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

IMPROVING FORECAST SKILL AND ENABLING FIRO THROUGH ATMOSPHERIC RIVERS RESEARCH

4 AUGUST 2020

F. MARTIN RALPH – CW3E/SCRIPPS/UCSD

SEVENTH ANNUAL FORECAST INFORMED RESERVOIR OPERATIONS WORKSHOP

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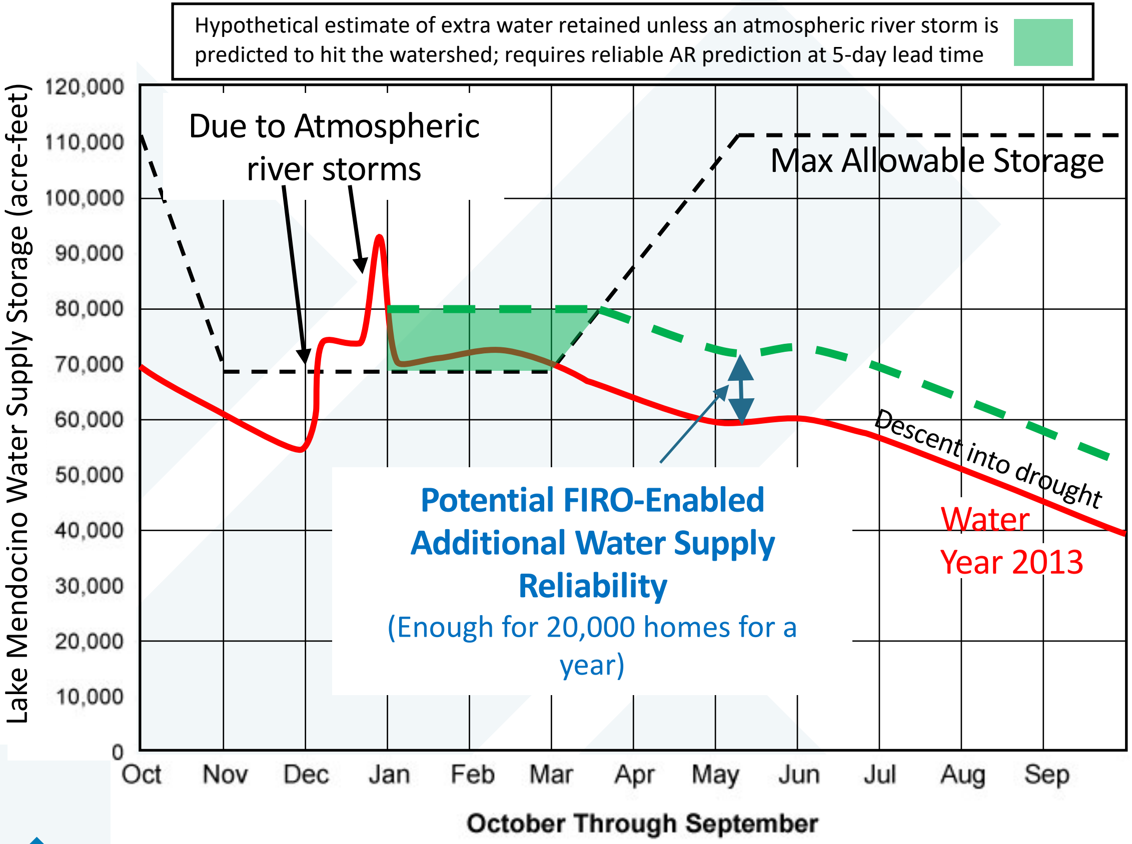
FORECAST-INFORMED RESERVOIR OPERATIONS



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Co-Chairs, Lake Mendocino FIRO:
F. Martin Ralph Jay Jasperse

Russian River Forecast Lead Time Requirement
Lake Mendocino Release

It takes 2 days to release 10,000 AF at 2500 cfs, plus 1.1 to 2.5 days for water released from Lake Mendocino to get past vulnerable communities downstream.

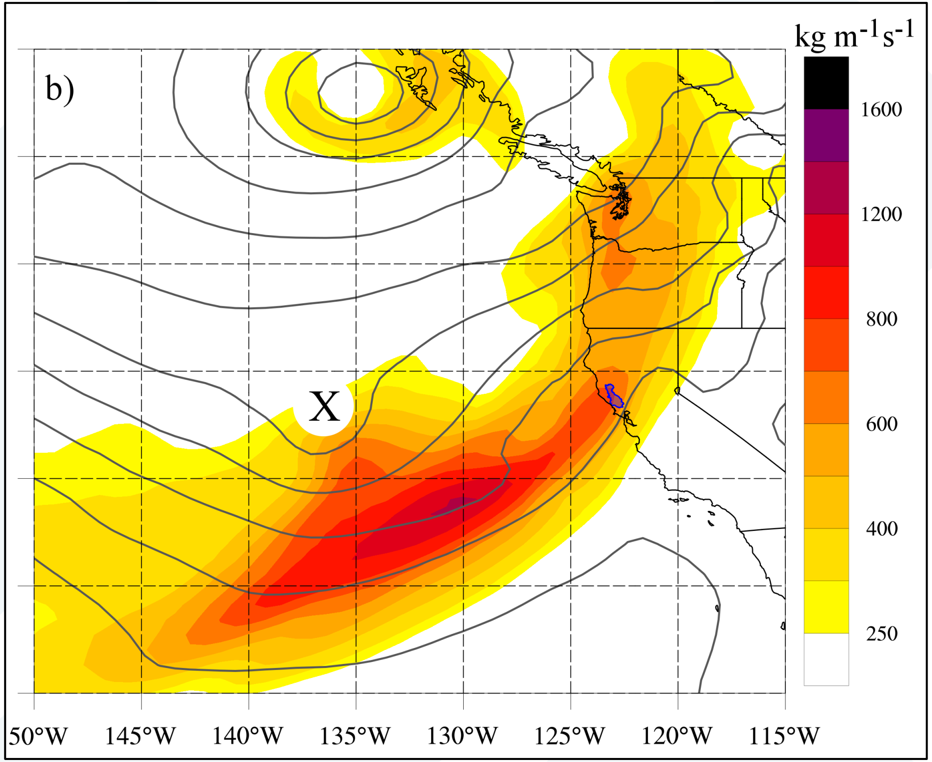
- **This sets a forecast lead time requirement of 2-5 days to predict landfalling atmospheric rivers.**

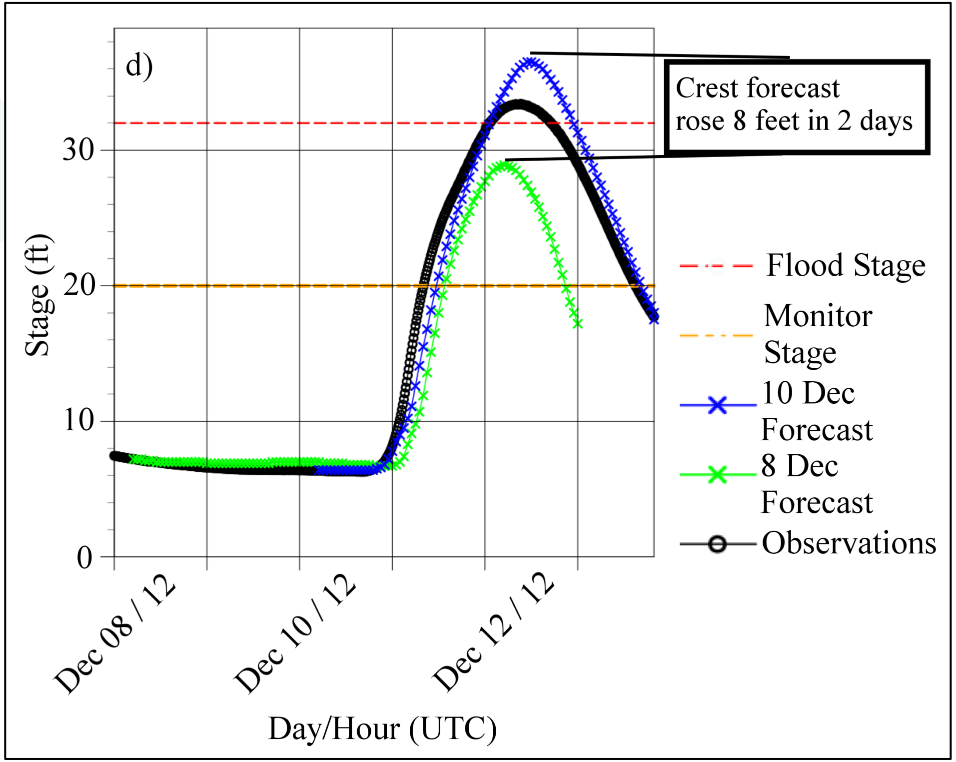
*Total travel time ranges from 26hrs to 85hrs (74 miles traveled)

*Coyote Valley Dam and Lake Mendocino Water Control Manual (1986)

AR Video

ERRORS IN PREDICTING THE STRUCTURE AND STRENGTH OF AN ATMOSPHERIC RIVER CAN CREATE MAJOR ERRORS IN FLOOD FORECASTS





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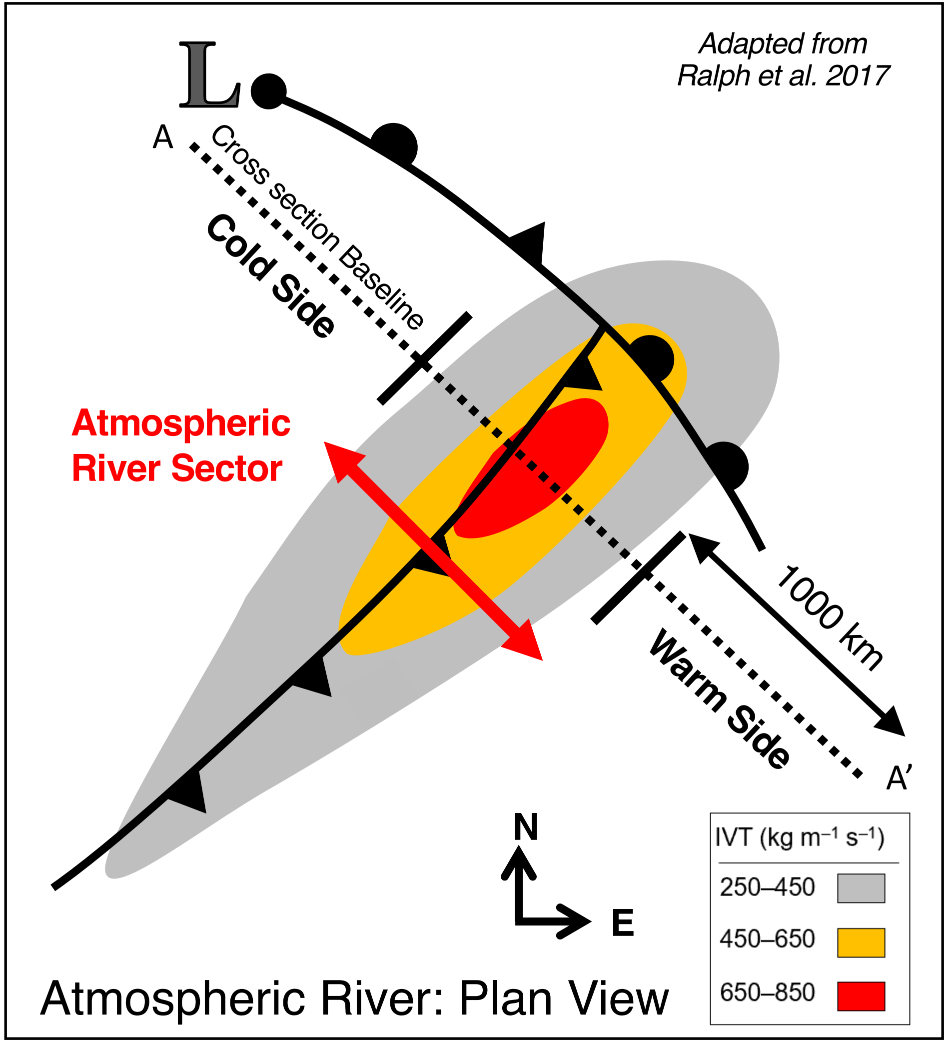
A. Martin, F.M. Ralph, A. Wilson, L. DeHaan, B. Kawzenuk (J. Hydrometeor., 2019)

FIRO Mendocino is recommending a framework to enable future improvements in forecast skill to be incorporated seamlessly into FIRO-related operational flexibility

- The full viability assessment for Lake Mendocino has found adequate skill currently to enable FIRO operations there.
- Additional benefits can be achieved as forecast skill improves
- Lake Mendo FVA is recommending a pathway for future improvement in relevant forecast skill to trigger enhanced reservoir operations flexibility after skill surpasses an established skill threshold.



1) Create a meteorologically based geometric framework

a) **Horizontal:** Define three regions associated with an AR

- "Atmospheric River Sector" (each 1000 km wide on avg)
- "Warm side"
- "Cold side"

b) **Vertical (see next slide):** Define three layers in the vertical for which observations and initial condition error sensitivities can vary substantially (each about 3-4 km thick vertically)

- Upper: 450-200 hPa
- Middle: 700-450 hPa
- Lower: surface to 700 hPa

2) Consider the adjoint sensitivity results in this framework

Caste the results from the Reynolds et al. 2019 (MWR) adjoint sensitivity study (i.e., what initial condition errors offshore trigger the greatest errors in precipitation and wind associated with landfalling ARs) in this framework.

3) Document non-AR Recon observations in this framework

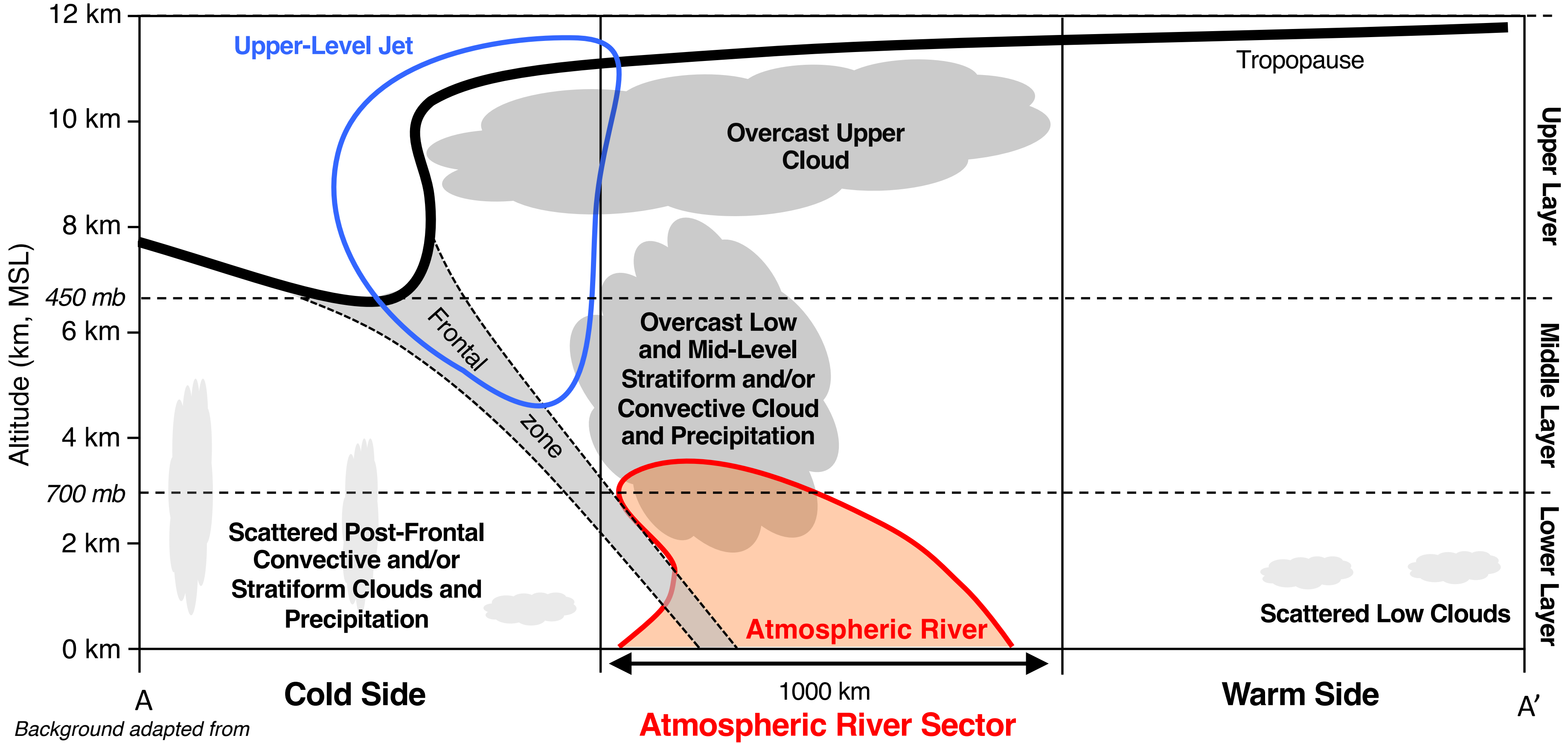
Caste the analysis of observation locations relative to the AR objects in 15 AR Recon case studies from 2016, 2018 and 2019) in Zheng et al (2020. draft) in this framework.

4) Compare the sensitivity patterns with the availability of non-AR Recon observations

Demonstrate that the biggest gap in non-AR recon observations is exactly where the greatest initial condition error sensitivity exists.

(Zheng et al., in revision)

SCHEMATIC CROSS-SECTION OF KEY METEOROLOGICAL FEATURES IN/NEAR AN ATMOSPHERIC RIVER OVER THE NORTHEAST PACIFIC OCEAN BASED ON AIRCRAFT AND CLOUD OBSERVATIONS OF MANY ARs (*Ralph et al. 2004, 2017; Matrosov 2013 MWR; Cannon et al. 2020*)



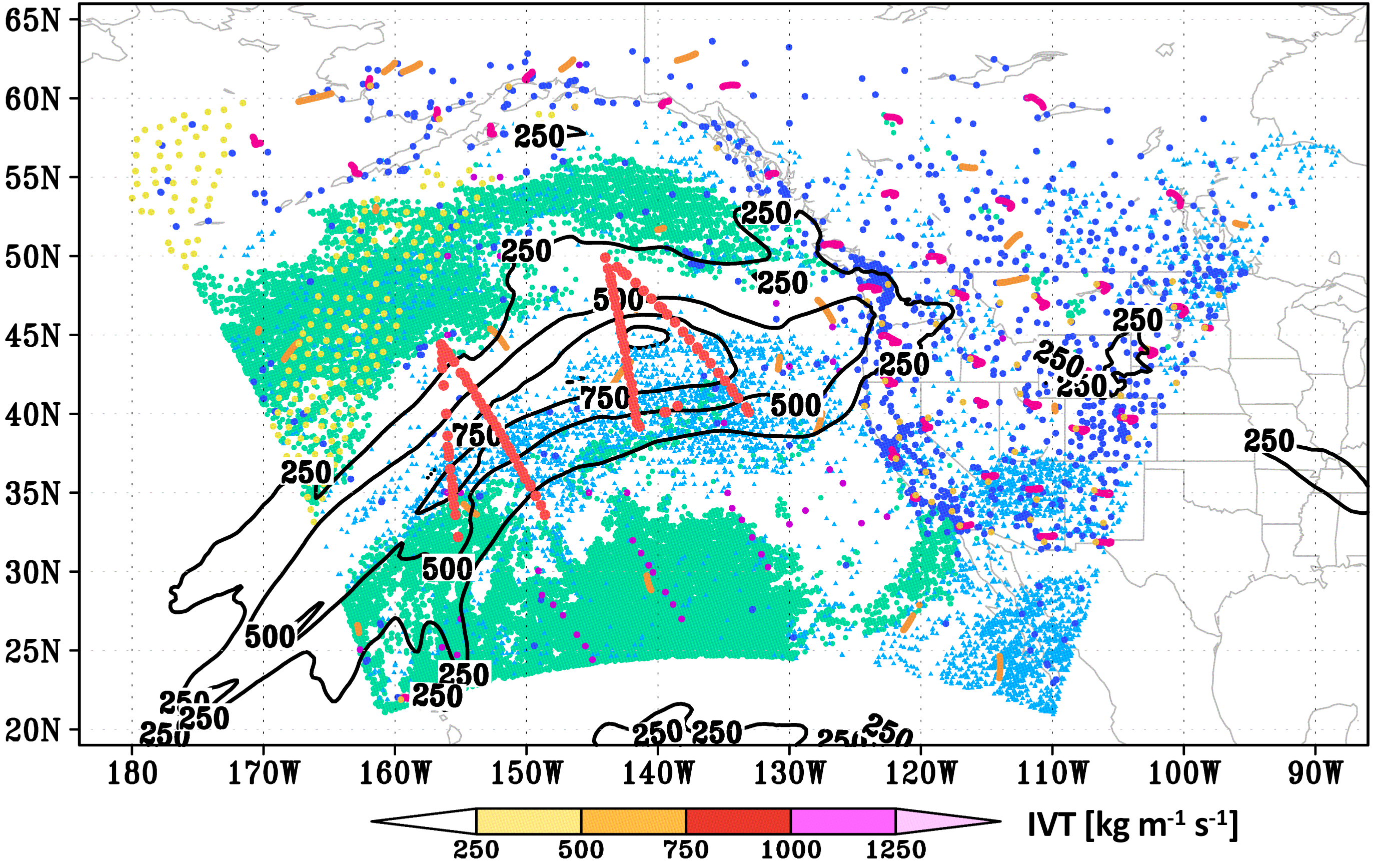
Background adapted from
Ralph et al. 2004, 2017; Matrosov 2013, Cannon et al. 2020

Zheng et al. 2020 (BAMS, in revision)

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

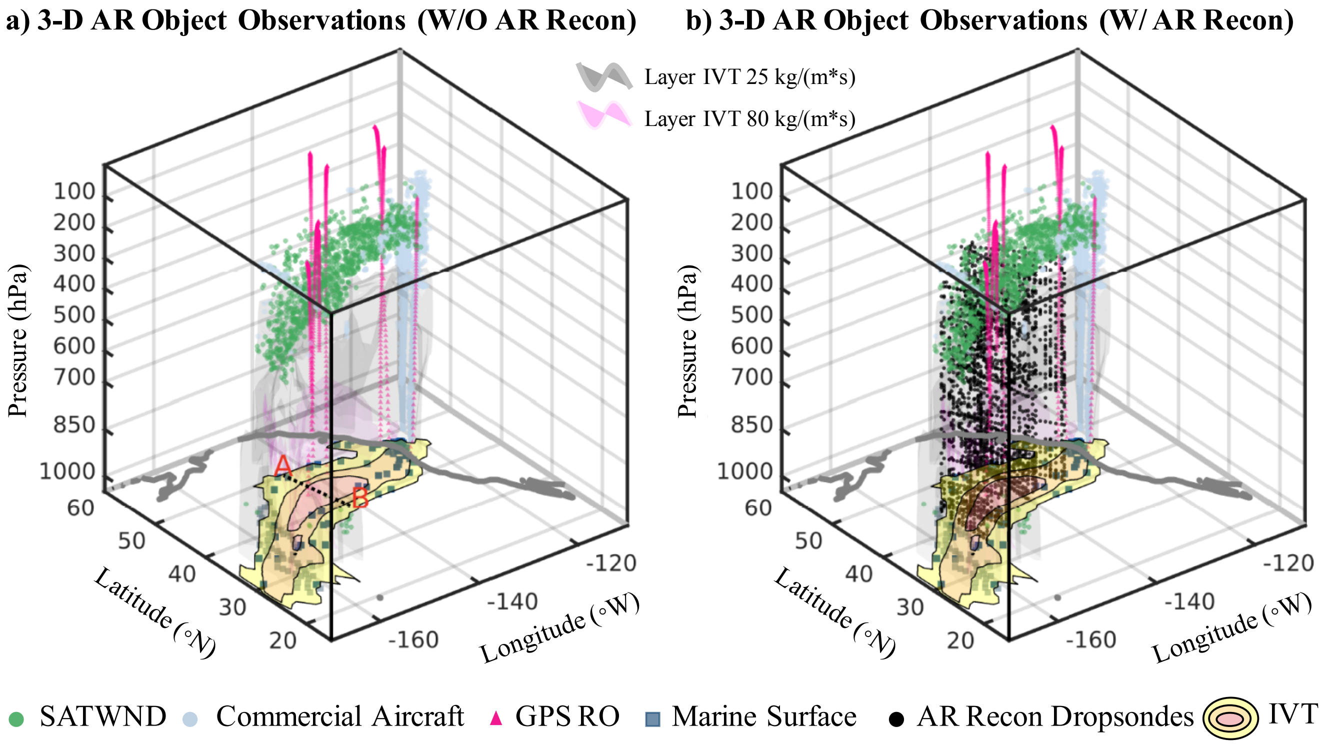


IOP1: collected data for 0000 UTC 14 Feb 2016 (6h window)

- 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

OBSERVATION DENSITY ANALYSIS



Zheng et al. 2020 (BAMS, in revision)

Adjoint Sensitivity of North Pacific Atmospheric River Forecasts

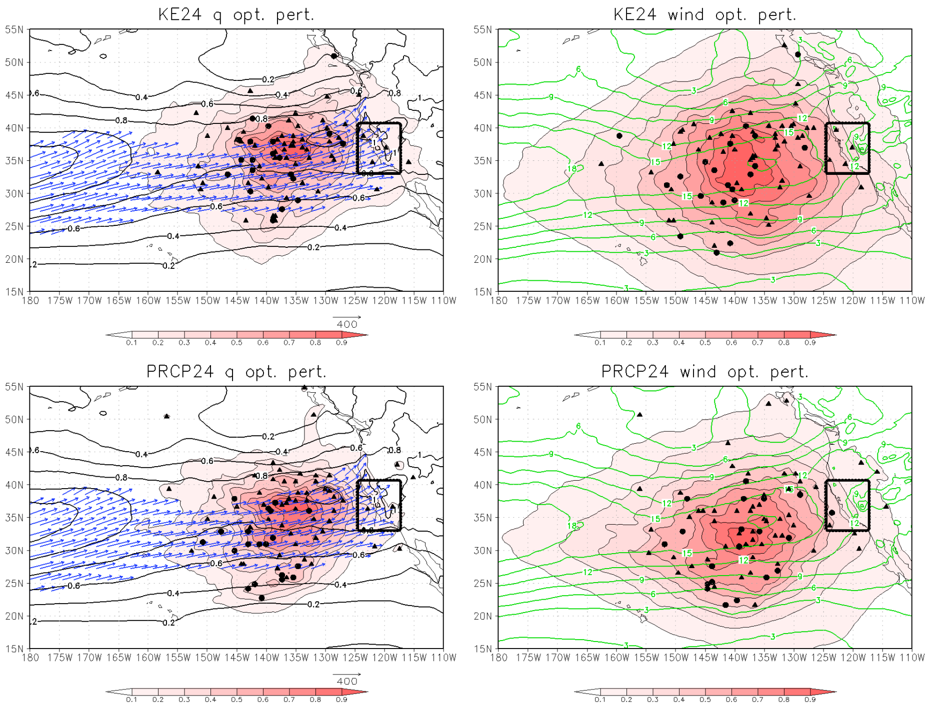
U.S. NAVAL RESEARCH LABORATORY

Reynolds, C.A., J. D. Doyle, F.M. Ralph, and R. Demirdjian, *Mon. Wea. Rev.* (June 2019)

Black box is the area where forecast improvement is desired

Blue arrows are IVT vectors, marking the atmospheric river

Pink shaded area is where errors in initial conditions for water vapor (q) and wind are greatest for 1-day forecasts of precipitation (bottom row) and for Kinetic energy (top row) in the black box area



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).

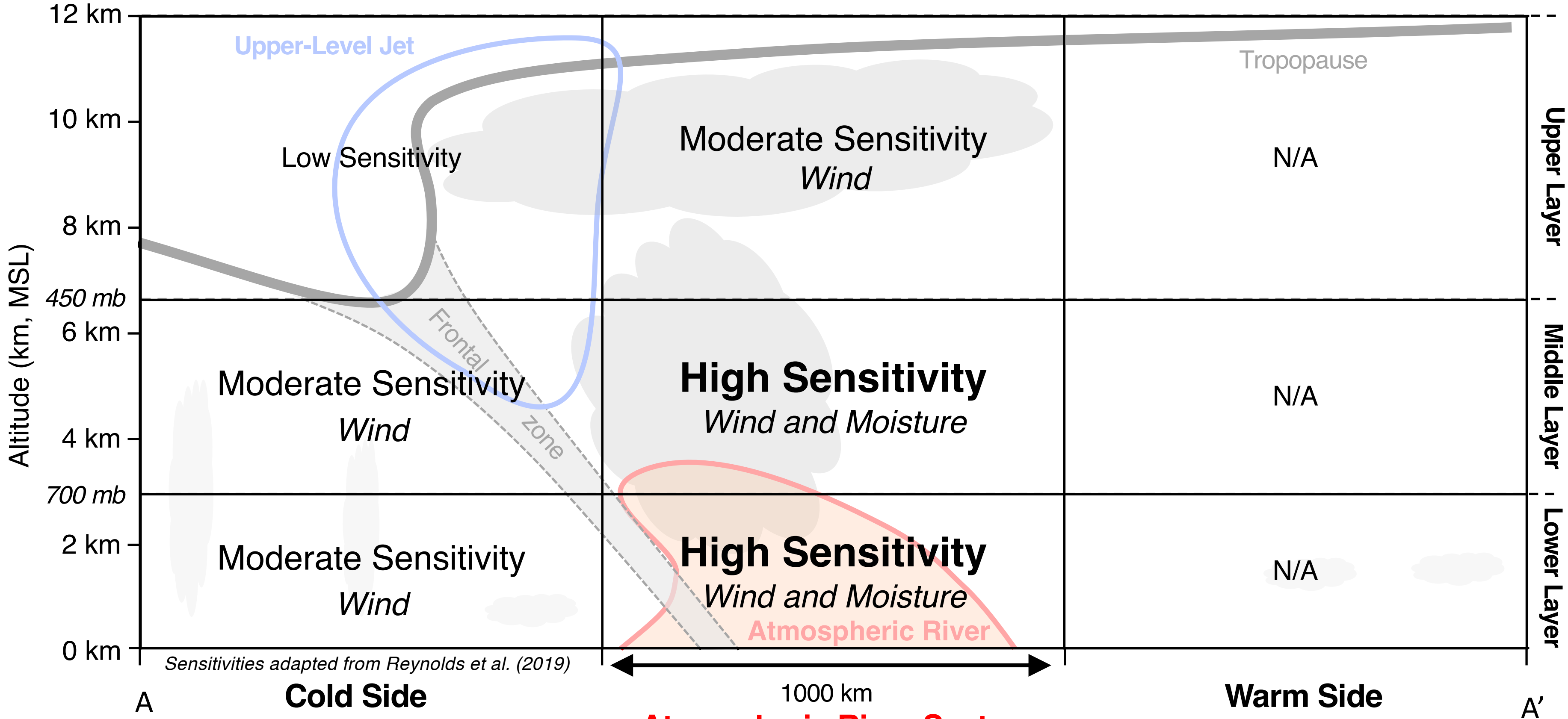
On average, sensitivity of the wind forecasts (top) and precipitation forecasts(bottom) are very similar, with maxima occurring on average over and slightly north of the strongest IVT and near the latitudinal maximum in baroclinic instability.

*On average the greatest sensitivity of 1-day lead time precipitation and wind forecasts over California coincides with **initial condition errors in water vapor and wind in an offshore Atmospheric River** and its edges.*

CW3E

SENSITIVTY OF WEST COAST FORECASTS OF LANDFALLING ARs AT 1-2 DAYS LEAD TIME TO INITIAL CONDITION ERRORS

BASED ON ADJOINT SENSITIVITY TO WIND AND MOISTURE PERTURBATIONS OFFSHORE (*from Reynolds et al. 2019, Mon. Wea. Rev.*)



Background adapted from
Ralph et al. 2004, 2017; Matrosov 2013, Cannon et al. 2020

A Case Study of the Physical Processes Associated with the Atmospheric River Initial Condition Sensitivity from an Adjoint Model

Reuben Demirdjian[1], Jim Doyle[2], Carolyn Reynolds[2], Joel Norris[1], Allison Michaelis[1], F. Martin Ralph[1]
[1]UCSD/SIO/CW3E, [2]NRL (*J. Atmos. Sci.* 2020, in press)

Purpose of Study

- Diagnose the dynamical processes linking the initial condition sensitivities offshore in an adjoint model to errors in forecasts of AR landfall and associated precipitation

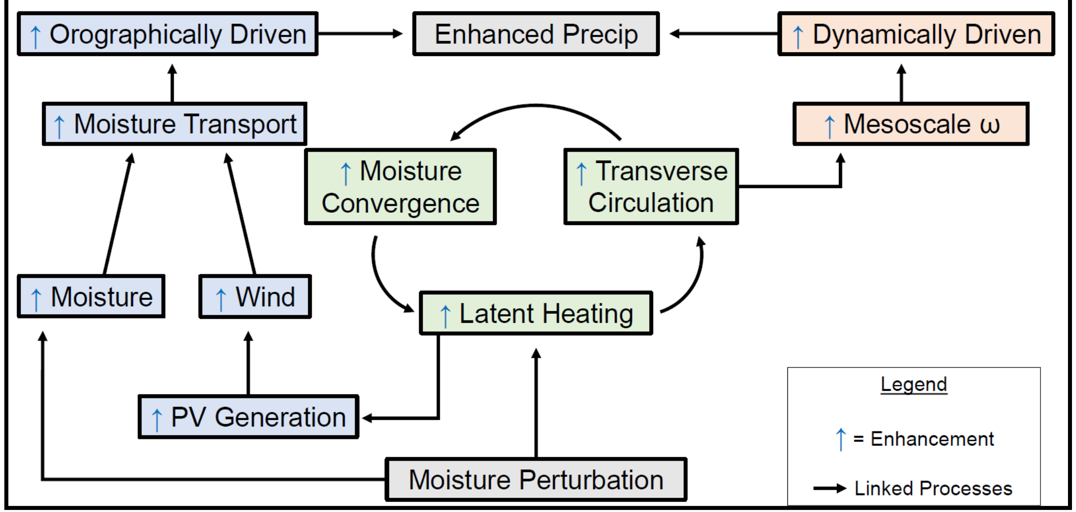
Why Bother?

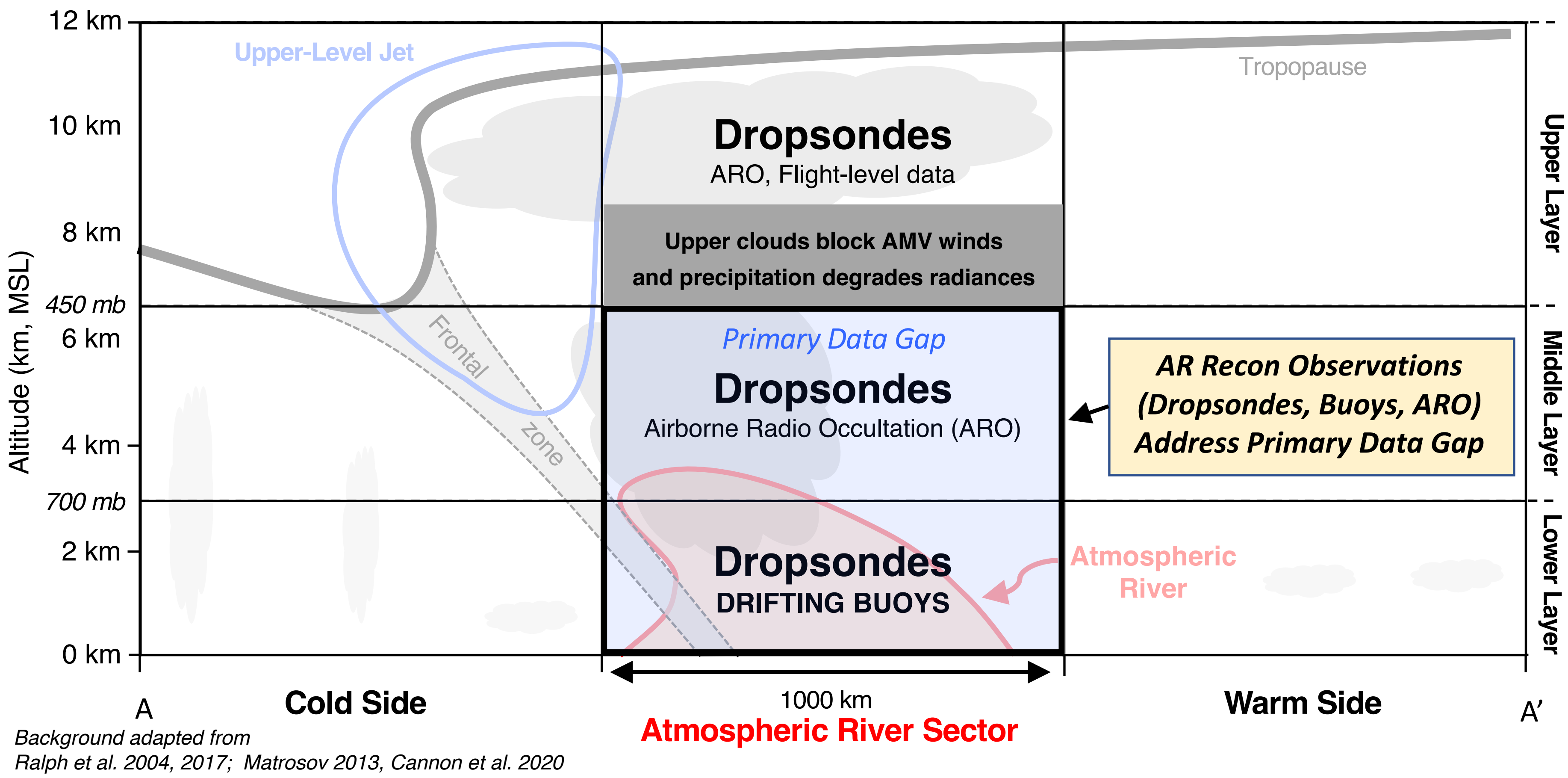
- To understand how errors in weather forecast model representation of AR initial conditions offshore can lead to errors in the prediction of AR landfall.

Result

- An error in water vapor initial condition within the AR modifies precipitation (both d*ynamically and orographically forced*) by amplifying the latent heating in a dynamical feedback process involving wind and PV anomalies that act to reinforce the initial perturbation.

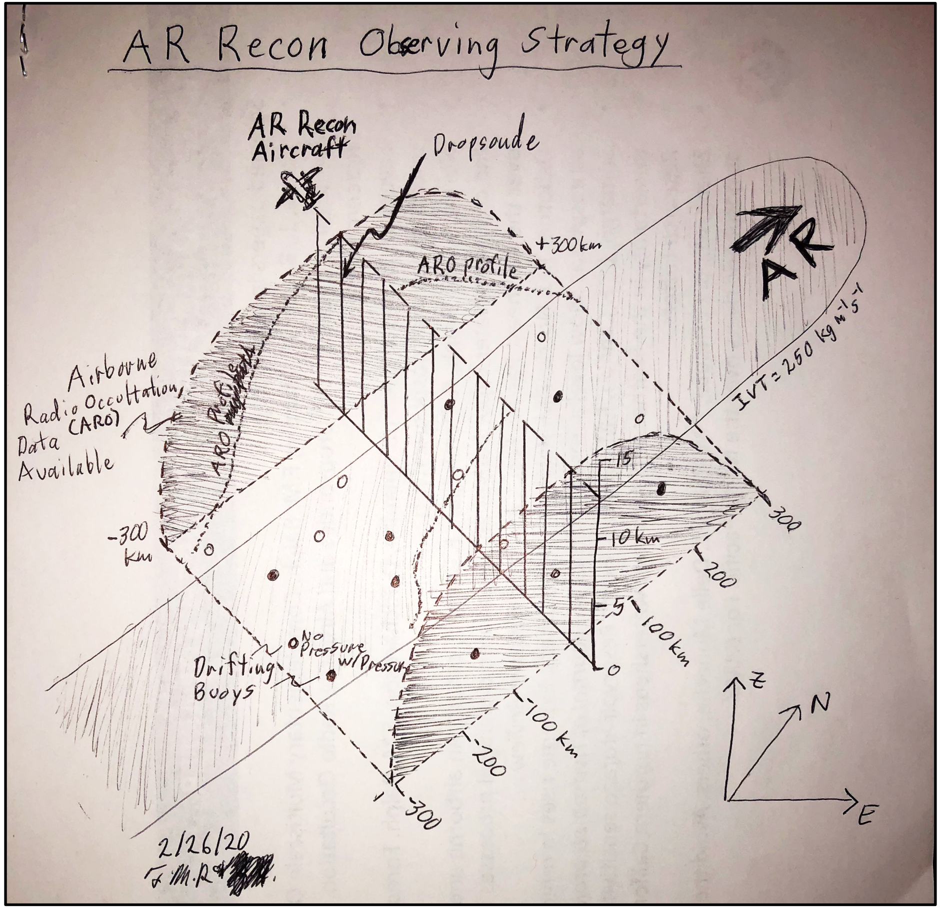
Processes Leading to Changes in the Perturbed Run's Precipitation





12 km
10 km
8 km
450 mb
6 km
4 km
700 mb
2 km
0 km
Altitude (km, MSL)
Upper-Level Jet
Tropopause
Dropsondes
ARO, Flight-level data
Upper clouds block AMV winds
and precipitation degrades radiances
Primary Data Gap
Dropsondes
Airborne Radio Occultation (ARO)
Dropsondes
DRIFTING BUOYS
Frontal
zone
AR Recon Observations
(Dropsondes, Buoys, ARO)
Address Primary Data Gap
Atmospheric
River
Upper Layer
Middle Layer
Lower Layer
A
Cold Side
1000 km
Atmospheric River Sector
Warm Side
A′
Background adapted from
Ralph et al. 2004, 2017; Matrosov 2013, Cannon et al. 2020

AR Recon Sensor Suite and Sampling Strategy

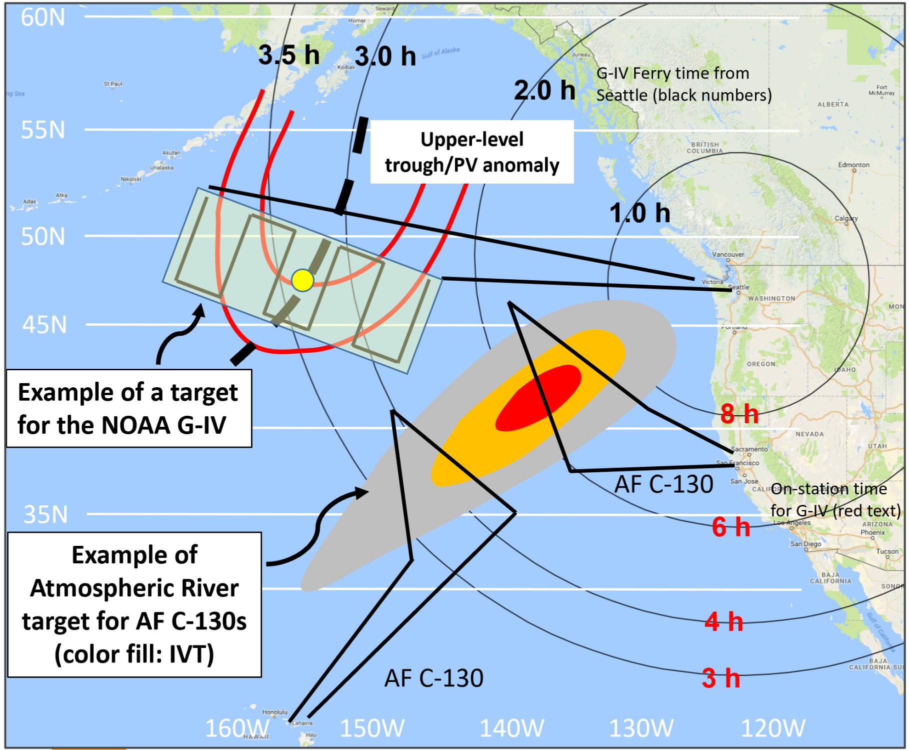


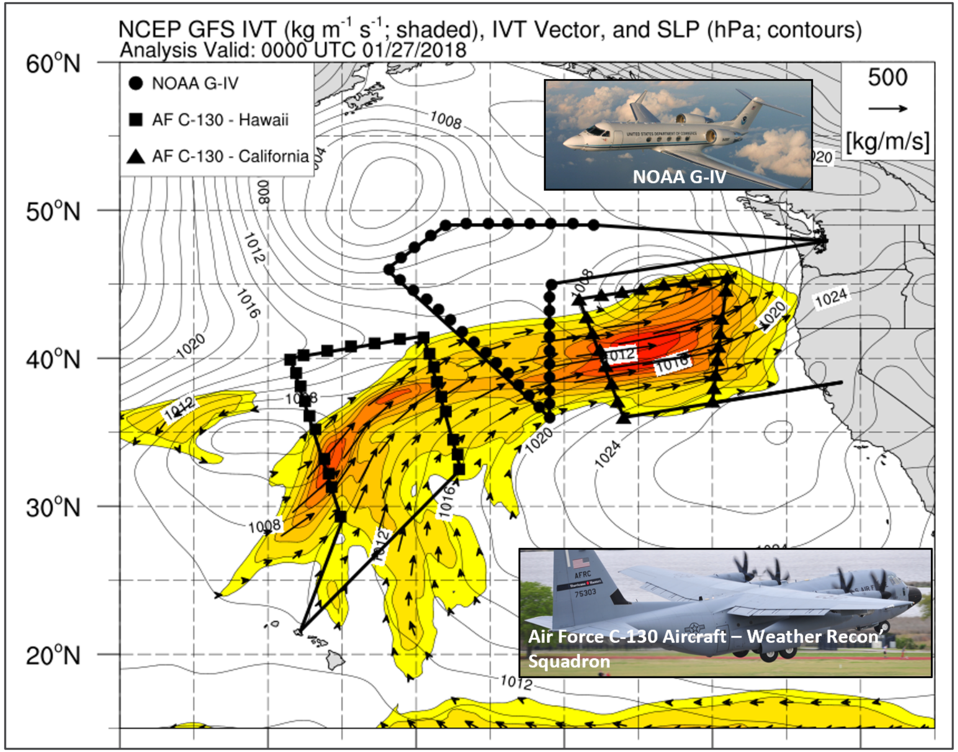
CW3E

AR Recon - 2020 deployment

- Dropsondes (aircraft)
  - Ralph, Tallapragada, Doyle
- Airborne Radio Occultation (aircraft)
  - Haase
- Pressure sensors on ocean surface (drifting buoys)
  - Centurioni, Ingleby

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

ATMOSPHERIC RIVER RECONNAISSANCE – A RESEARCH AND OPERATIONS PARTNERSHIP

- Better weather observations over the Pacific can help AR landfall predictions and associated precipitation, water supply and flooding
- Better AR forecasts can support both flood preparations and water management decisions
- AR Recon Modeling and Data Assimilation Steering Committee is doing detailed impact studies
- AR Recon has been included in the National Winter Season Operations Plan directing NOAA and AF to execute AR Recon, including in winter 2021

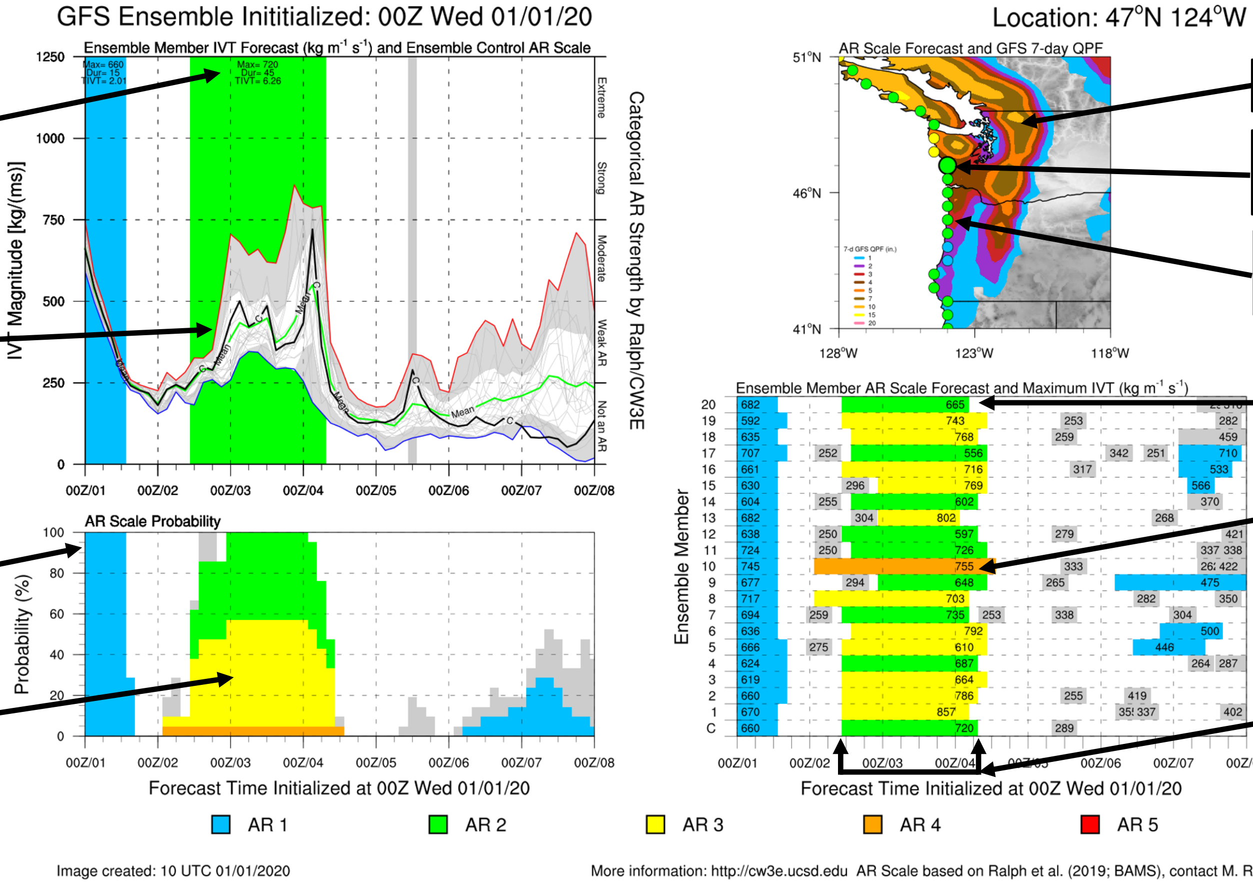
AR SCALE FORECAST PRODUCTS

Shading shows the AR Scale from the control or mean

IVT Plume Diagram

Probability of AR Scale based on each ensemble member

AR4: ~5 %
AR3: ~52 %
AR2: ~43 %



QPF

Location of current plot

AR Scale at each location

AR Scale forecast from each ensemble member

Max IVT during AR

Duration of AR

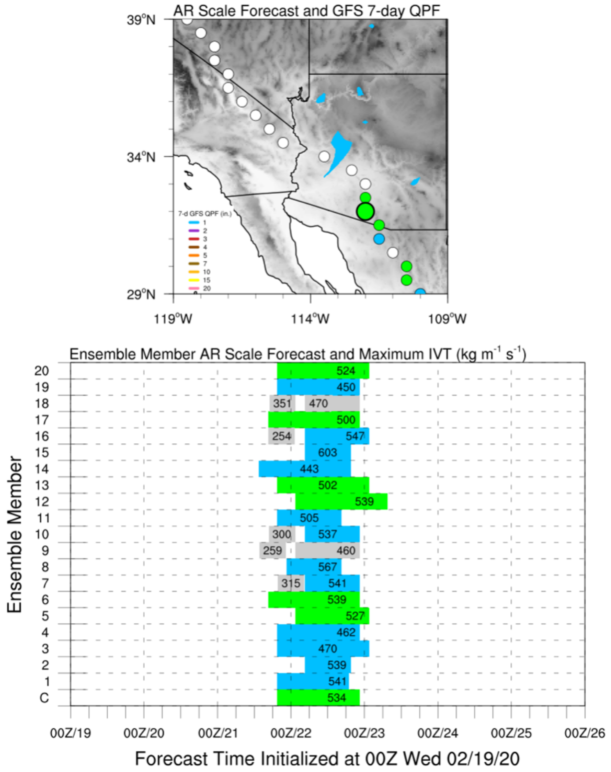
Provided by: B. Kawzenuk

AR Scale* Forecasts: Example from Feb 2020

*(*Ralph et al. 2019, BAMS)*

Center for Western Weather and Water Extremes

Issued: 00Z 19 Feb



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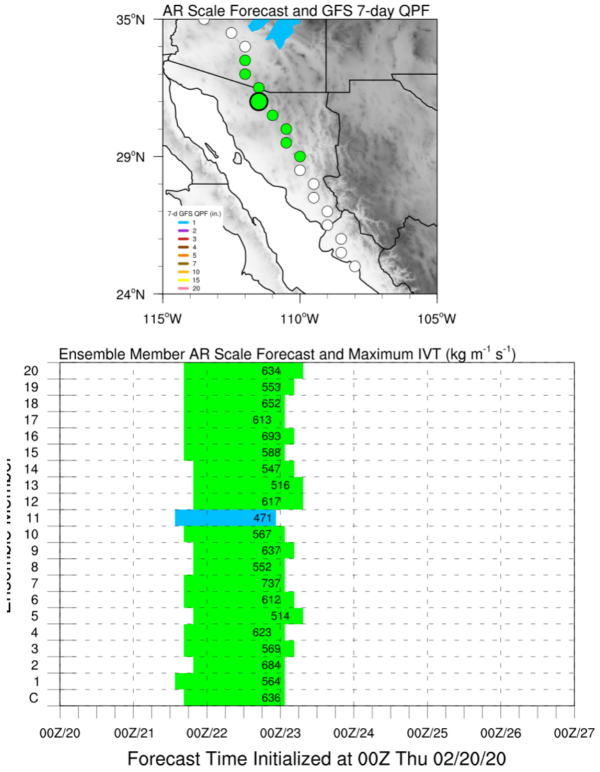

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