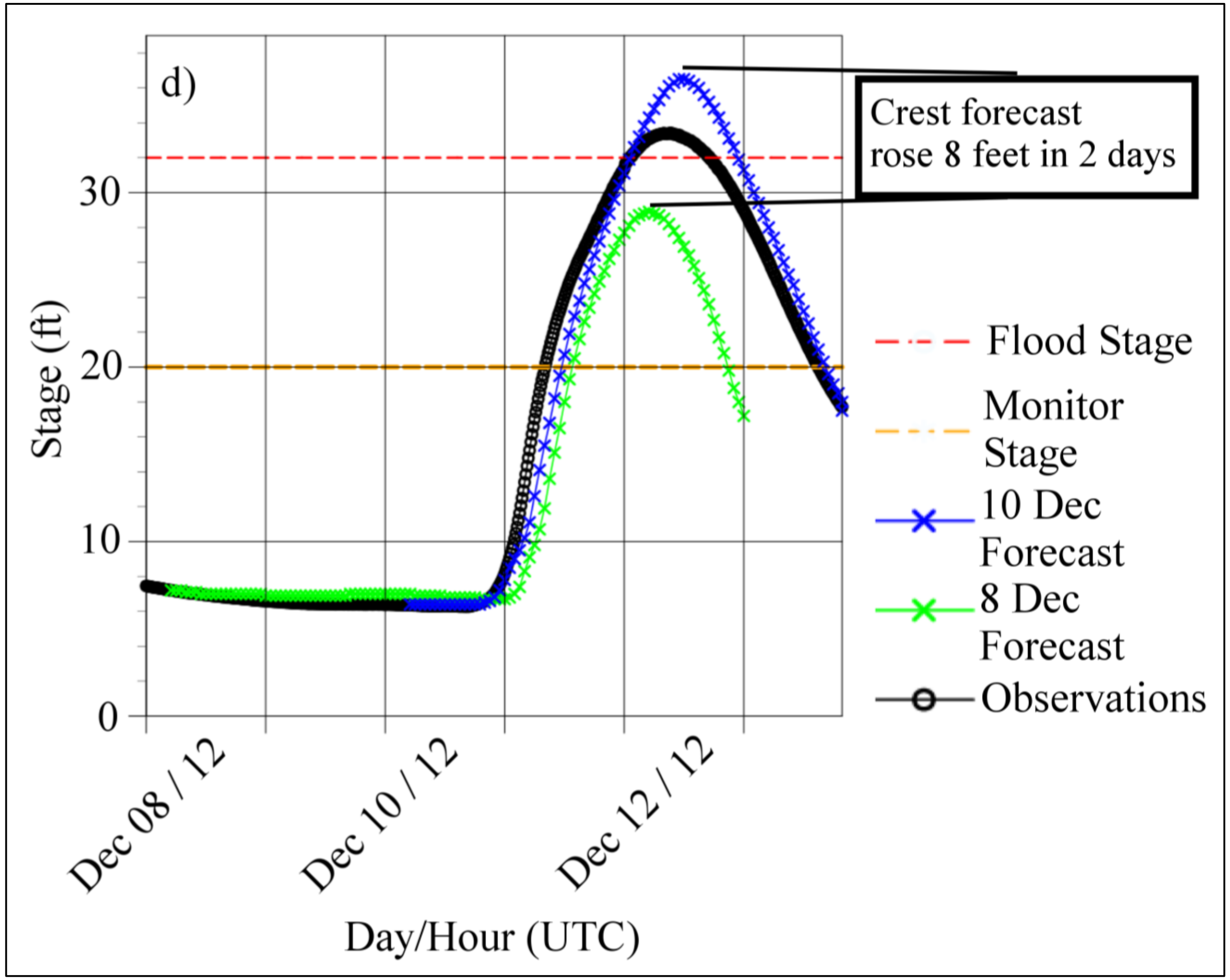
On average the greatest sensitivity coincides with the AR and its edges.

Reynolds et al. MWR in press (2019)

Errors in Predicting a Mesoscale Frontal Wave on an AR Can Create Major Errors in Flood Forecasts

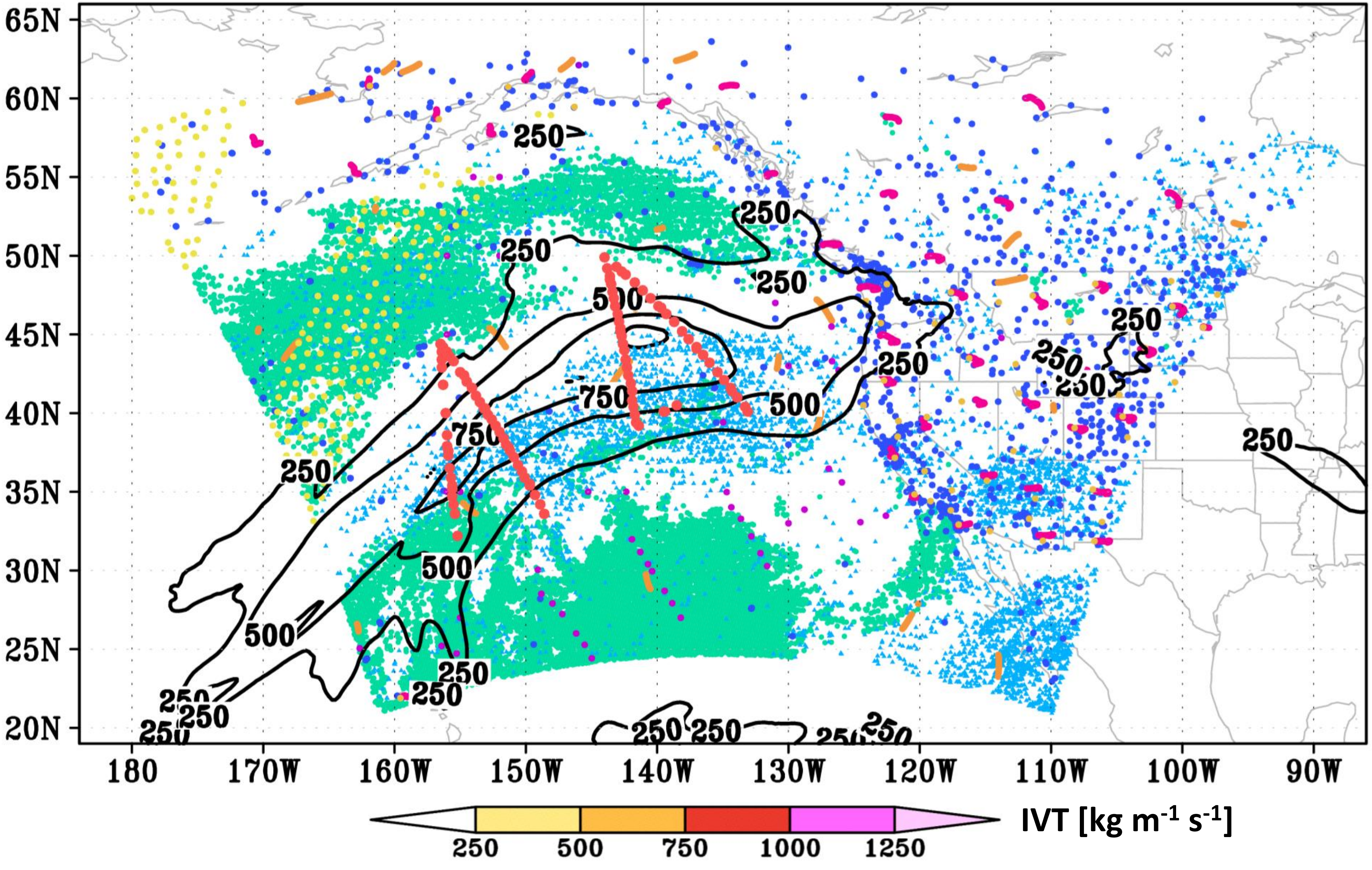
A. Martin, F.M. Ralph, A. Wilson, L. DeHaan, B. Kawzenuk (J. Hydrometeor., in press June 2019)





Data distribution of (non)conventional observations

– Assimilated in West-WRF for 2016 IOP1 at 0000 UTC Feb 14, 2016



Max IVT: 508.3 kg m^{-1} s^{-1}
Location: 124.0°W, 46.3°N

IOP1: collected data for 0000 UTC Feb 14 (6h window)

- Radiosonde
- Profiler
- VADRAD
- Surface
  - SYNOP + METAR (land)
  - SHIP+BUOY (ocean)
- AI/PIREP
- GPSRO
- ASCATW (ocean)
- AMV below 500mb
- ▲ AMV above 500mb
- Dropsonde
  - From AR Recon

*AI/PIREP: aircraft/pilot report
*ASCATW: scatterometer wind

of obs over the areas btw 150°W-124° W on AR object (Guan and Waliser 2015)

Pressure Level (mb)	DROPS + RSONDE	PROFILER + VADWND	Surface	GPSRO + AI/PIRES	ASCATW	AMV
200-100	0	0	0	350	0	2
300-200	0	0	0	69	0	1556
400-300	470	2	0	49	0	90
500-400	363	20	0	[illegible]	[illegible]	0
600-500	222	66	0	[illegible]	[illegible]	2
700-600	409	48	0	[illegible]	[illegible]	58
800-700	141	42	[illegible]	18	0	50
900-800	239	36	[illegible]	15	0	22
>900	799	62	342	11	0	0
All Levels	2643	276	342	596	0	1780
>700 (AR)	1179	140	342	44	0	72

dropsonde obs can contribute to 2/3 of the total obs over the upstream AR object

66.3% of total obs

*Areas east of 150°W are directly linked to the 2.5-day fcst along the coast assuming a 10 m/s synoptic phase speed

Assessing the predictability of mesoscale precipitation processes in landfalling atmospheric rivers using AR Recon dropsonde observations

Center for Western Weather And Water Extremes

Forest Cannon, Nina Oakley, Chad Hecht, Allison Michaelis, Brian Kawzenuk, Reuben Demerdjian, Meredith Fish, Anna Wilson, Jason Cordeira, and F. Martin Ralph

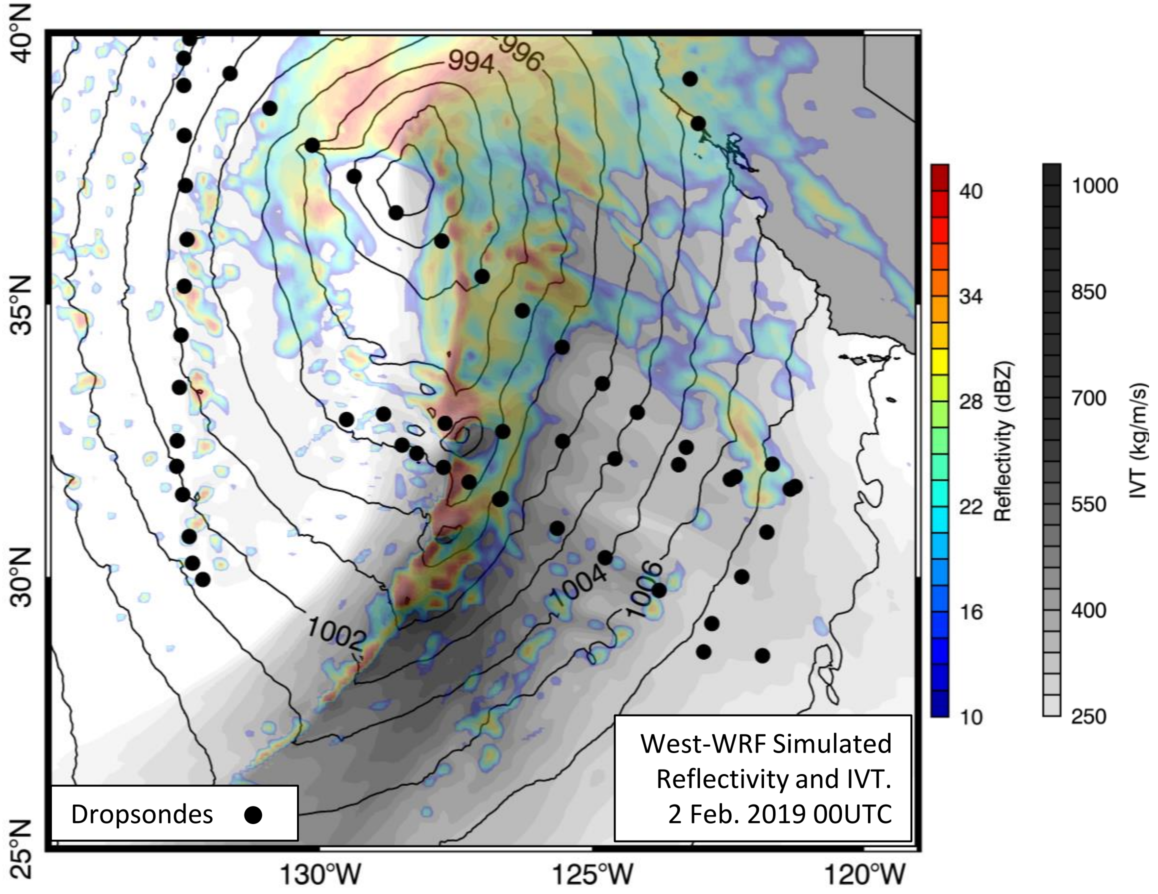
Center for Western Weather and Water Extremes at
UC San Diego/Scripps Institution of Oceanography, La Jolla, CA

See Cannon et al. Poster on Use of AR Recon data for Physical Process Studies

This presentation discusses the synoptic and mesoscale origins of a band of intense precipitation that developed within the AR that was observed in IOP 1 of AR Recon 2019.

Hazard precipitation rates over the West Coast associated with these features have not received substantial attention from the scientific community, yet are an important consideration for emergency management during AR events.

AR Recon dropsondes ahead of landfall provide a unique data source for studying the event's meteorology and evaluating the ability of CW3E's West-WRF model skill.



Impact of Dropsonde Observations on the Predictability of Landfalling Atmospheric Rivers

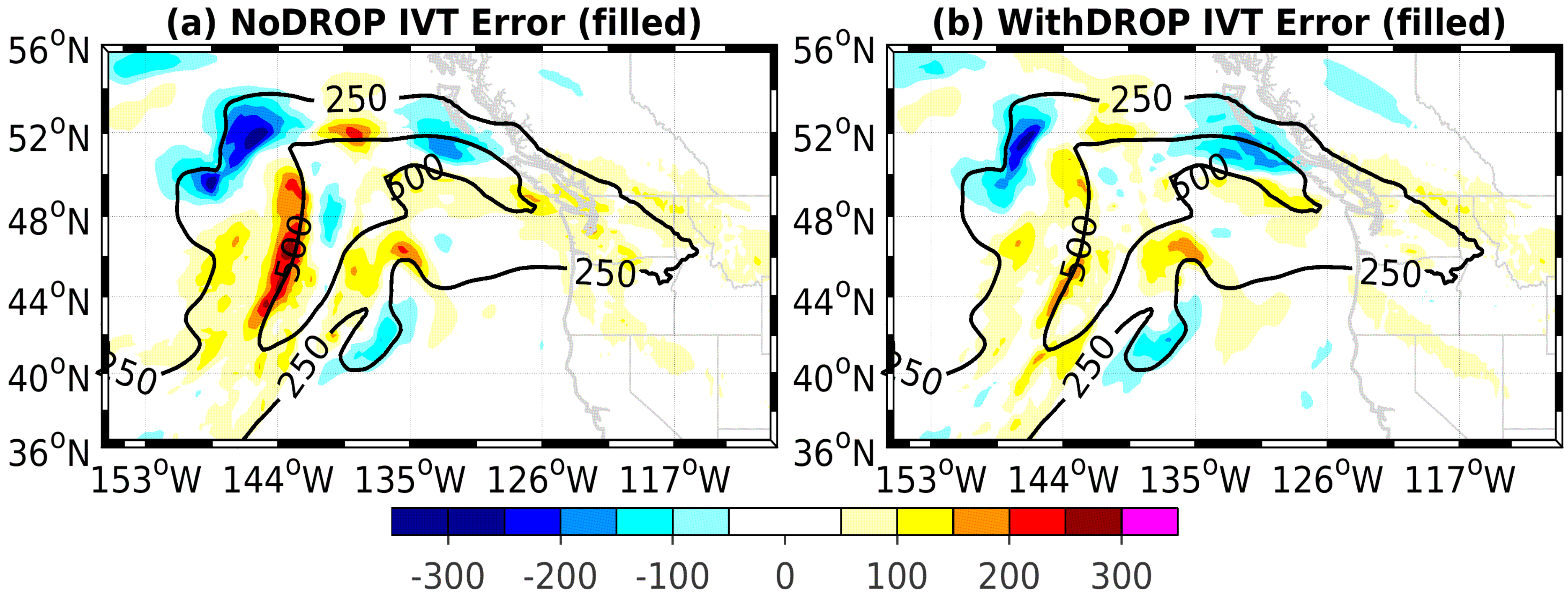
Center for Western Weather
And Water Extremes

Minghua Zheng, Bruce Cornuelle, Luca Delle Monache, F. Martin Ralph

Center for Western Weather and Water Extremes (CW3E)
UC San Diego/Scripps Institution of Oceanography, La Jolla, California, USA

See Zheng et al. Poster on the Impact of Dropsondes Assimilation

- West - Weather Research and Forecasting (West-WRF) model
- Community Gridpoint Statistical Interpolation (GSI) data assimilation system (Hybrid 4DEnVar)



- Tests over 15 AR Recon IOPs
- DA of conventional data, satellite derived winds, GPS RO refractivity, and dropsondes (right panel only)
- Improvements for most lead times (0-5 days)
- Improvements for most IOPs
- Largest improvements for consecutive IOPs
- Next: add DA of satellite radiances

Thank You

- More information on AR Recon is available at
  - http://cw3e.ucsd.edu/arrecon_overview/

- Thank you to our primary sponsors and partners

  Sponsors: US Army Corps of Engineers, California Dept. of Water Resources

  Aircraft Operations: US Air Force Weather Recon Squadron, NOAA Aircraft Operations Center

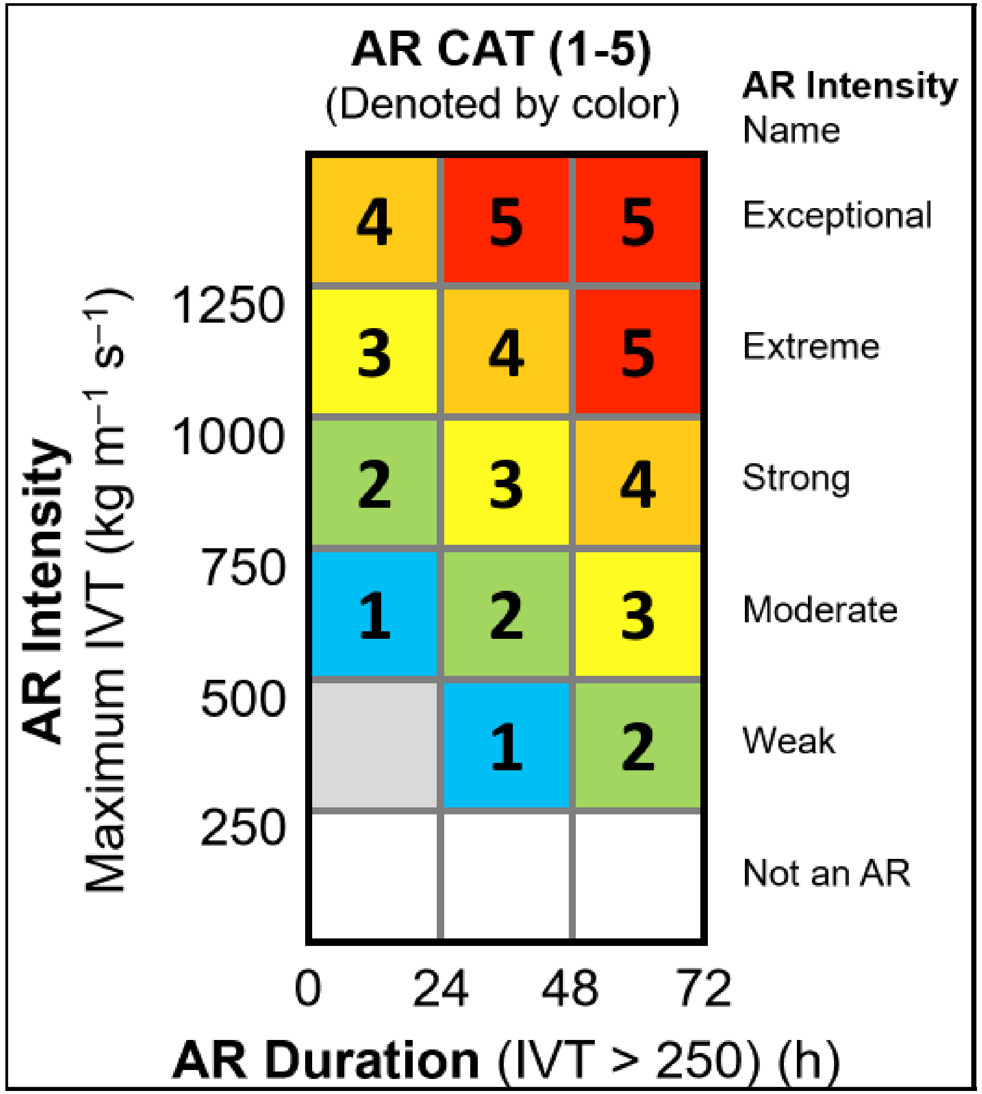
  Operational weather forecasting centers: NWS/NCEP, NWS/Western Region, ECMWF

  Weather Research Centers: Naval Research Laboratory, National Center for Atmospheric Research

  Universities: UC San Diego, Plymouth State Univ., SUNY Albany, CU Boulder

Backup

AR Scale introduced by Ralph et al. 2019 (BAMS)

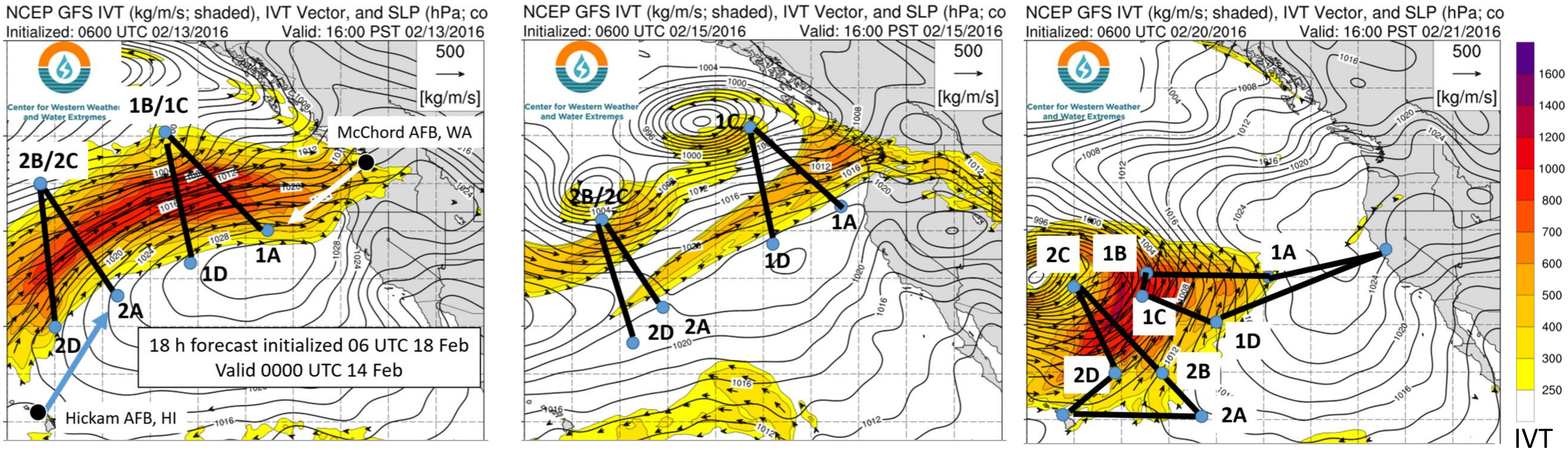


Atmospheric River Reconnaissance 2016

Center for Western Weather and Water Extremes

Contacts: F. M. Ralph (PI; mralph@ucsd.edu); V. Tallapragada (Co-PI; vijay.tallapragada@noaa.gov)

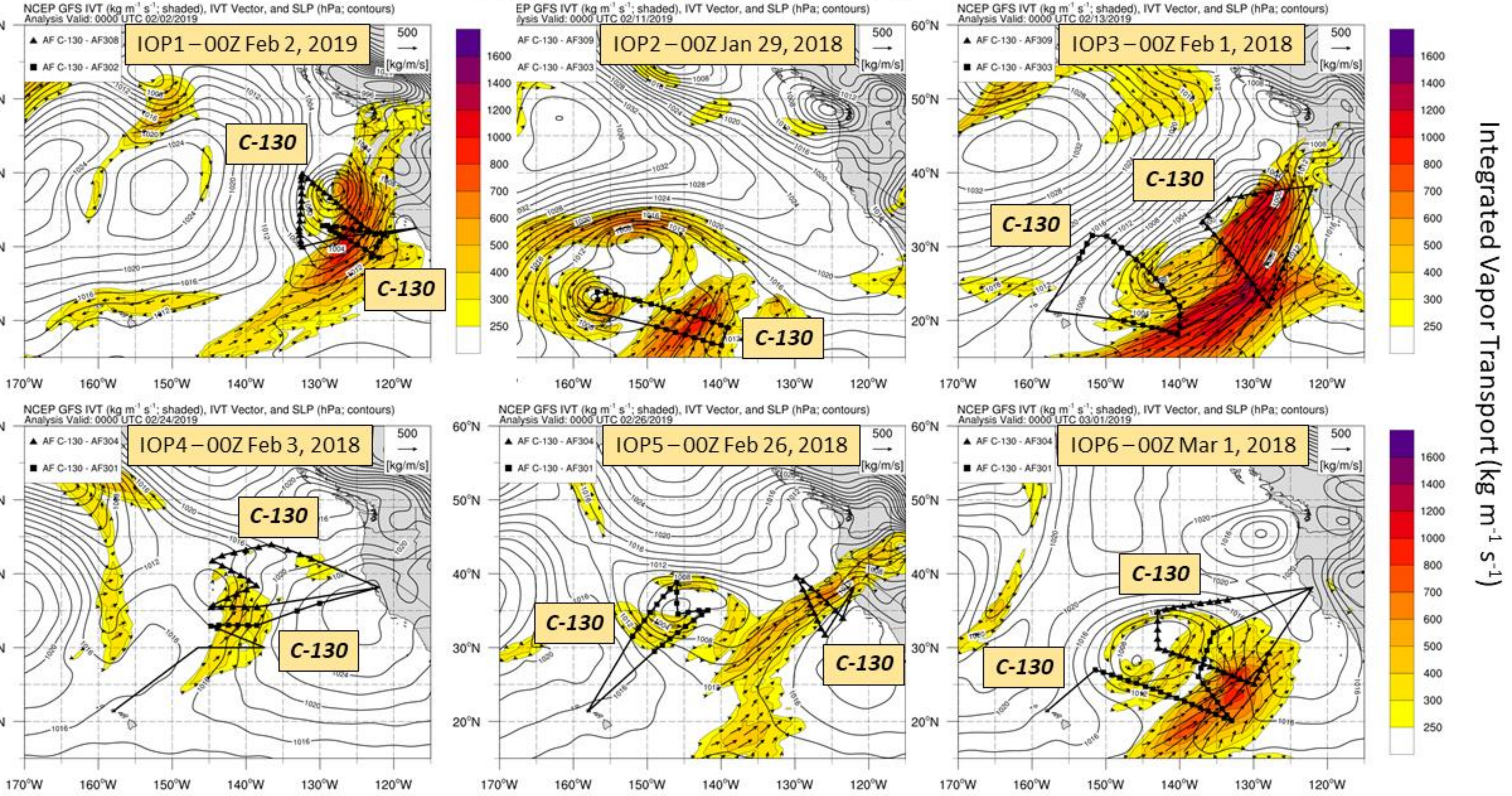
U.S. AIR FORCE



Center for Western Weather and Water Extremes

Atmospheric River Reconnaissance 2019

Contacts: F.M. Ralph (PI; mralph@ucsd.edu); V. Tallapragada (Co PI; vijay.tallapragada@noaa.gov) U.S. AIR FORCE

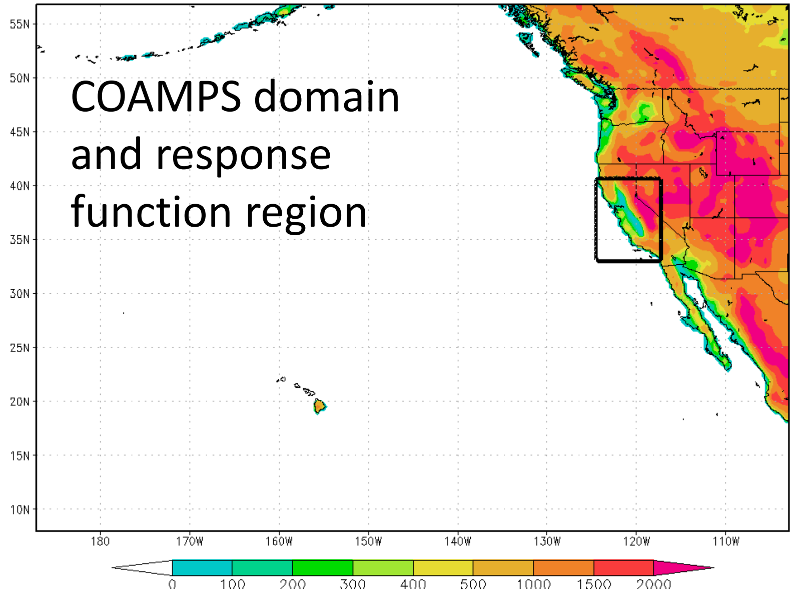


Adjoint Sensitivity of North Pacific Atmospheric River Forecasts

Adjoint allows for the mathematically rigorous calculation of forecast sensitivity of a response function to changes in the initial state

COAMPS® Moist Adjoint Model

- Dynamics: nonhydrostatic, nested
- Physics: PBL, surface fluxes, microphysics
- 40-km resolution, 24-h and 36-h optimization times
- Response function (RF) J:
  - KE in box (1 km deep);
  - PRCP (21-24h),
- Optimal Perturbations (1 m/s, 1 K, 1 g/kg)
- Cases: 00Z and 12Z 01JAN to 20FEB 2017



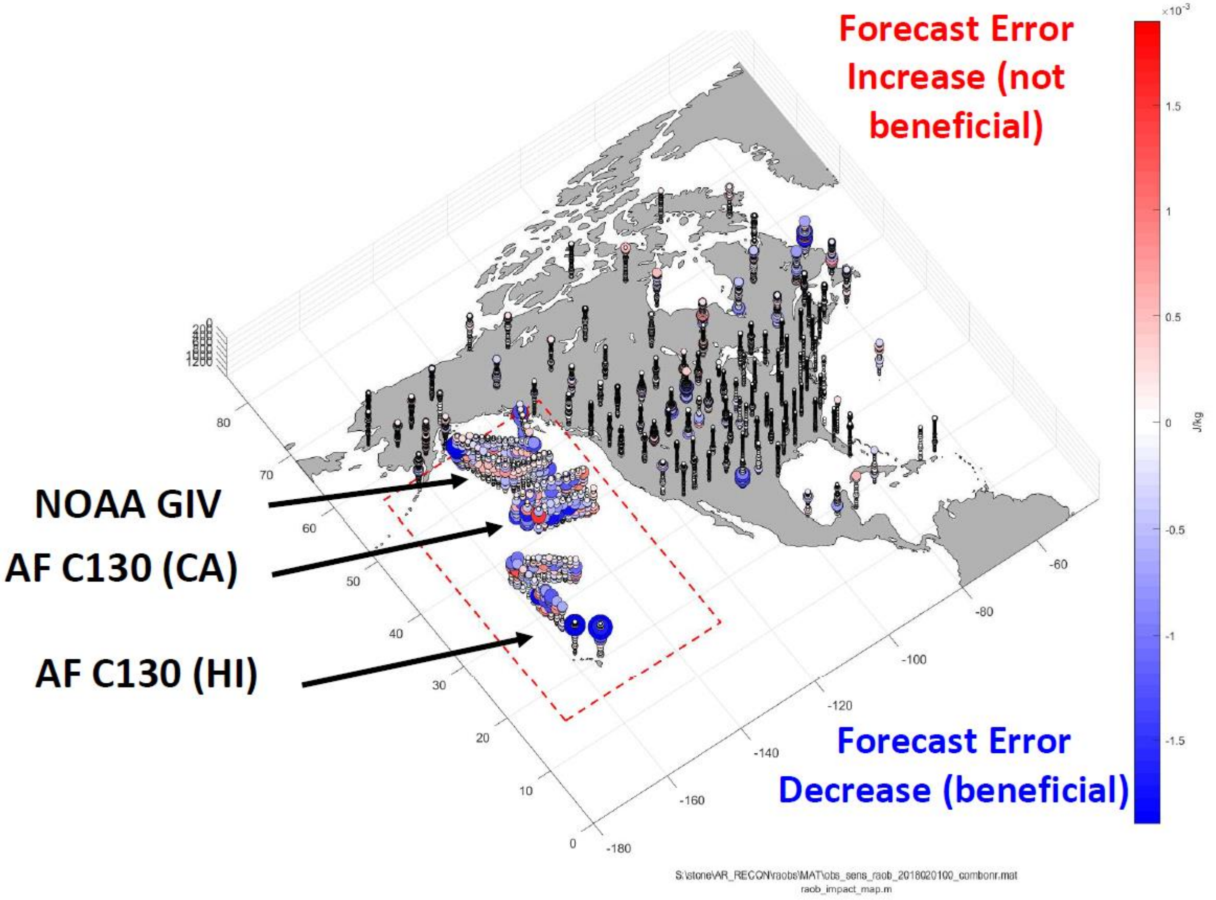
Manuscript (Reynolds, Doyle, Ralph and Demirdjian) submitted to MWR, currently being revised.

Reynolds et al. MWR in revision Dec 2018

AR Recon Data Impact Studies at NRL

U.S. NAVAL RESEARCH LABORATORY

IOP 3: Obs Impact for Dropsondes and NA Radiosondes in NAVGEM: Wind Observations



Wind observations have larger impact than moisture observations (true for both dropsondes and radiosondes).

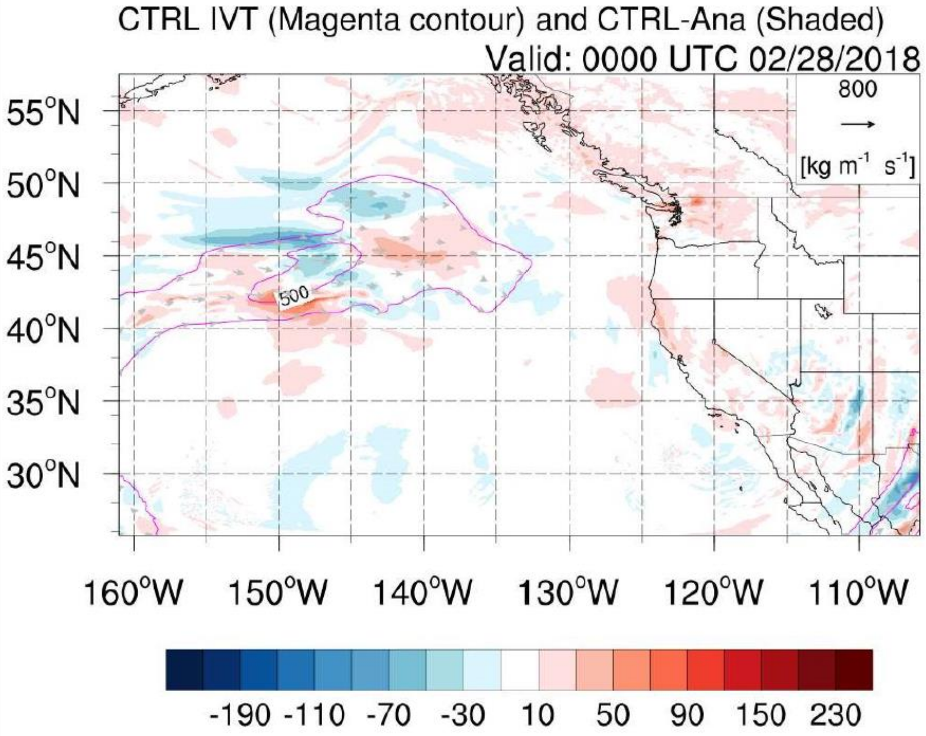
Currently investigating why moisture observations have smaller impact than winds/temp (qc? metric? model?). Moisture obs are rejected at higher rate than temperature or wind obs.

courtesy: Carolyn Reynolds (NRL)

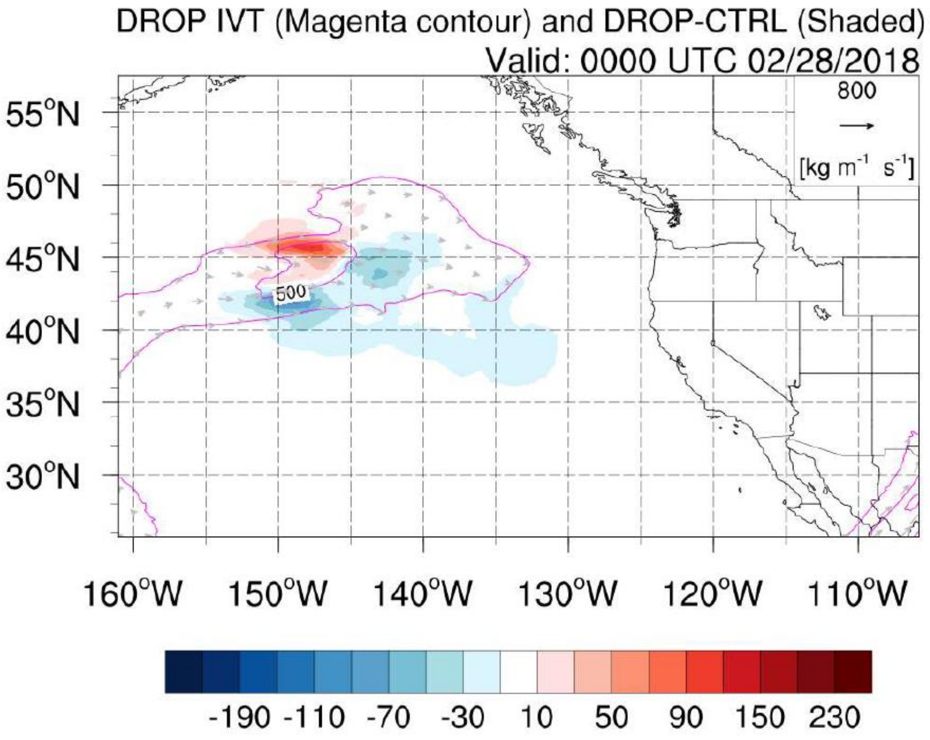
Dropsonde impact on initial errors for IOP6

WestWRF Experiments for AR Recon

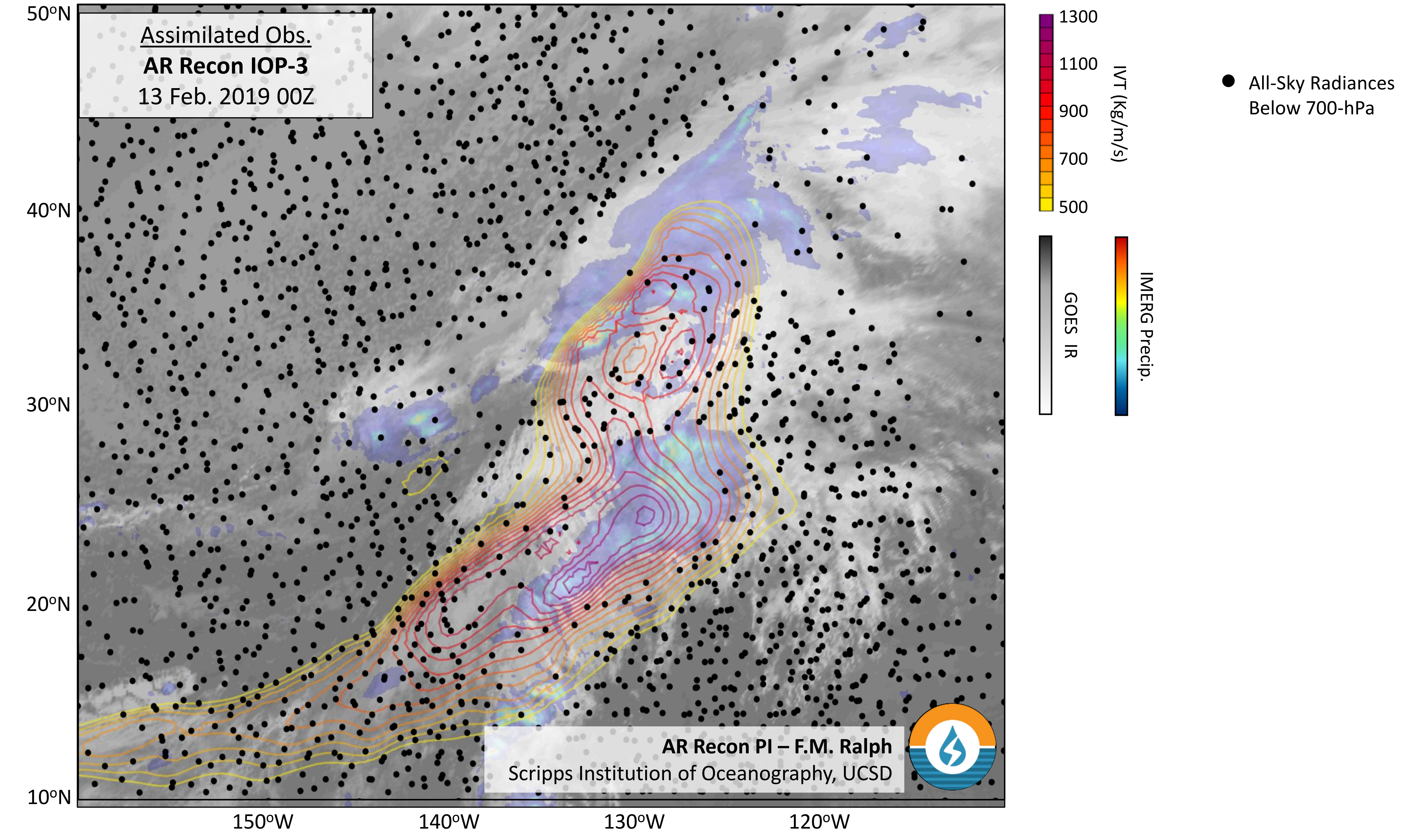
NoDROP run IVT error (shaded)



DROP-NoDROP IVT (shaded)



courtesy: Minghua Zheng (CW3E)


Assimilated Obs.
AR Recon IOP-3
13 Feb. 2019 00Z
50°N
40°N
30°N
20°N
10°N
150°W
140°W
130°W
120°W
AR Recon PI – F.M. Ralph
Scripps Institution of Oceanography, UCSD
1300
1100
900
700
500
IVT (kg/m/s)
GOES IR
IMERG Precip.
All-Sky Radiances
Below 700-hPa

A Scale to Characterize the Strength and Impacts of Atmospheric Rivers

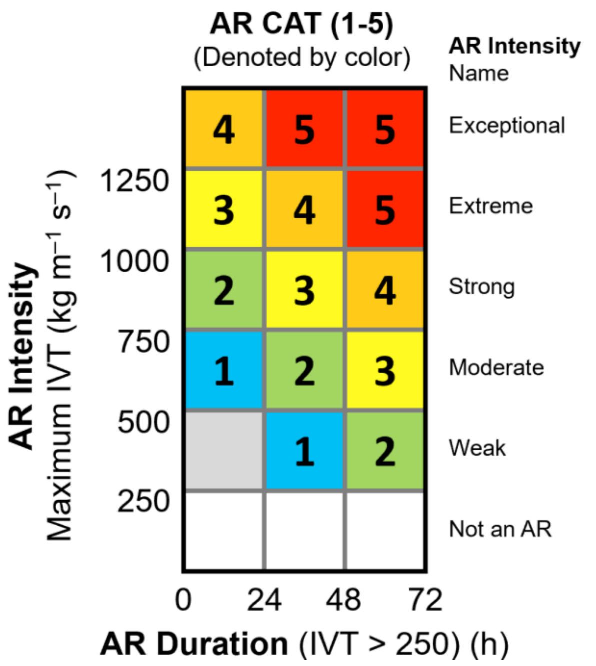
F. Martin Ralph (SIO/CW3E), J. J. Rutz (NWS), J. M. Cordeira (Plymouth State), M. Dettinger (USGS), M. Anderson (CA DWR), D. Reynolds (CIRES), L. Schick (USACE), C. Smallcomb (NWS); *Bull. Amer. Meteor. Soc. (Feb. 2019); DOI/10.1175/BAMS-D-18-0023.1*

The AR CAT level of an AR Event* is based on its *Duration* and max *Intensity* (IVT)*****

** An "AR Event" refers to the existence of AR conditions at a specific location for a specific period of time.*
*** How long IVT>250 at that location. If duration is <24 h, reduce AR CAT by 1, if longer than 48 h, add 1.*
**** This is the max IVT at the location of interest during the AR.*

IMPACTS

- AR Cat 5 – Primarily hazardous
- AR Cat 4 – Mostly hazardous, also beneficial
- AR Cat 3 – Balance of beneficial and hazardous
- AR Cat 2 – Mostly beneficial, also hazardous
- AR Cat 1 – Primarily beneficial



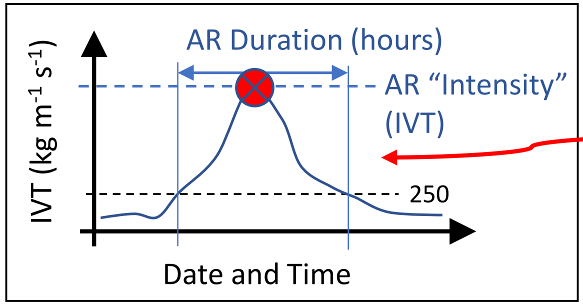
Determining AR Intensity and AR Category

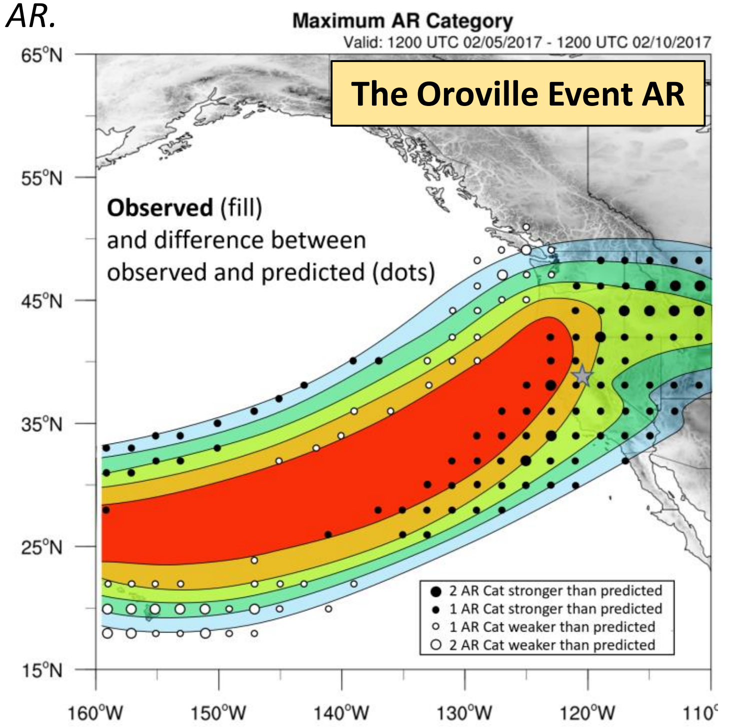
Step 1: Pick a location

Step 2: Determine a time period when IVT > 250 (using 3 hourly data) at that location, either in the past or as a forecast. The period when IVT continuously exceeds 250 determines the start and end times of the AR, and thus also the **AR Duration** for the AR event at that location.

Step 3: Determine **AR Intensity**
- Determine max IVT during the AR at that location
- This sets the AR Intensity and *preliminary* AR CAT

Step 4: Determine *final* value of **AR CAT** to assign
- If the AR Duration is > 48 h, then promote by 1 Category
- If the AR Duration is < 24 h, then demote by 1 Category



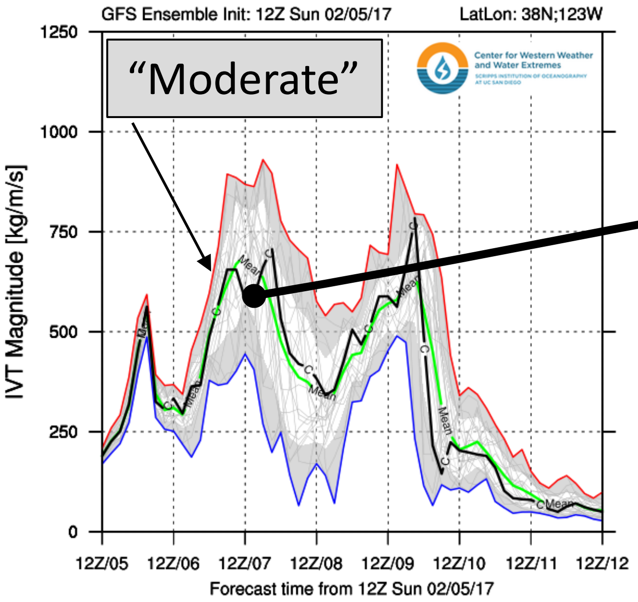


On the Web: CW3E.UCSD.EDU
On Twitter: @CW3E_Scripps

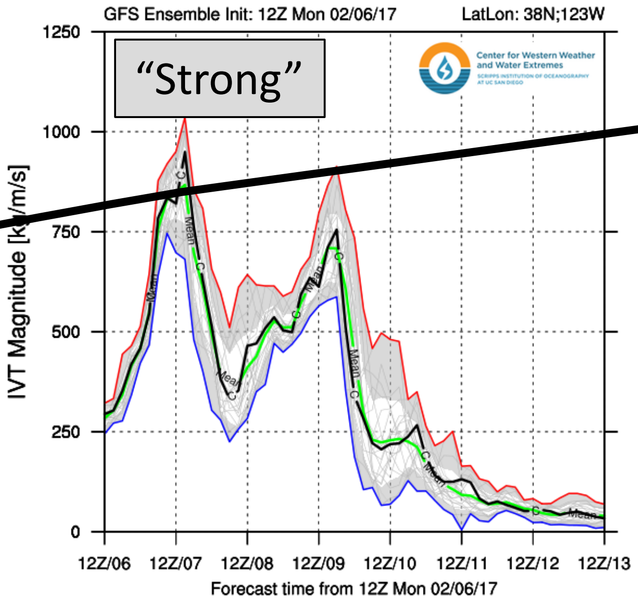
Center for Western Weather and Water Extremes

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

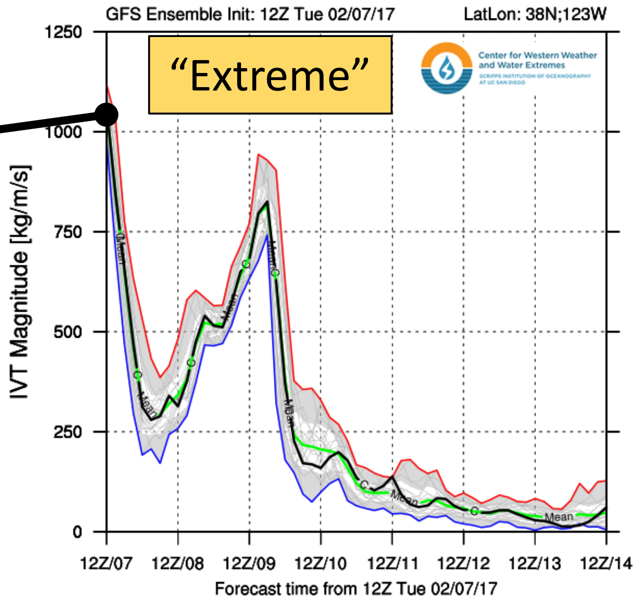
Oroville Dam Spillway



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**.

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

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

SCRIPPS INSTITUTION OF OCEANOGRAPHY UCSD