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

# ATMOSPHERIC RIVERS AND THEIR IMPACT ON PRECIPITATION FORECASTS ON THE US WEST COAST


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**NOAA-DOE Precipitation Processes and Predictability Workshop**

2 December 2020

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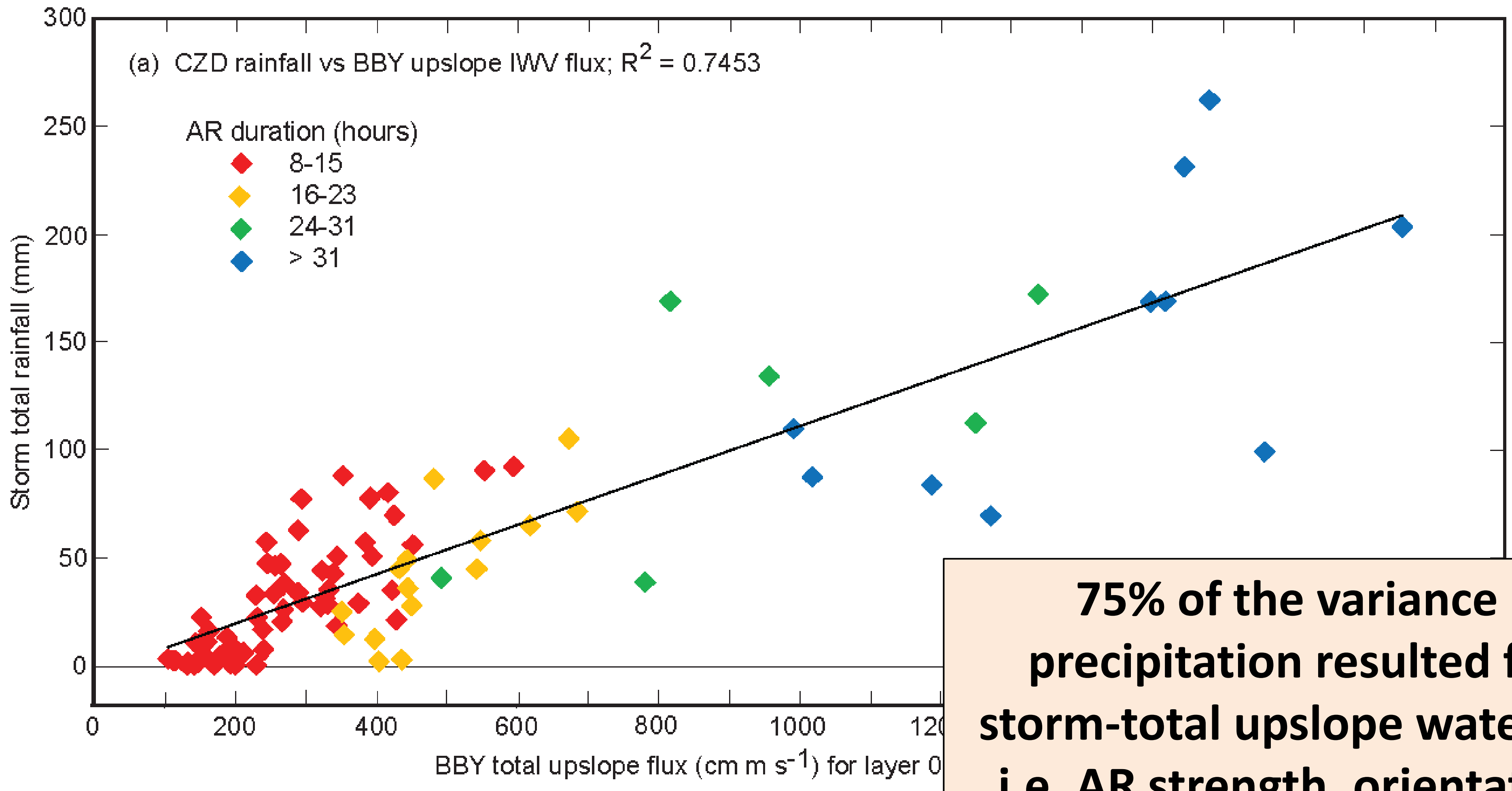
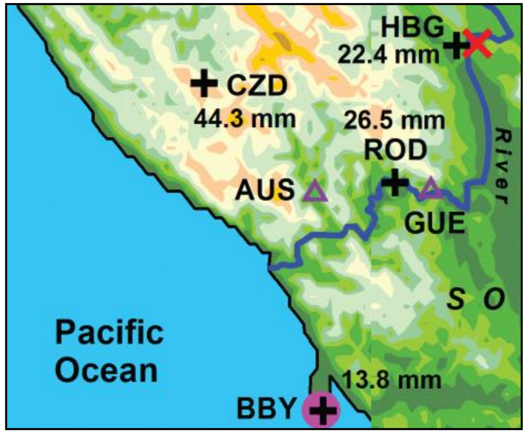
# Observed impacts of duration and seasonality of atmospheric-river landfalls on soil moisture and runoff in coastal northern California

*Ralph, F. M., T. Coleman, P.J. Neiman, R. Zamora, and M.D. Dettinger, J. Hydrometeorology, 2013*

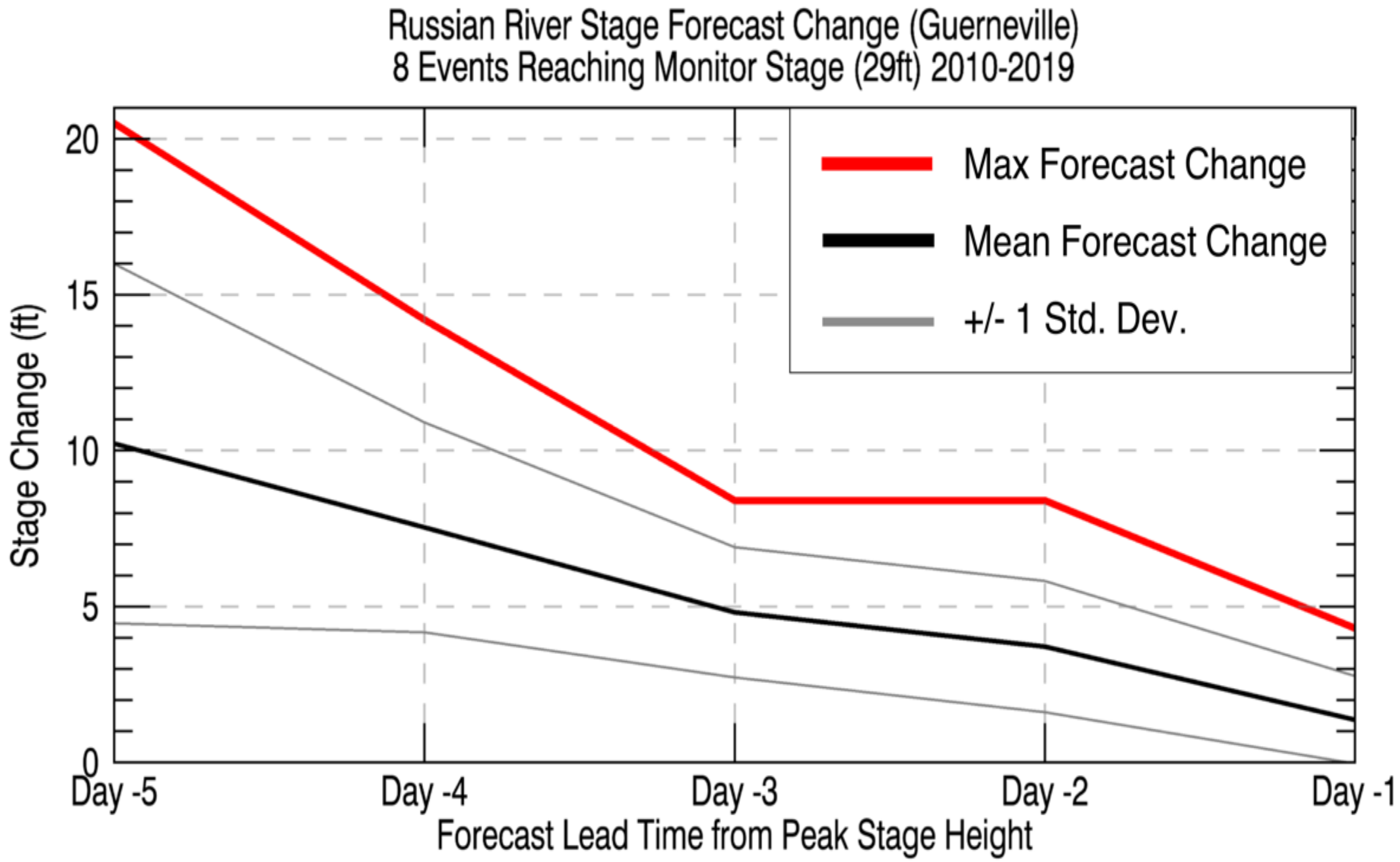



**91 AR events observed over 6 years**

**75% of the variance in storm-total precipitation resulted from variance in storm-total upslope water vapor transport, i.e. AR strength, orientation and duration**

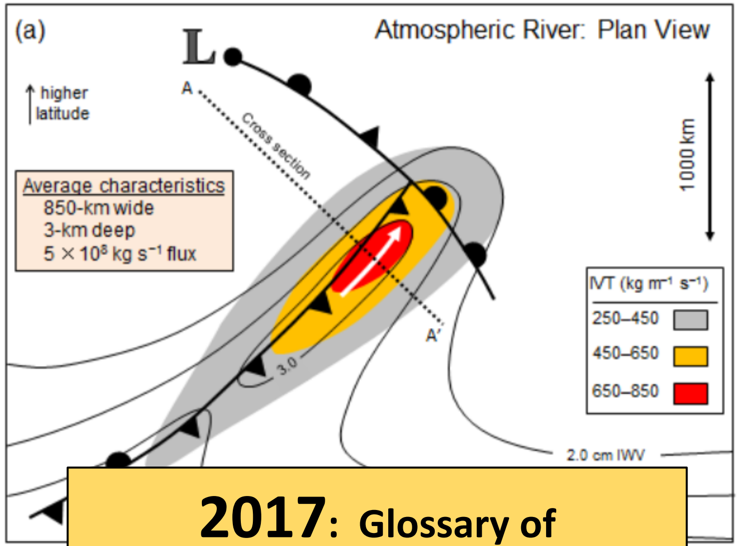
# ATMOSPHERIC RIVERS: FORECAST IMPROVEMENTS ARE NEEDED

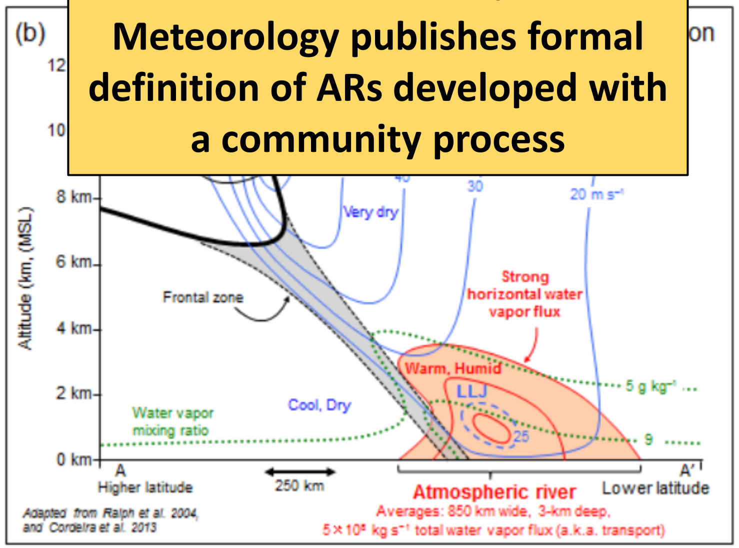



- Flood forecasts are often significantly off at even 1-5 days lead time
- Errors in predictions of heavy precipitation are the primary cause
- Errors in AR forecasts are the leading cause of errors in heavy precipitation and flood predictions

Glossary of Meteorology

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…

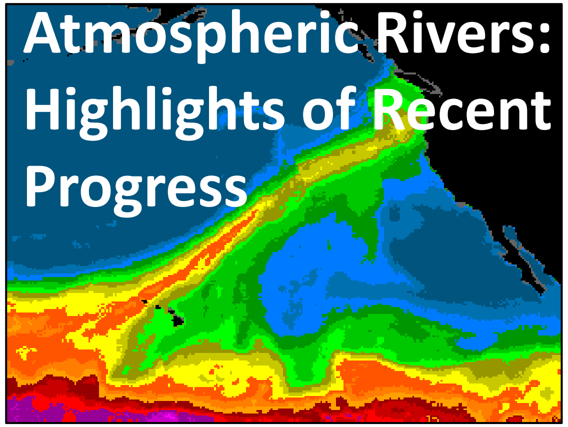


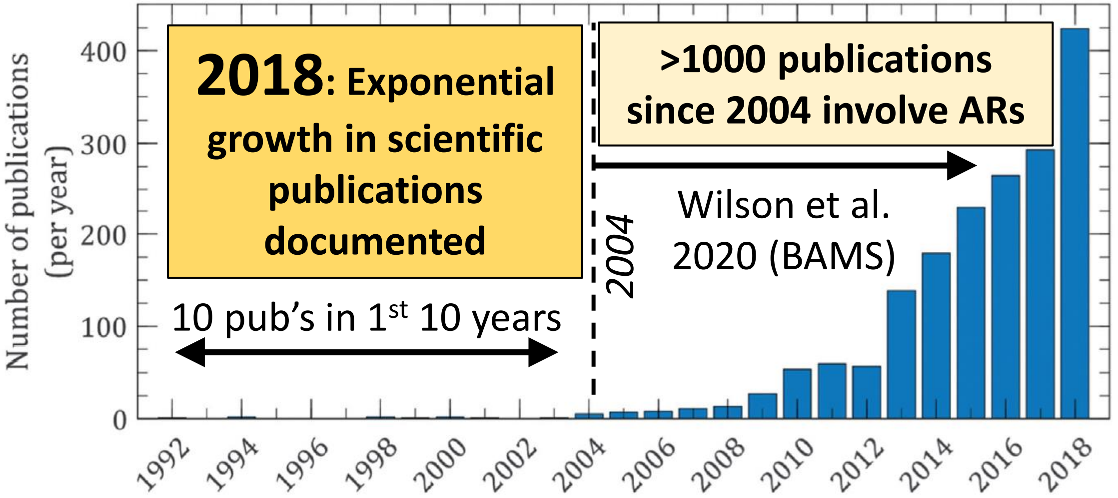




See Ralph et al. 2018 (BAMS) for description of the development of the definition

**2017: Glossary of Meteorology publishes formal definition of ARs developed with a community process**

# Atmospheric Rivers: Highlights of Recent Progress



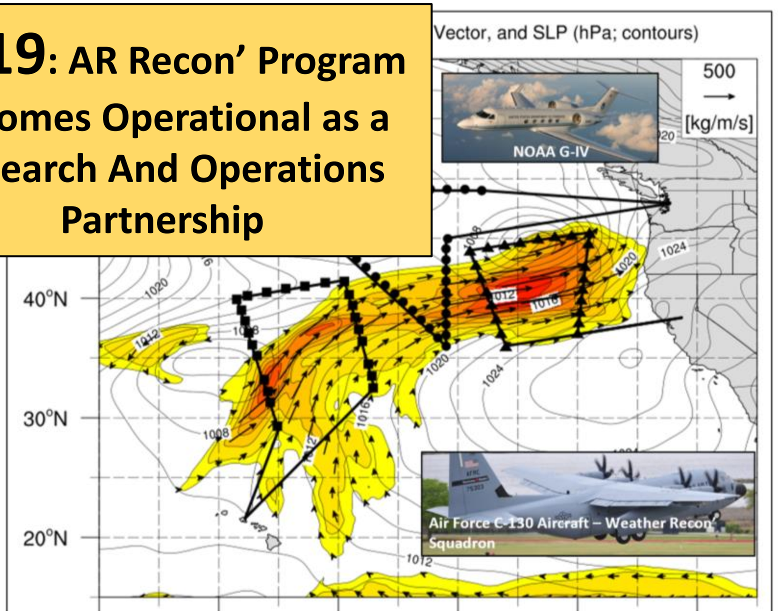



**2018: Exponential growth in scientific publications documented**

**>1000 publications since 2004 involve ARs**

## Atmospheric Rivers Reconnaissance

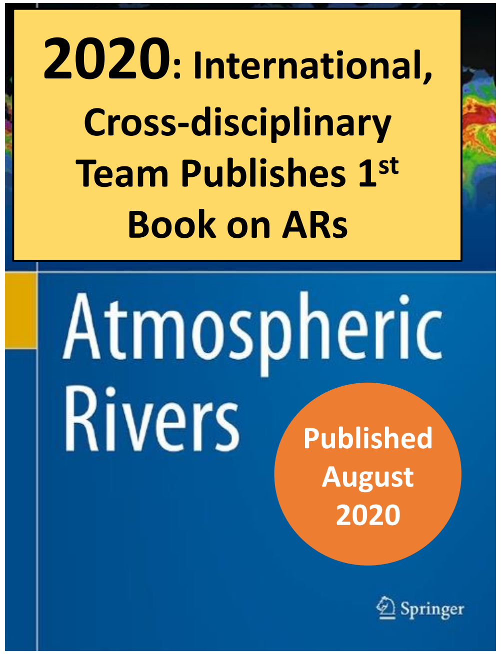
Ralph, Tallapragada, Doyle, Davis, Pappenberger…
In 2019 it became a requirement in the "National Winter Season Operations Plan" supporting Western water, flood, post-fire debris flows (Ralph et al. 2020 BAMS)




**2019: AR Recon' Program becomes Operational as a Research And Operations Partnership**

## Atmospheric Rivers Book

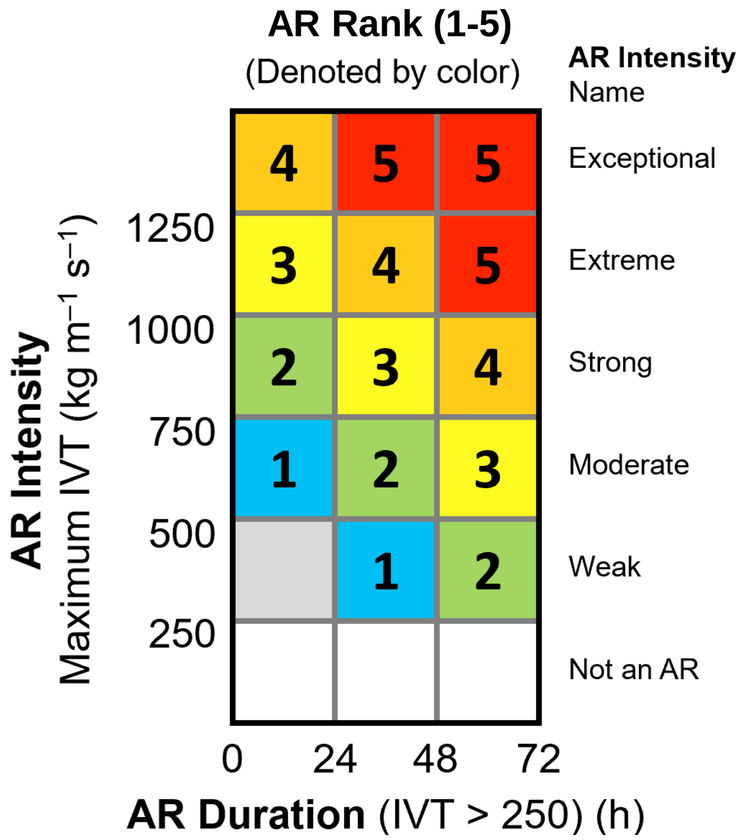
Ralph, Dettinger, Rutz, Waliser (Eds)
Published by Springer in August 2020
34 Contributing Authors




**2020: International, Cross-disciplinary Team Publishes 1st Book on ARs**

# AR Scale, Precipitation, and Western Flood Damages

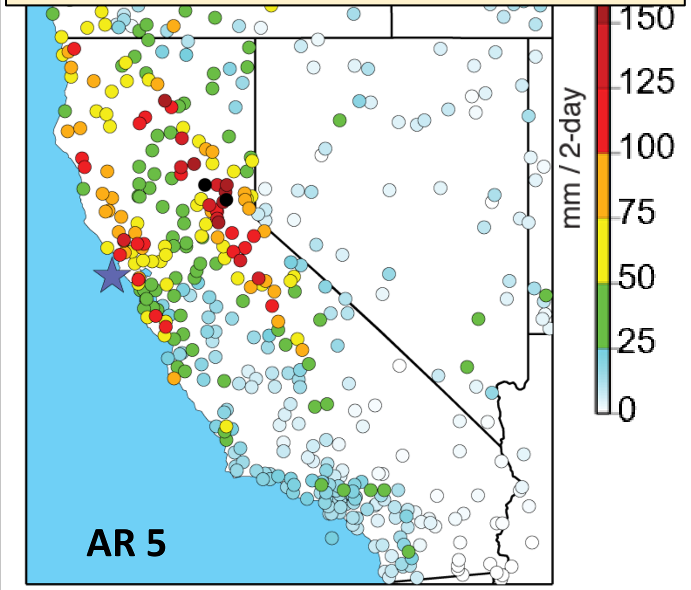
## AR Scale Created to Characterize the Strength and Impacts of ARs



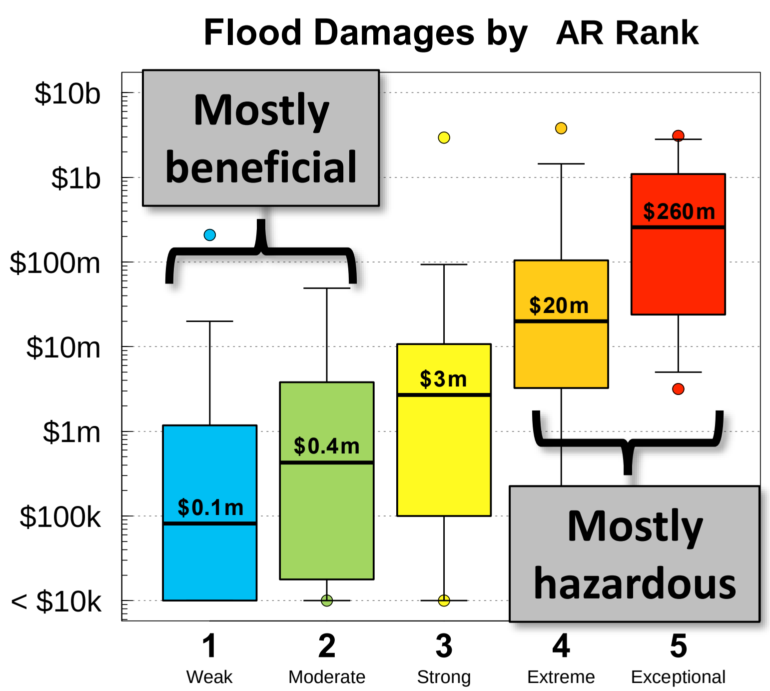

*Ralph et al. 2019 BAMS*

## Landfalling ARs Trigger Heavy Precipitation

**Of the 11 floods on the Russian River over 38 years, 6 were AR4, 3 were AR5 and 2 were AR3**




48-h average precipitation starting on AR 5 landfall day at 38ºN,123.125ºW (1980–2010)




*Corringham et al.2019, Science Advances*

**Flood damages increase exponentially with AR Ranking**

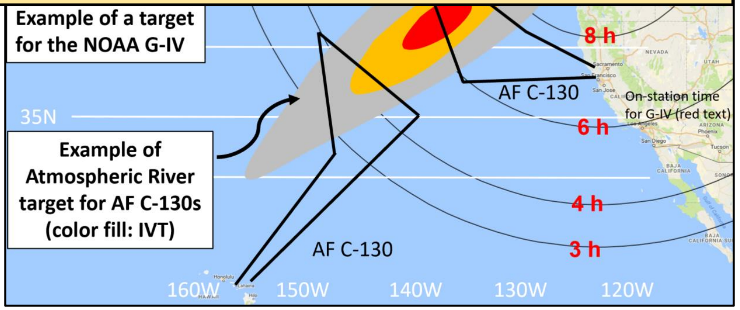
# West Coast Forecast Challenges and Development of Atmospheric River Reconnaissance

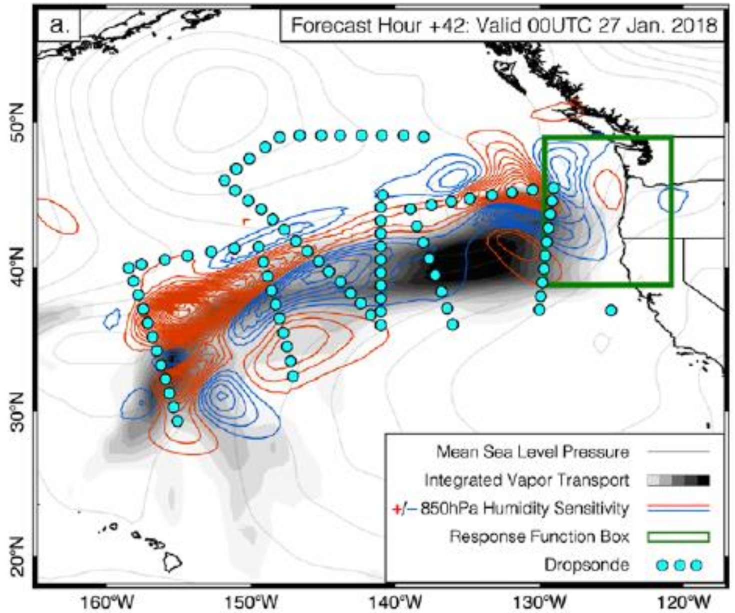
Center for Western Weather and Water Extremes

**Ralph, F.M. (PI),** F. Cannon, **V. Tallapragada (Co-PI), C.A. Davis, J.D. Doyle, F. Pappenberger, A. Subramanian**, A.M. Wilson, D.A. Lavers**, C.A. Reynolds**, J. Haase, J.J. Rutz, J.M. Cordeira, M. Zheng, C.W. Hecht, B. Kawzenuk, **L. Delle Monache (BAMS 2020)**

ARs cause >90% of US West Coast flood damages and 25-50% of annual water supply.
Better forecasts support water supply management and emergency preparedness.
ARs are the leading area where initial condition errors grow into precipitation forecast errors on the west coast.
ARs represent a major gap in traditional and satellite observations.
**AR Recon fills this gap with dropsondes, airborne radio occultation, drifting buoys with surface pressure, and data assimilation.**
It is led by CW3E (cw3e.ucsd.edu) and NWS/NCEP and includes NCAR, ECMWF, U.S. Navy, U.S. Air Force and others.
AR Recon began in 2016, uses a research and operations partnership approach, and became an operational requirement in 2019.

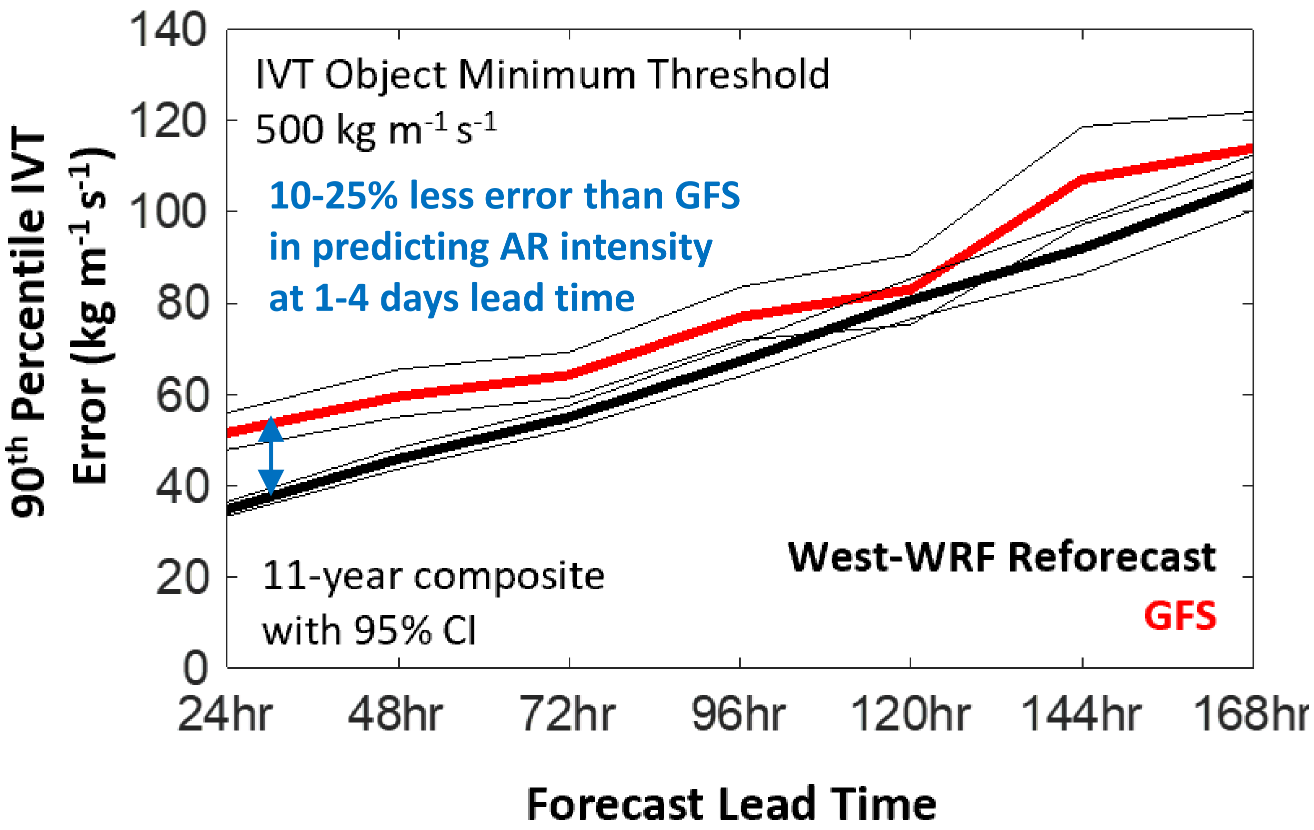
***"The 24-h global forecast error reduction from the reconnaissance soundings can be comparable to the reduction from the North American radiosonde network for the field program dates that include at least two flights."***
***(Stone et al. 2020; MWR)***

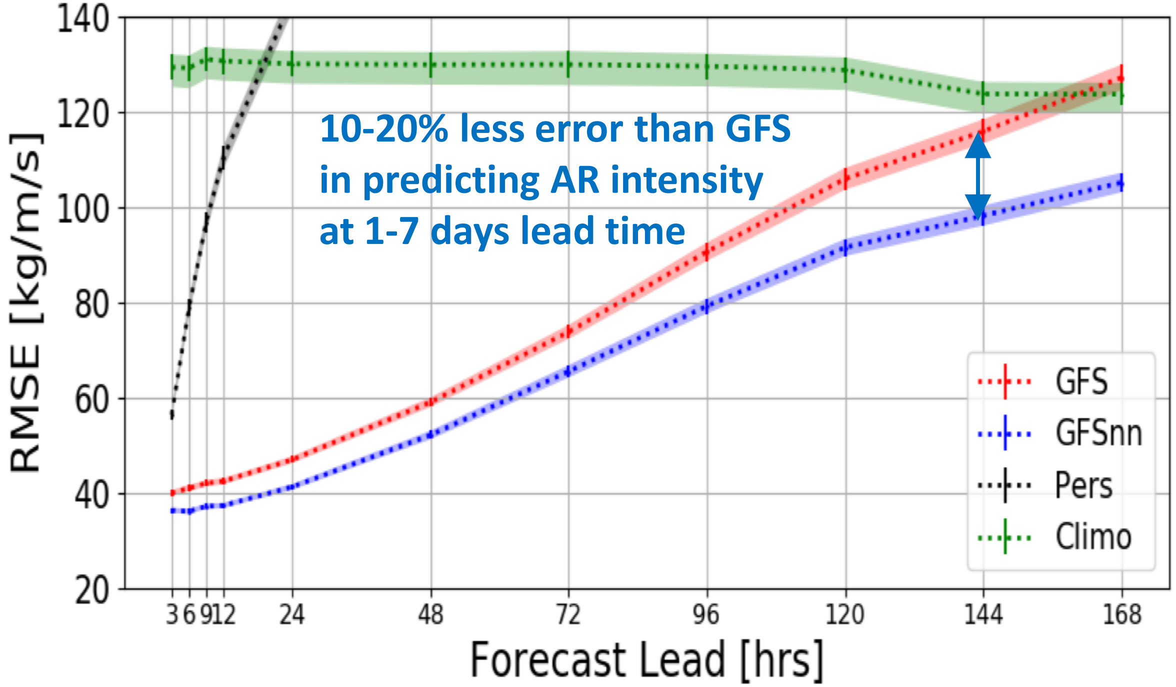
# Improving Predictions: Week 1

CW3E has developed "**West-WRF**," a regional version of WRF tailored to West Coast ARs/precip




West-WRF has smaller intensity error compared with GFS out to 4-day lead time.

Improving ARForecasts with **Machine Learning** (*Chapman et al. 2019, GRL*)



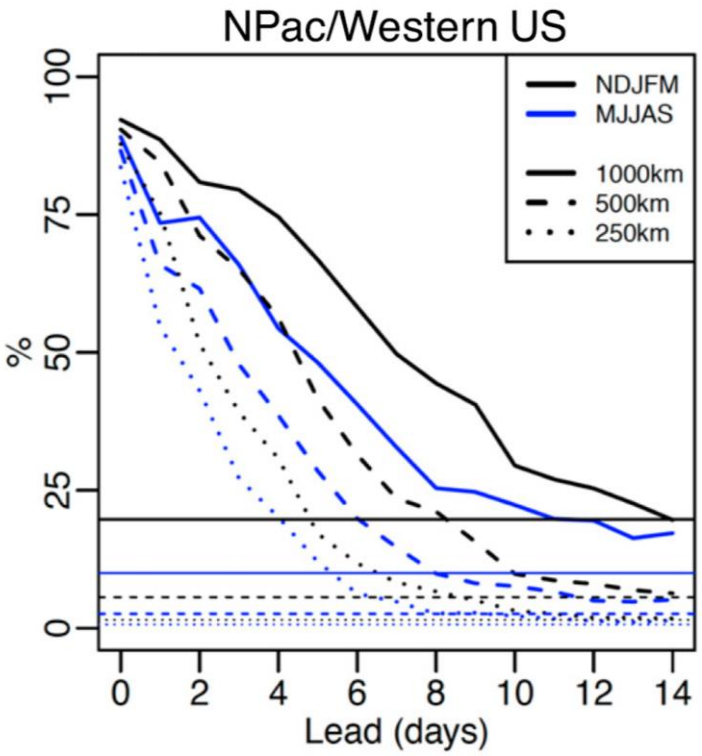

Convolutional Neural Network
0-168 h IVT (atmospheric river) predictions

~10 years of GFS
Ground-truth: MERRA 2

# Explore Predictive Skill for Atmospheric Rivers at Week-2 and Beyond

## DeFlorio et al. 2018 (JHM)

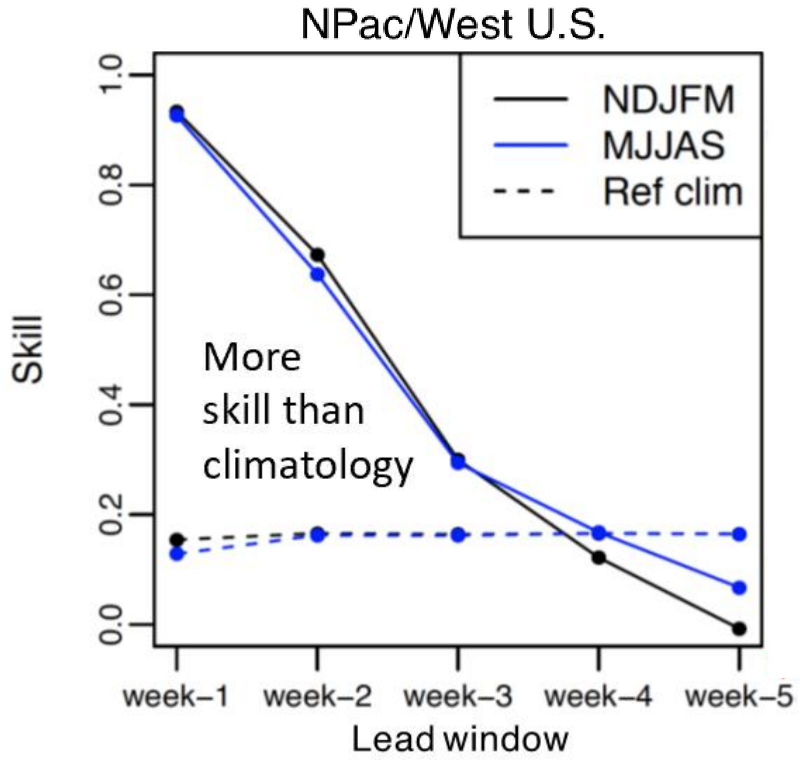
Uses ECMWF forecasts and Guan and Waliser (2015) AR Catalog




Some skill to 10-12 days in predicting location of AR within 500-1000 km of observed

## DeFlorio et al. 2018 (Clim Dyn)

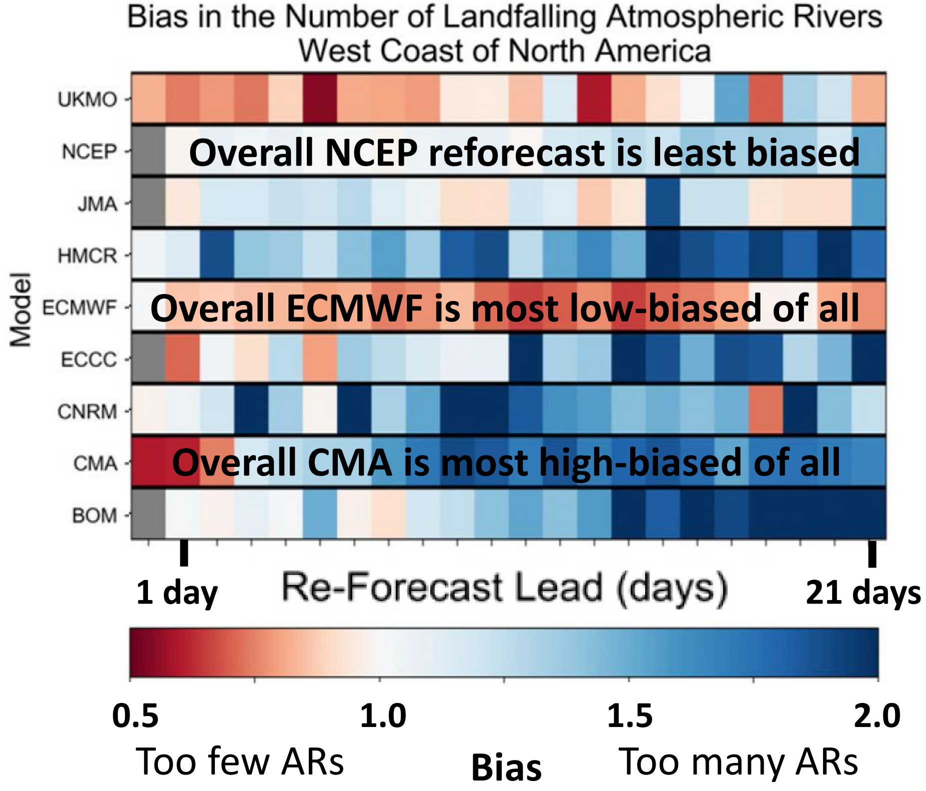
Evaluate global ECMWF hindcast prediction skill of number of AR days per week




Significant skill in predicting weekly number of ARs during week-2; some skill in week-3

## Nardi et al. 2018 (MWR)

Multi-model assessment of AR occurrence




Most models within 10 days become significantly biased with too many AR landfalls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# West-Coast ARs and Extreme Precipitation: Promising Directions

## Science:

- Origins of mesoscale frontal waves?
- Factors modulating inland penetration of ARs
- Quantify extreme precip triggers of post-wildfire debris flows
- Identify precursors of synoptic regime transitions for S2S
- Explore Machine Learning methods for ARs and precip.

## Observations:

- AR Recon
  - Add “BUFR” sounding transmission capacity to AF’s C-130s
  - Add airborne radio occultation to all of AF’s C-130s
  - Add pressure to all North Pacific drifting buoys
- Piggyback on AR Recon for physical process studies, e.g., water vapor budget, impacts of latent heating, boundary layer, microphysics, aerosols, and for satellite Cal-Val
- Update ocean observing systems for surface and subsurface
- Expand CA Mesonet across the west, incl. X- & C-band radars

## Modeling:

- Deploy a West-coast regional operational model (like HWRF)
- Expand western edge of regional domain much farther west
- Data assimilation that fully uses AR Recon and west-mesonet
  - Dropsondes
  - Airborne radio occultation
  - Drifting buoys
  - Wind profilers, snow-level radars, GPS-met, soil moisture
- Adapt National Water Model to western watersheds

## Prediction:

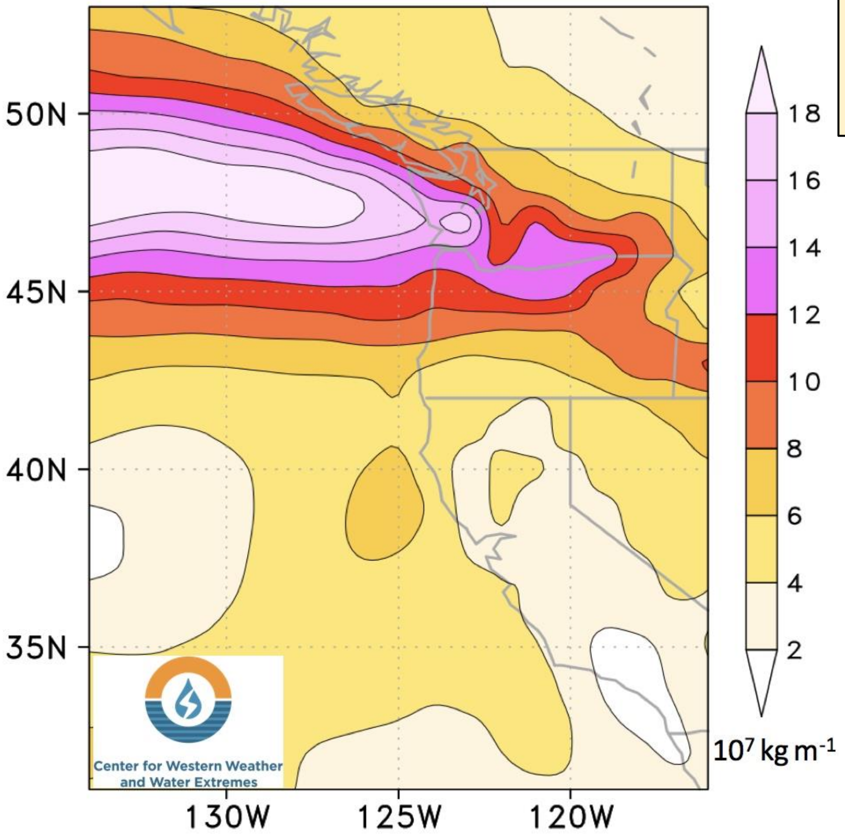
- Adopt the AR Scale in NWS’ Western and Alaskan Operations
- Use AR and mountain-aware forecast performance metrics
  - AR landfall position, duration, intensity, orientation
  - Implement regional performance metrics for extreme QPF
  - Adopt snow-level as a formal GPRA measure
- Establish S2S products tailored to water management needs

# Supplemental Material

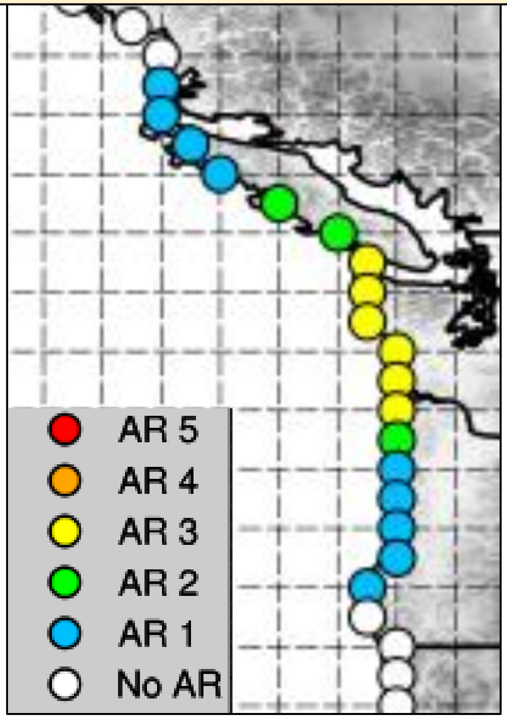
# ARs drive flood damages in the western U.S.


Broadcast Meteorologists are starting to use Atmospheric River in the West

3-day TIVT for Feb.5-Feb.7




Real-Time AR Scale analyses and forecasts available at cw3e.ucsd.edu (GFS and ECMWF)

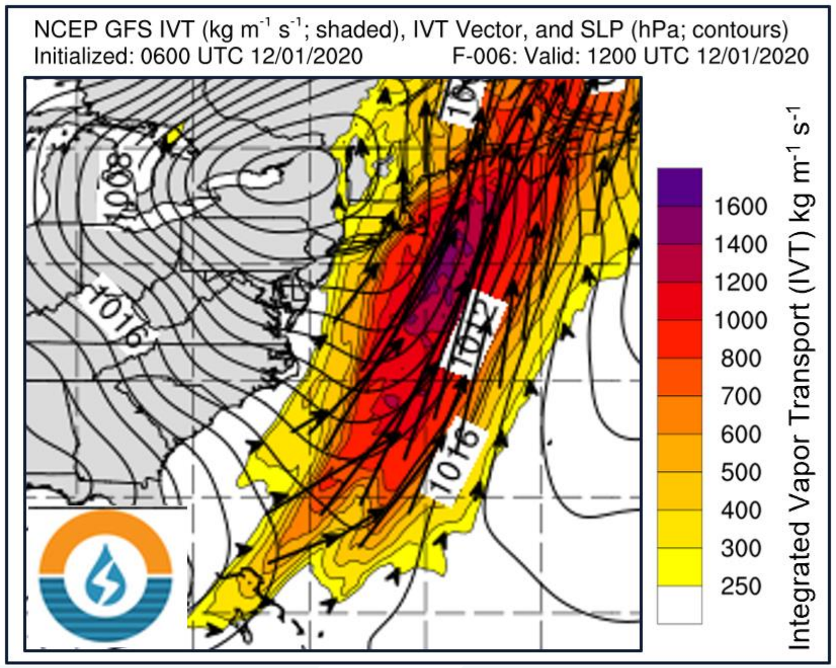


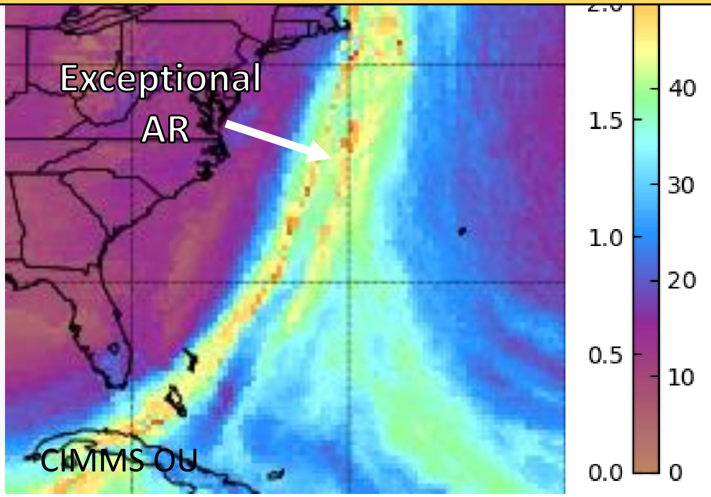
# East Coast AR 11/30–12/1 2020

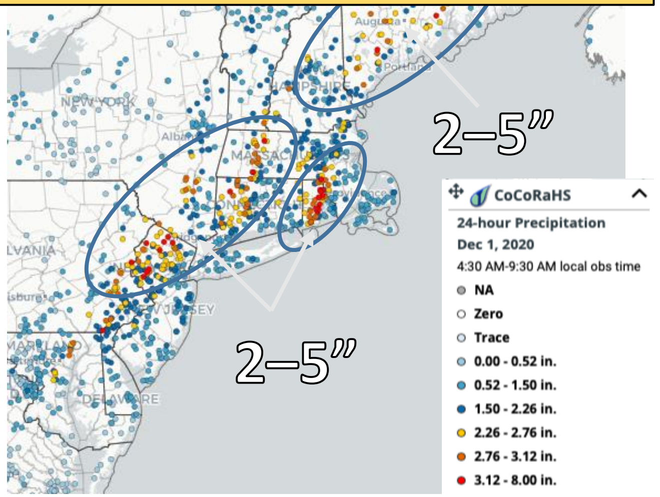
Jay Cordeira, PhD, *Plymouth State Univ.*

## Atmospheric Rivers play a key role in eastern and central US extreme precipitation

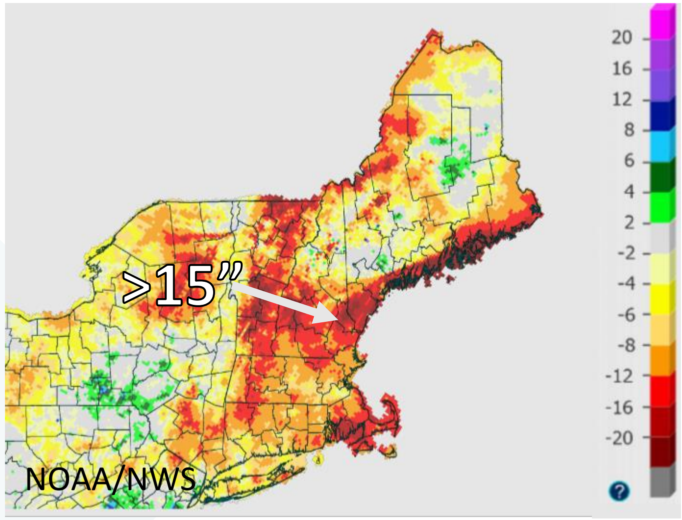
- Cyclone developed over Southeast and tracked into NY associated with "***exceptional" intensity atmospheric river*** using the Ralph et al. AR Scale
- Widespread Rainfall totals 2–5"
- Flooding despite dry initial state



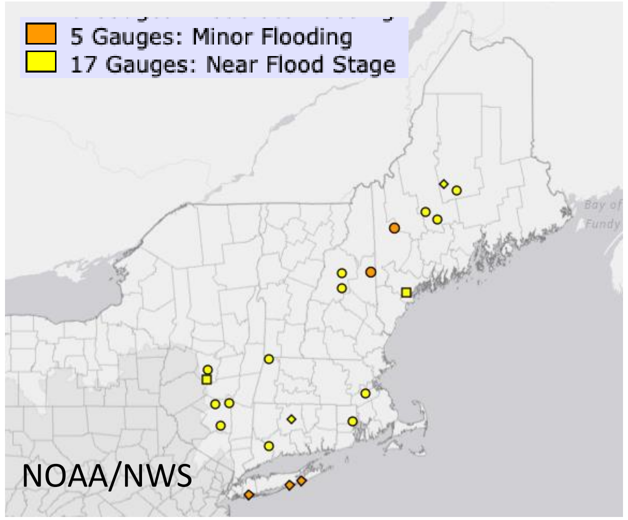



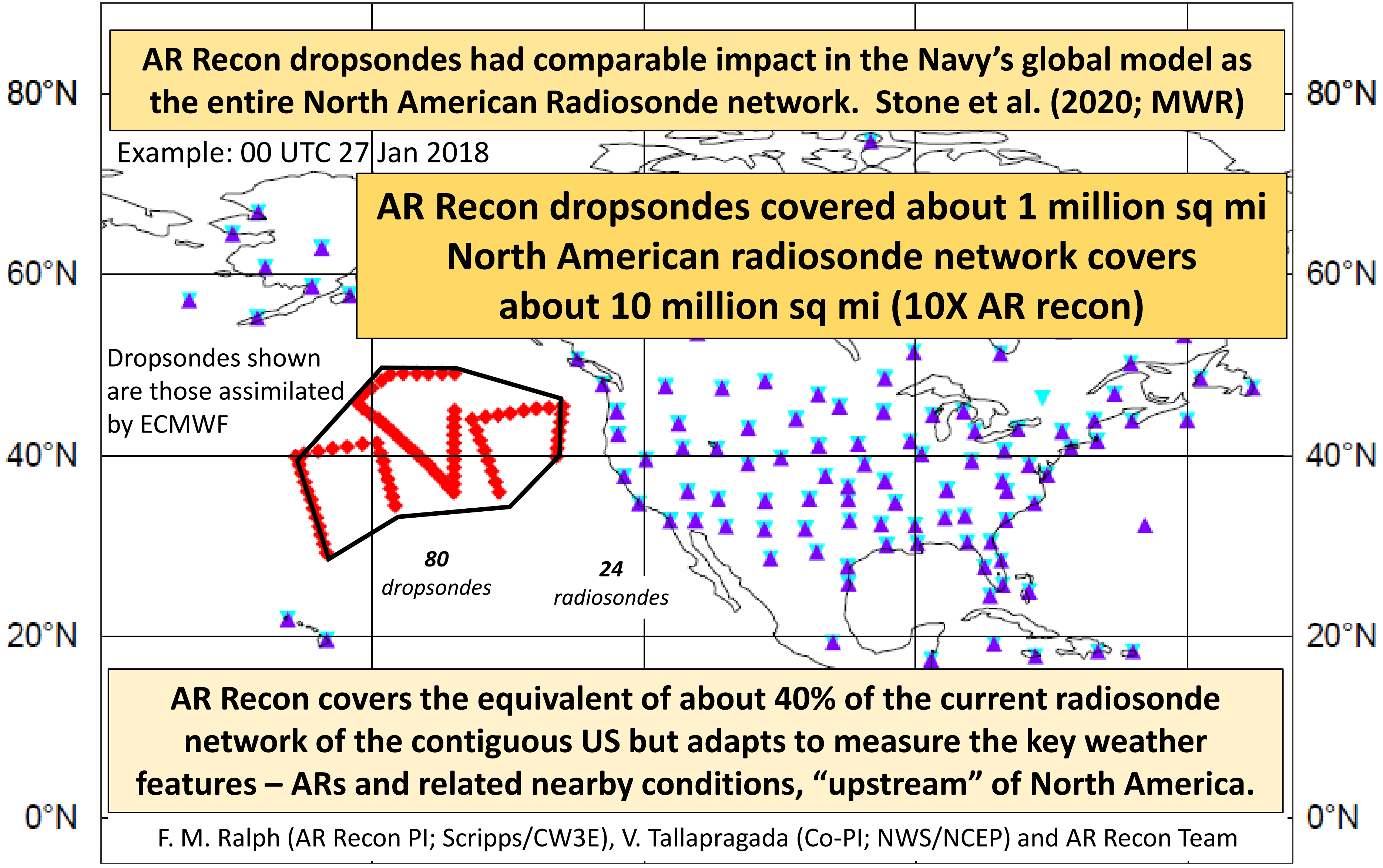

YTD Precip Departure (in.) 11/30/20




Near Flood or in Flood; 12Z 12/1/20



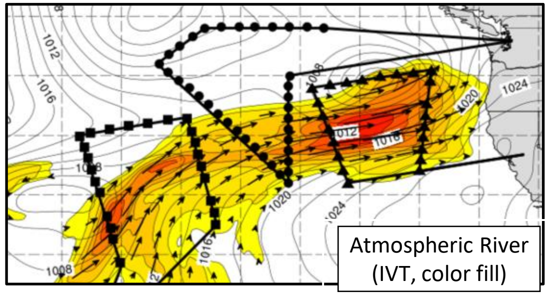
# Atmospheric River Reconnaissance (Ralph et al. 2020, BAMS) Aerial Coverage Compared to North American Radiosonde Network and Highlights of Stone et al. (2020, MWR) Navy-Model Impact Study




F. M. Ralph (AR Recon PI; Scripps/CW3E), V. Tallapragada (Co-PI; NWS/NCEP) and AR Recon Team

Map courtesy of ECMWF

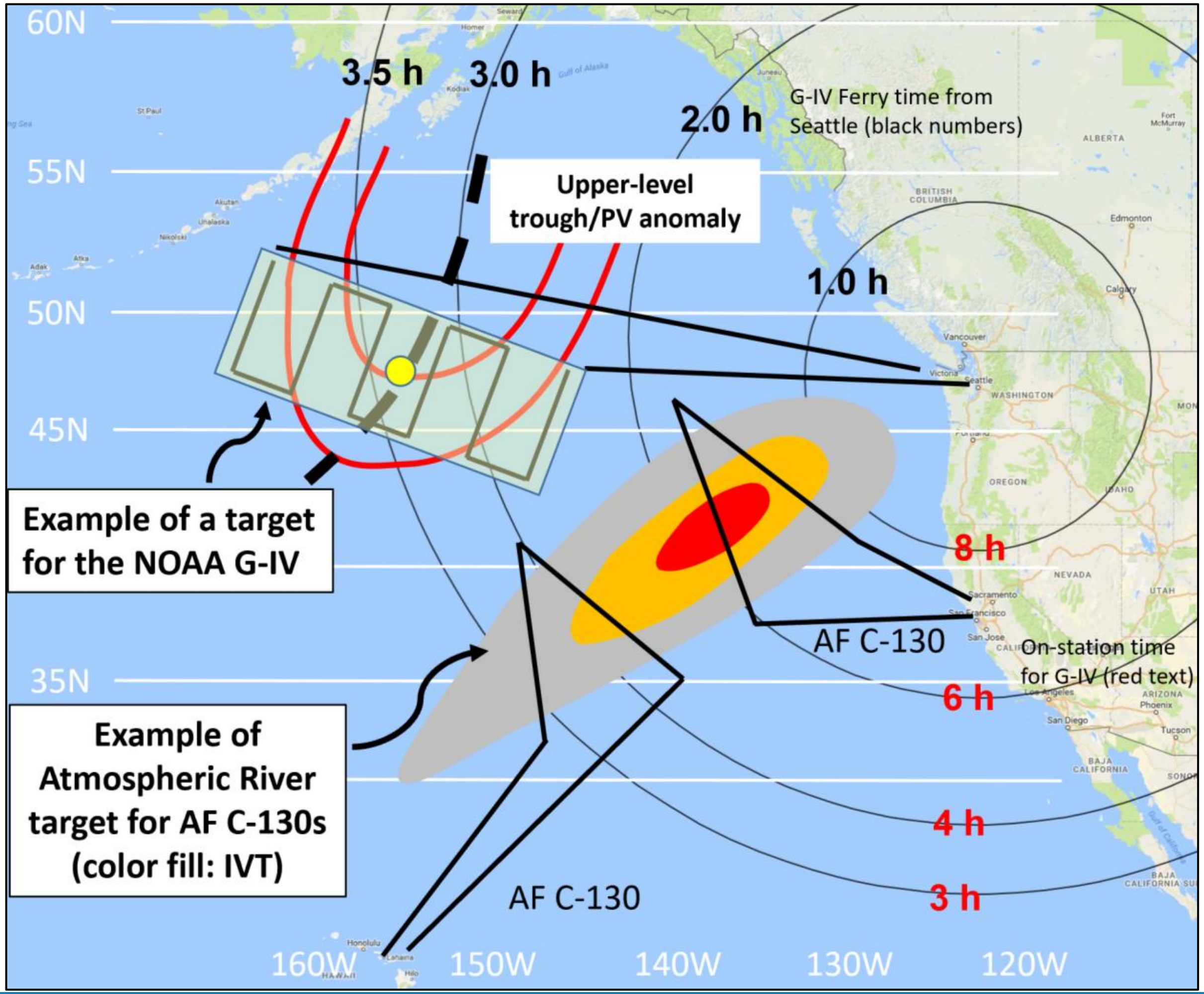


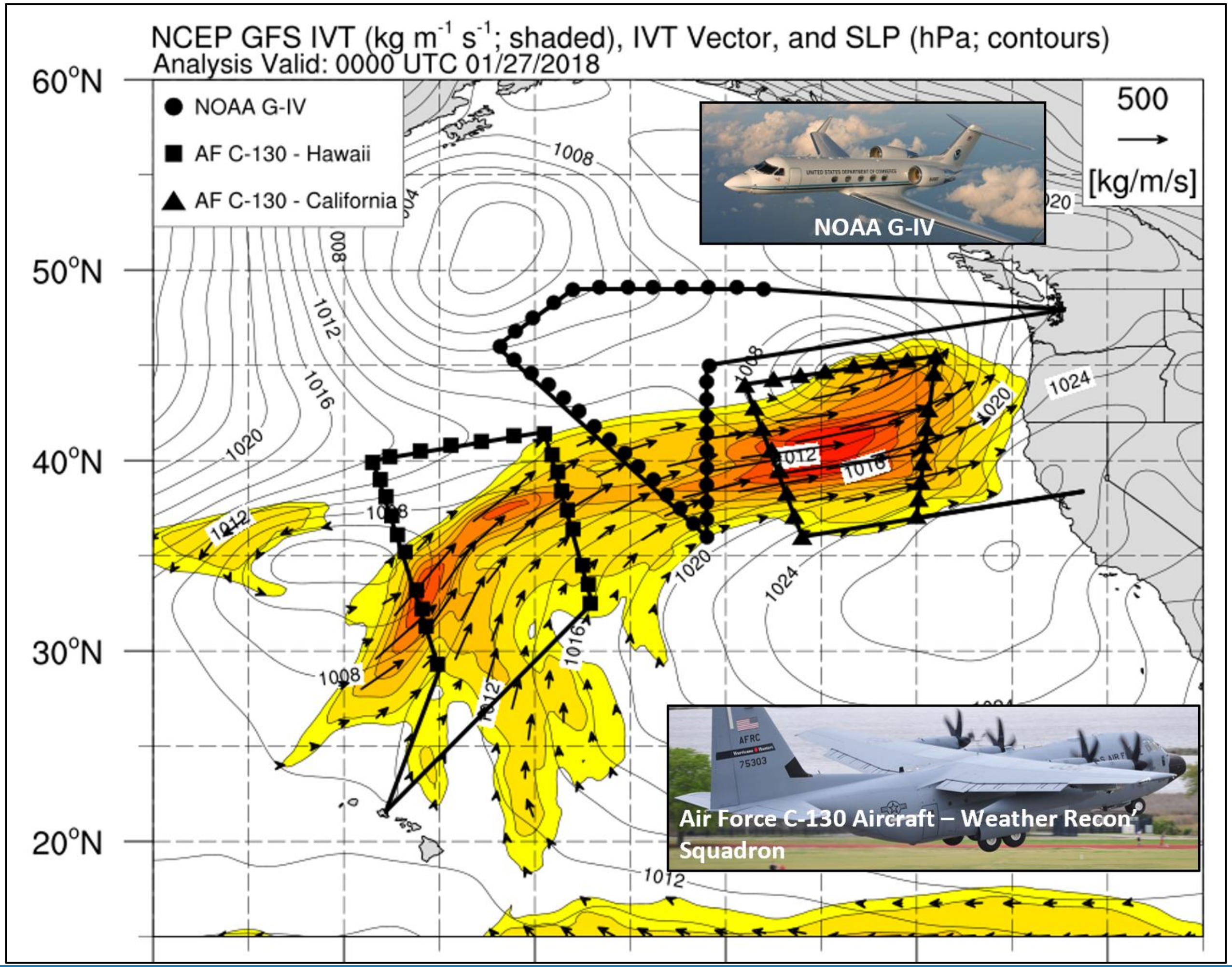


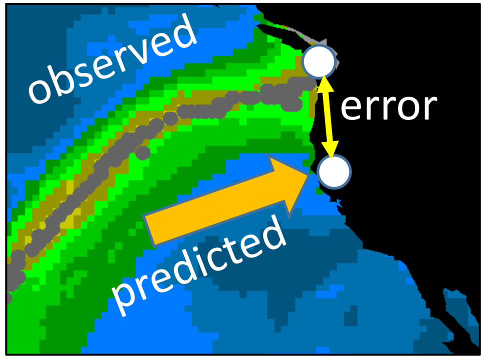

***"The 24-h global forecast error reduction from the reconnaissance soundings can be comparable to the reduction from the North American radiosonde network for the field program dates that include at least two flights." (Stone et al. 2020; MWR)***

# 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



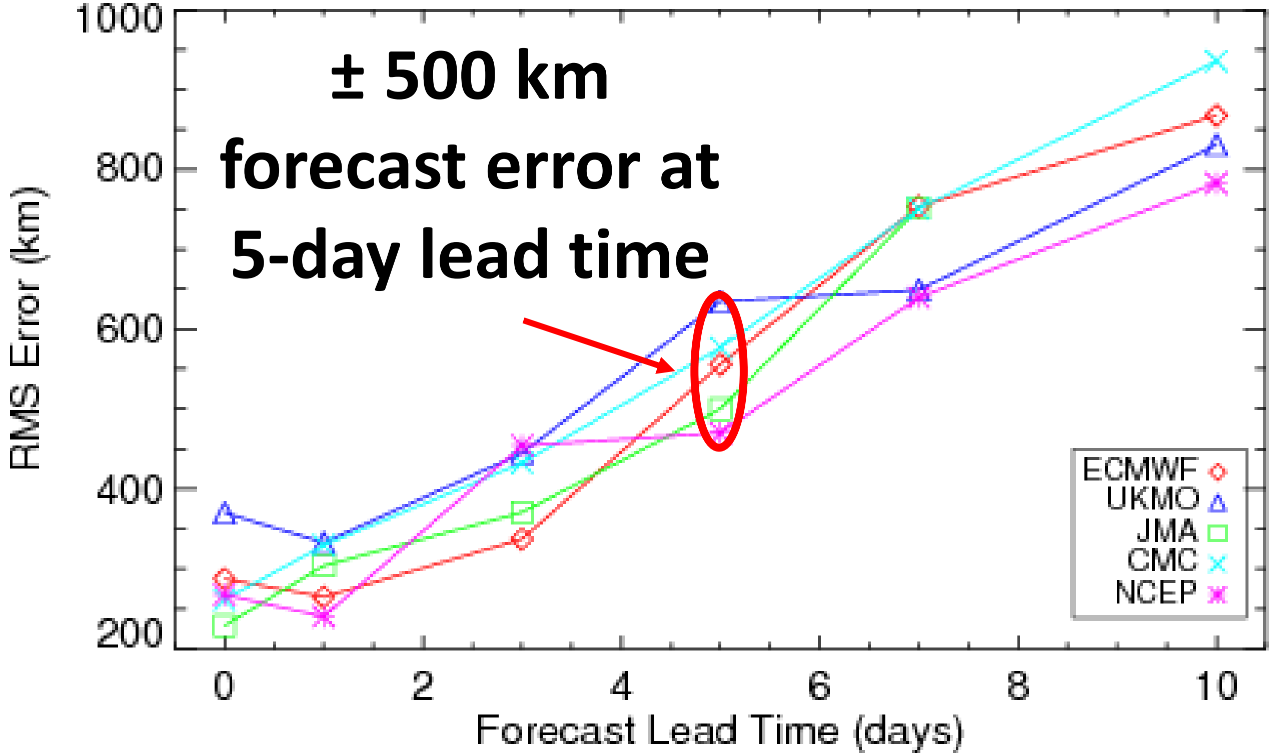



# Evaluation of forecasts of the water vapor signature of atmospheric rivers in numerical weather prediction models

Wick, G.A., P.J. Neiman, F.M. Ralph, and T.M. Hamill, *Wea. Forecasting* (2013)

**While overall occurrence well forecast out to 10 days, landfall is less well predicted and the location is subject to significant errors, especially at longer lead times**

**RMS Error in Forecast AR Landfall Location**




- Errors in location increase to over 800 km at 10-day lead
- Errors in 3-5 day forecasts comparable with current hurricane track errors
- Model resolution a key factor

- **Models provide useful heads-up for AR impact and IWV content, but location highly uncertain**
- **Location uncertainty highlights limitations in ability to predict extreme precipitation and flooding**