



Center for Western Weather
and Water Extremes

SCRIPPS INSTITUTION OF OCEANOGRAPHY
AT UC SAN DIEGO

UC San Diego



Atmospheric River Reconnaissance - Overview

F. Martin Ralph, Director of CW3E
Principal Investigator, AR Recon
Principal Investigator, Global AR Recon Program

AR Recon Workshop

European Centre for Medium-Range Weather Forecasts

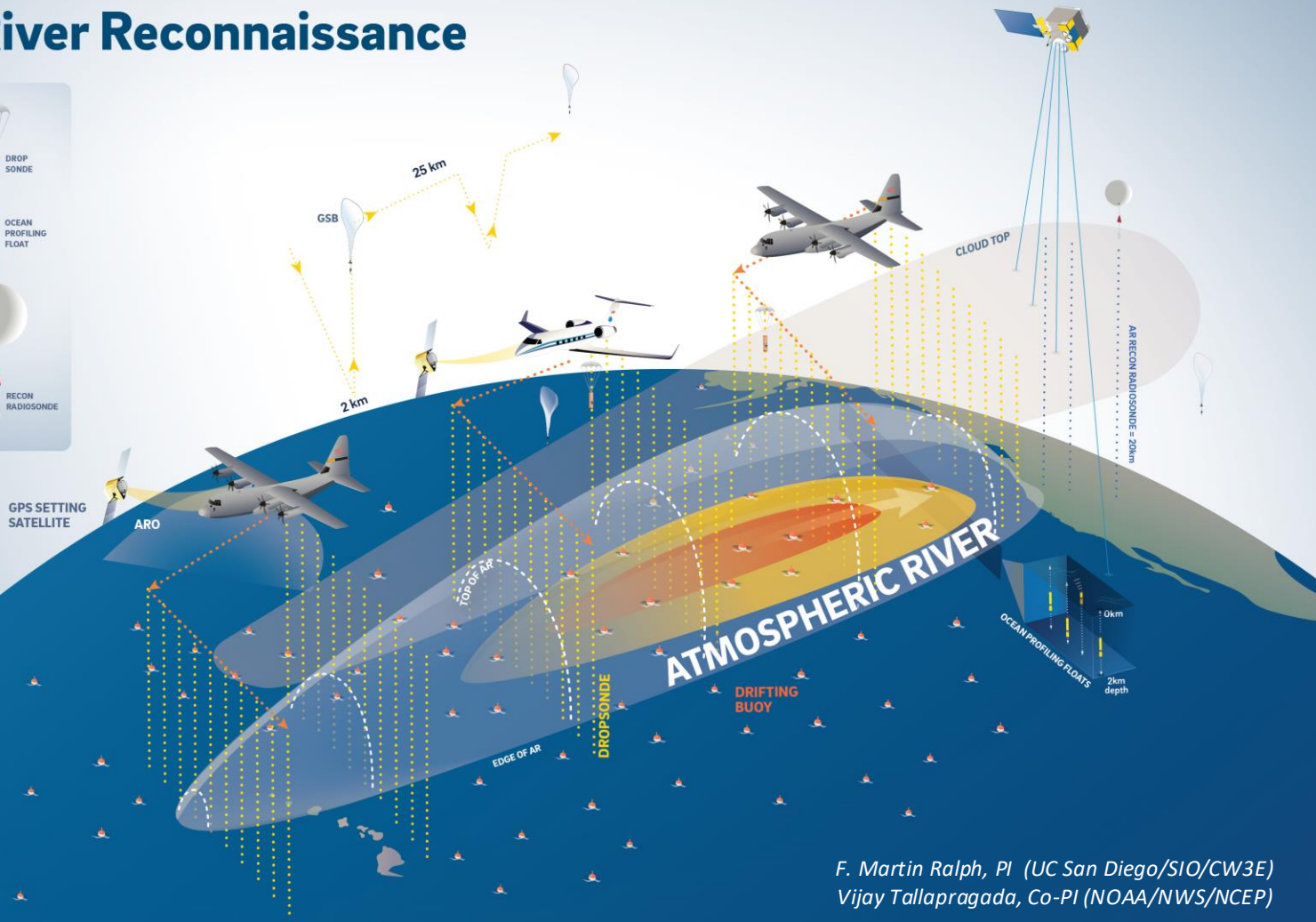
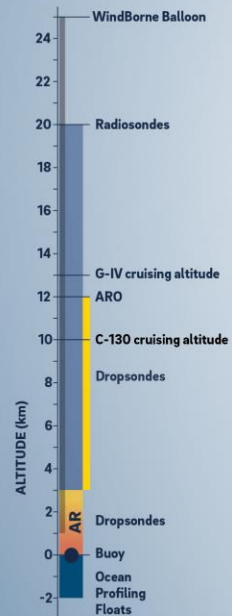
29 Jun 2026

Outline

- 1 – Setting the Stage
- 2 – Data Collection
- 3 – Research and Education
- 4 – Looking Ahead

Atmospheric River Reconnaissance

Offshore Sampling



Ralph et al. 2020
 (Bull. Amer. Meteorol. Soc.;
 AR Recon Overview)

F. Martin Ralph, PI (UC San Diego/SIO/CW3E)
 Vijay Tallapragada, Co-PI (NOAA/NWS/NCEP)

Research and Operations Partnership

- Flights planned by a team of meteorologists and flight directors.
- Data includes drifting buoys, moorings, profiling floats, long-duration balloons, and weather stations and balloon launches on land.
- Data assimilated into global forecast models.
- Consistently shows significant positive impact on forecasts.

Much more than a data collection and forecast improvement effort

- Pursues a rich spectrum of research questions.
- Creates student education and early career professional development opportunities.
- Receives strong Bipartisan support.
- Expanding to global partnerships, data collection and impacts – building bridges

Key Partners: CW3E/UC San Diego, NCEP/NWS, NOAA Aircraft Operations Center, US Air Force, ECMWF, Naval Research Laboratory, NSF-National Center for Atmospheric Research, Universities

U.S. SENATE COMMITTEE ON COMMERCE, SCIENCE, & TRANSPORTATION

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Cantwell, Cruz, Colleagues Introduce Weather Act Reauthorization to Modernize Weather Forecasting and Research

February 25, 2026

Act would establish an atmospheric river forecast improvement program, strengthen landslide preparedness, establish an official Fire Weather Services Program, and deploy new technology and tools to forecast droughts and heat waves that harm crops

WASHINGTON, D.C. – U.S. Senators Maria Cantwell (D-Wash.), Ranking Member of the Senate Committee on Commerce, Science and Transportation, Chairman Ted Cruz, (R-Texas), Lisa Blunt Rochester (D-Del.) Dan Sullivan (R-Alaska), Brian Schatz (D-Hawaii), Jerry Moran (R-Kan.), Jacky Rosen (D-Nev.) and Tim Sheehy (R-Mont.) today introduced the Weather Research and Forecasting Innovation Reauthorization Act of 2026, bipartisan legislation authorizing programs at the National Oceanic and Atmospheric Administration (NOAA) that would strengthen weather research and forecasting to save lives and better prepare our nation against dangerous weather disasters.

**ABBREVIATED A.R.,
THIS ELONGATED
BAND OF WATER VAPOR
HAS 5 CATEGORIES
OF STRENGTH,
JUST LIKE
A HURRICANE**

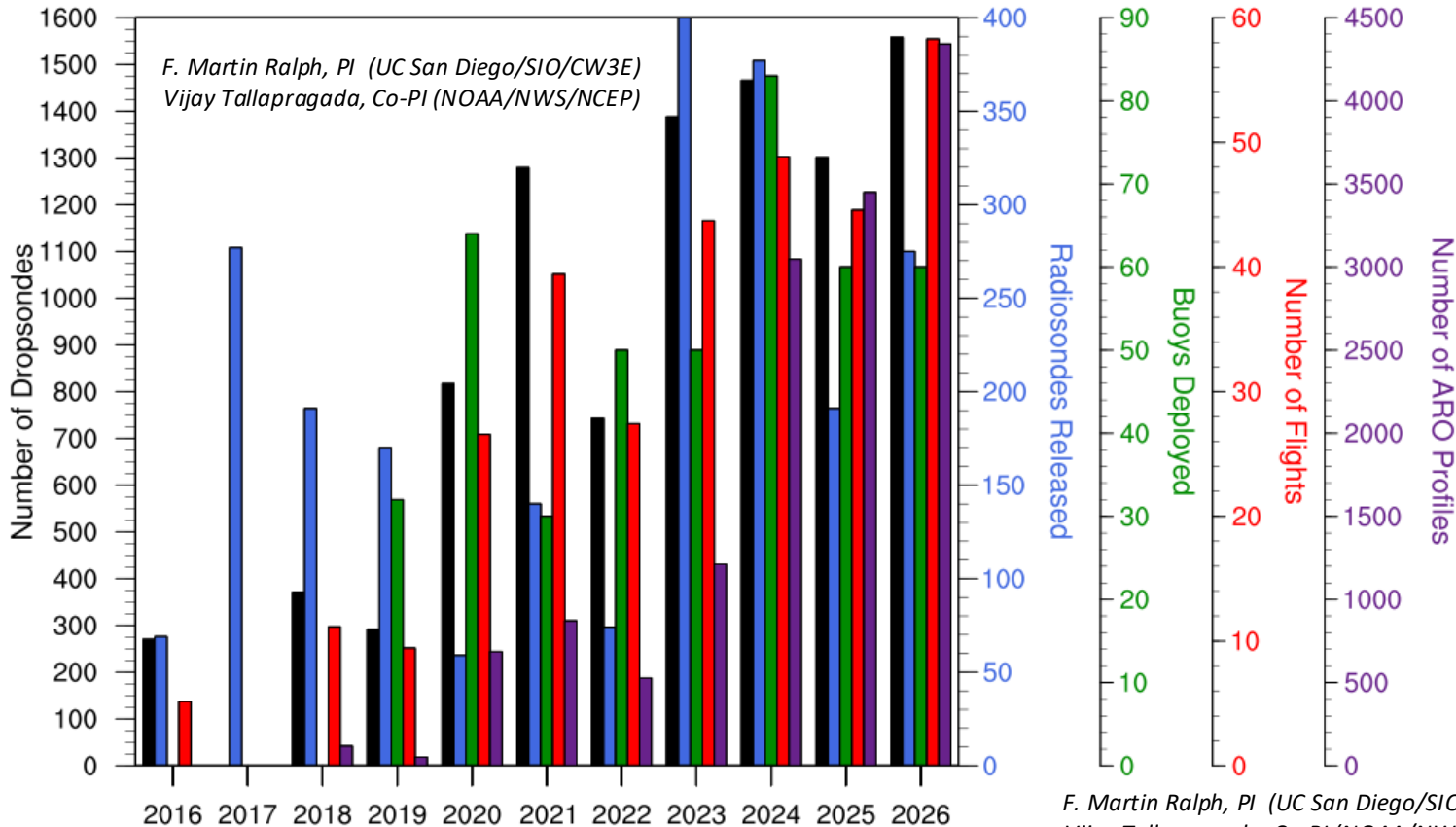


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ATMOSPHERIC RIVER RECONNAISSANCE

Atmospheric River Reconnaissance



- Significant growth since AR Recon became operational in 2020.
- Growth based on demonstration of success and value of observations.
- AR Recon data are critical to programs like Forecast Informed Reservoir Operations.

*F. Martin Ralph, PI (UC San Diego/SIO/CW3E)
Vijay Tallapragada, Co-PI (NOAA/NWS/NCEP)*



AR Recon: Sampling Platforms

AR Recon 2024 Dropsonde Locations

IOPs 1-40 (15 Nov - 29 Feb)

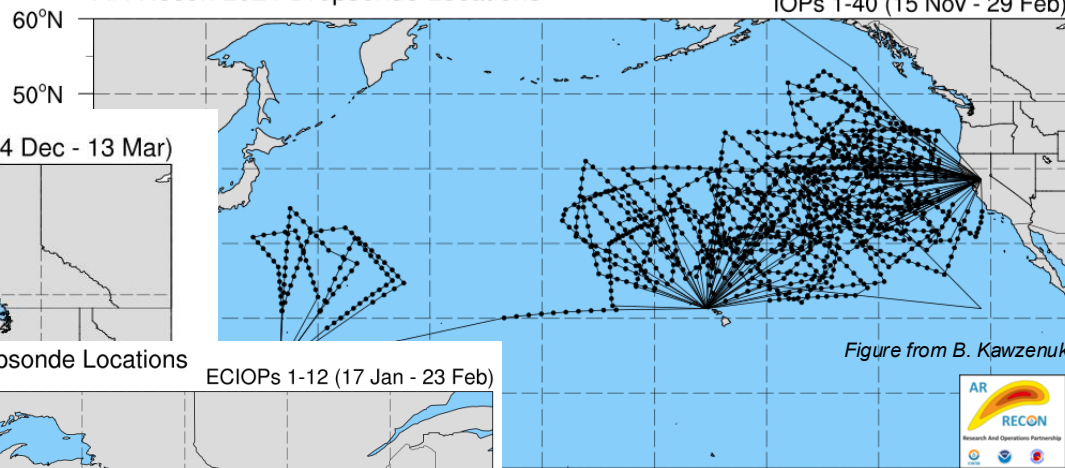
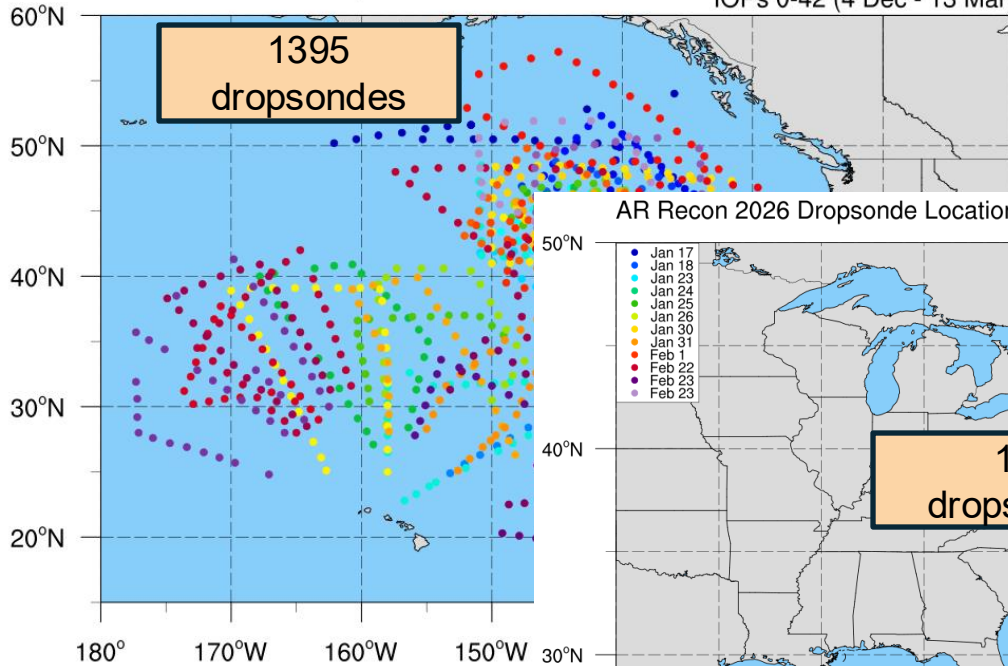


Figure from B. Kawzenuk

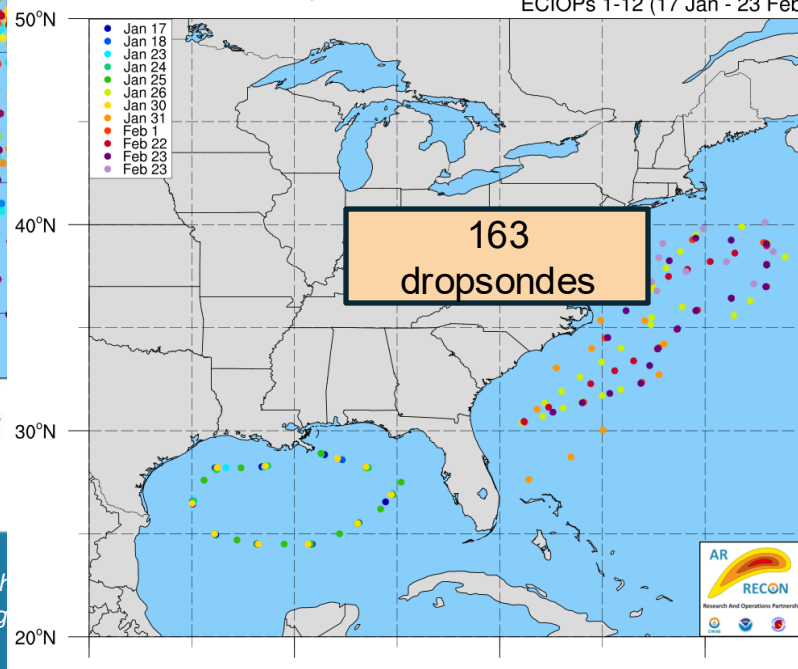
AR Recon 2026 Dropsonde Locations

IOPs 0-42 (4 Dec - 13 Mar)



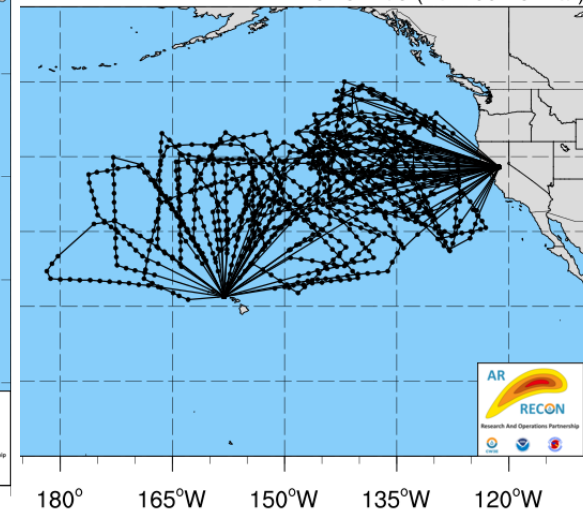
AR Recon 2026 Dropsonde Locations

ECIOPs 1-12 (17 Jan - 23 Feb)



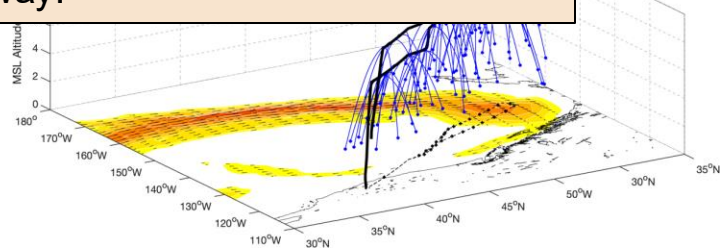
ONS

IOPs 1-35 (13 Dec - 5 Mar)

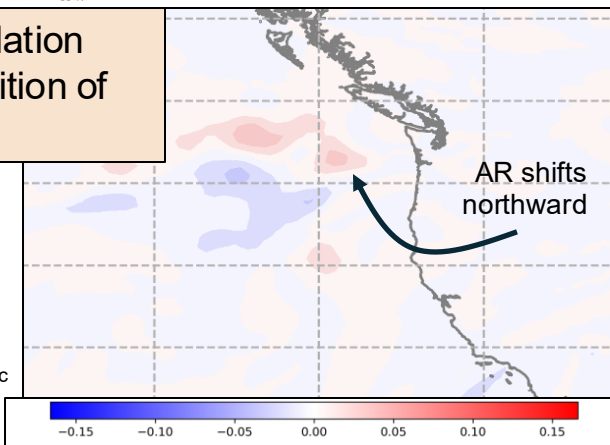


Airborne Radio Occultation in AR Recon

Slanted profiles stretch from the flight track sideways up to 400 km away.

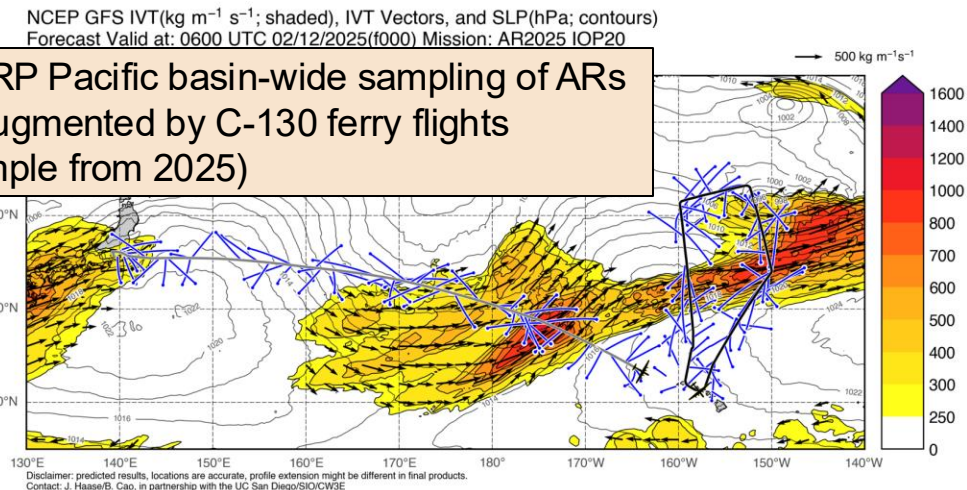


ARO data assimilation improves the position of the AR.



Change in midlevel specific humidity (g/kg)
Do et al., 2025, GRL

GARRP Pacific basin-wide sampling of ARs are augmented by C-130 ferry flights (example from 2025)



*ARO flying on all 11 aircraft.
Work ongoing on real time data processing and model ingest*

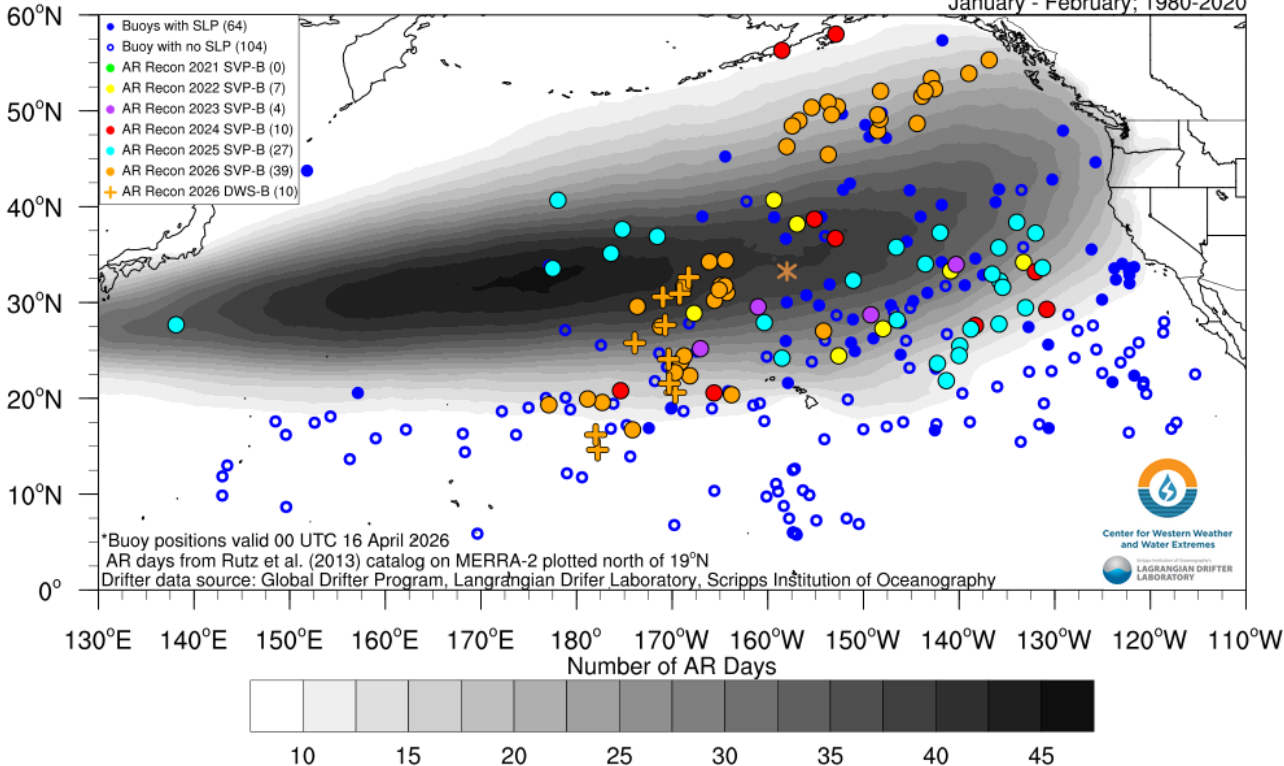
PI: Prof J.S. Haase Team: B. Cao, N. Do, N. Barton, B. Davis

AR Recon: Lagrangian Drifter Laboratory Sampling



Average AR Days Per Year (shaded)

January - February; 1980-2020



8th year of partnership with NOAA-funded Global Drifter Program at Scripps' Lagrangian Drifter Laboratory (PI, Dr L Centurioni).

Over 300 drifters deployed through this partnership since 2019

Studies consistently show the value of drifter data, including sea level pressure, to forecast skill using a variety of metrics

AR Recon: WindBorne Flights 2025-26 AR Recon Season



1,627

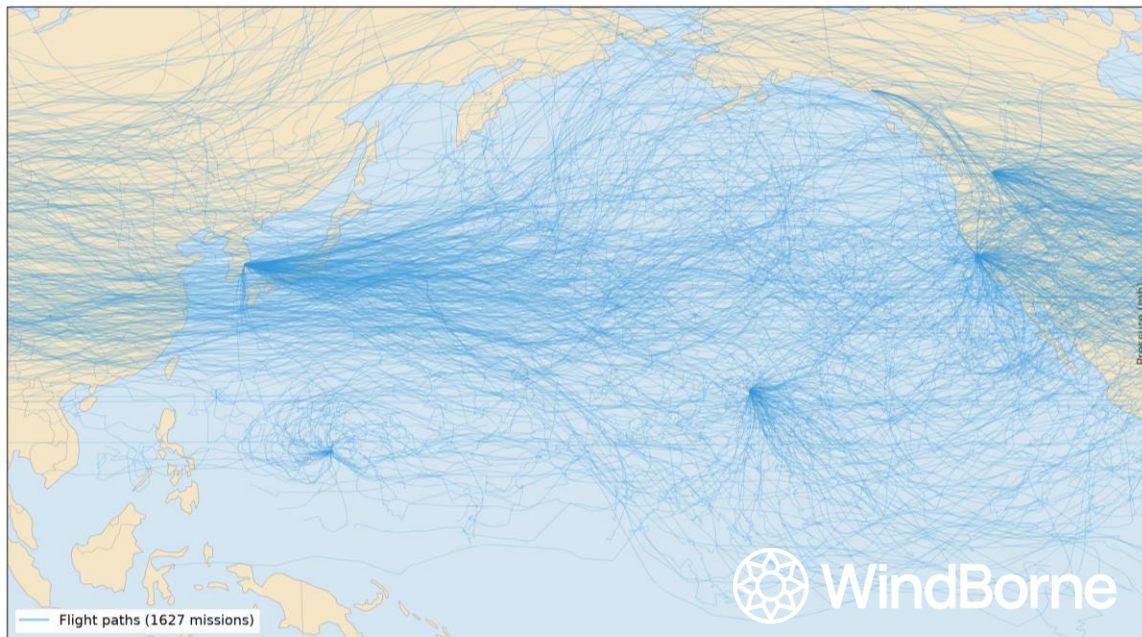
Missions in
N. Pacific

14,249

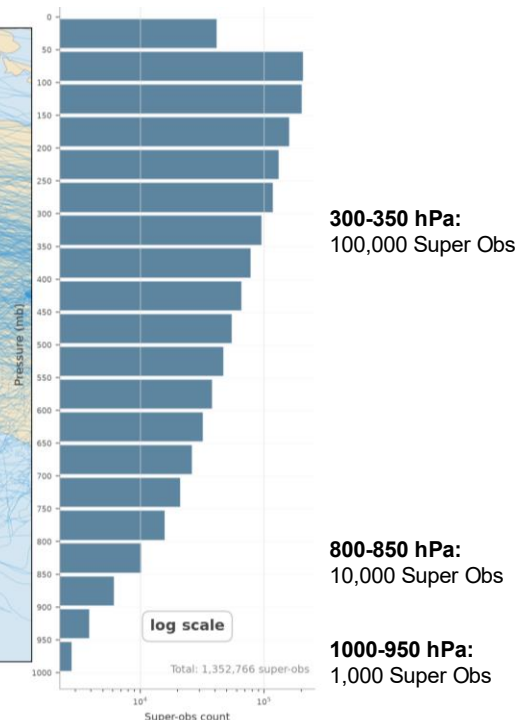
Sounding
Equivalents

1,352,766

Super-
Observations



Vertical distribution
(50 hPa layers)



Courtesy Todd Hutchinson - WindBorne

Sea-Air Fluxes and Atmospheric River Initiation (SAFARI) MOORED BUOY

Drew Lucas (SIO) and Tom Farrar (WHOI)

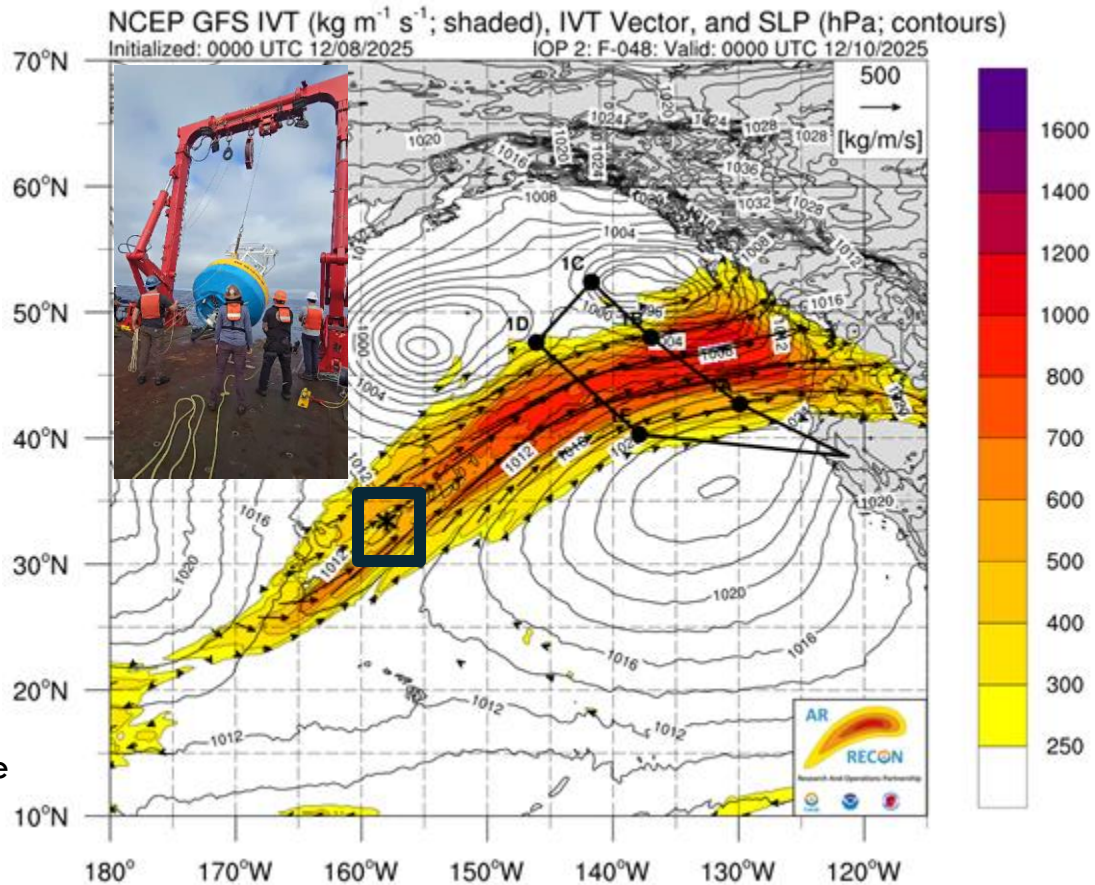


<https://uop.whoi.edu/currentprojects/SAFARI/SAFARI.html>

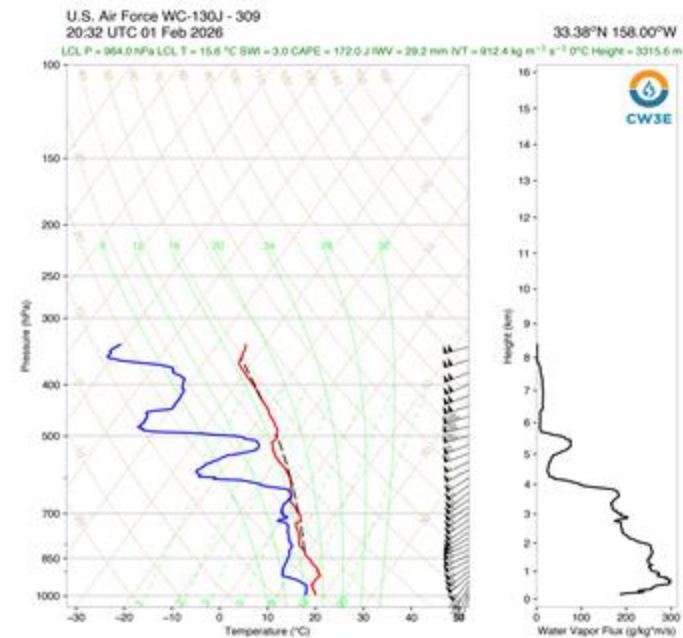
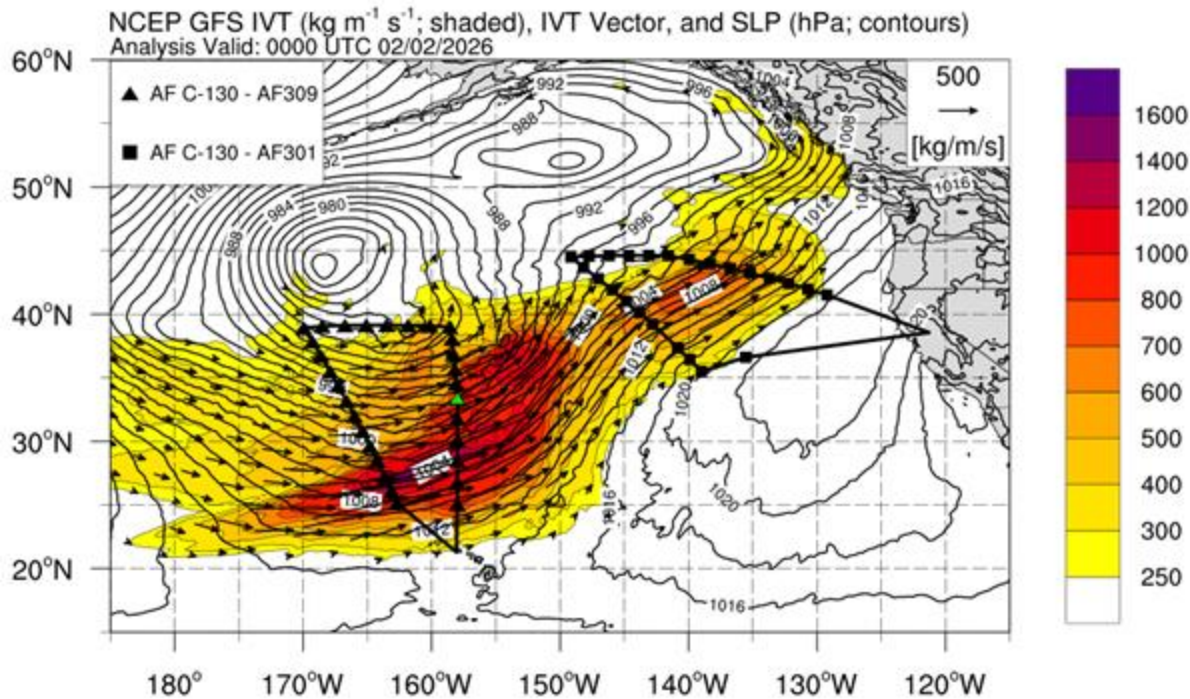
- Deployed Nov 20 2025
- Mooring location $\sim 33^\circ 25'N, 158^\circ W$
- Water depth $\sim 5,900$ m (3.5 miles)
- Mooring length $\sim 7,000$ m (4.4 miles)
- Ocean profiling range = 8 – 300 m depth
- Ocean profiling repeat rate ~ 75 per day
- **Challenges**– about 75% data rate on subsurface telemetry.

Surface Measurements: air temperature, humidity, barometric pressure, wind, precip, incoming shortwave and longwave radiation, SST, and surface wave directional spectra.

Ocean Measurements: salinity, temperature



AR Recon 2026 IOP21: 2 February 2026



IVT over buoy measured at $912.4 \text{ kg m}^{-1} \text{ s}^{-1}$

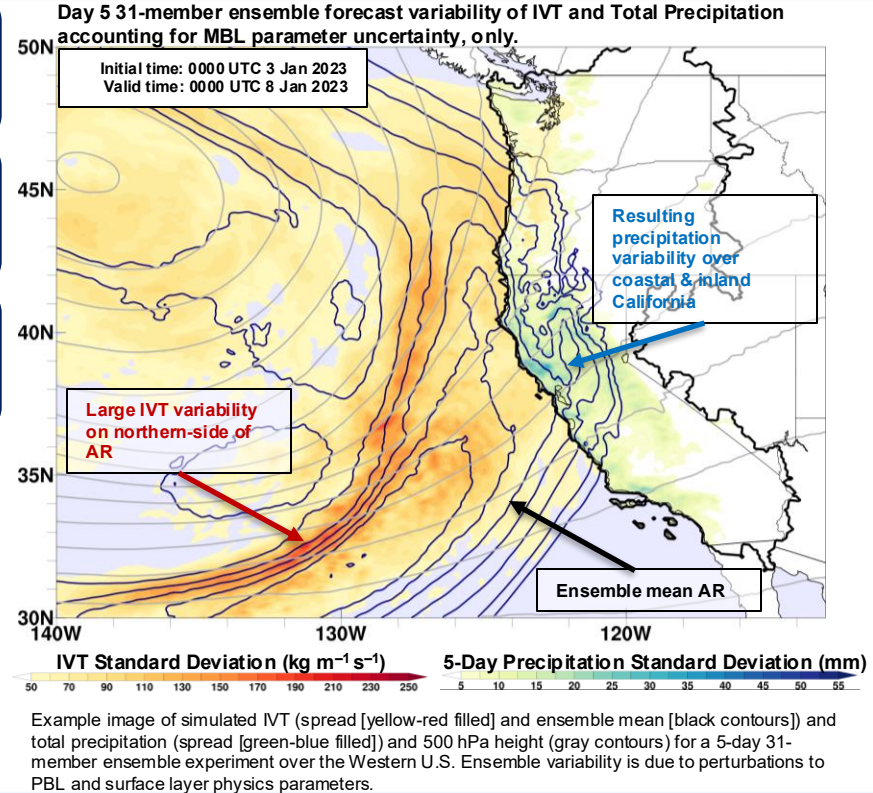


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Marine Boundary Layer Physics Parameter Uncertainty

- Research Hypothesis: The marine boundary layer (MBL) plays an important role in AR precipitation via atmospheric stability, air-sea interactions, and horizontal water vapor flux.
- Goal: Improve our understanding of the role of MBL errors in atmospheric river forecasts & how these errors influence onshore precipitation forecast skill.
- Methodology: Apply stochastic perturbations to components of the WRF-MYNN planetary boundary layer parameterization over the MBL only to isolate ensemble variability to MBL processes.
- Preliminary Results: MBL-only perturbations are effective at generating variability in precipitation and IVT forecasts (Figure) & representing an important source of model error impacting onshore precipitation.
- Work is ongoing to evaluate the contribution of MBL parameter uncertainty compared to initial and boundary condition errors, and to identify the processes by which these perturbations can modulate forecast skill.



AR Recon Coordinated University Sounding Program (AR Recon CUSP)



AR Recon CUSP is a partnership between universities across the U.S. and Canada to provide land-based observations to complement airborne campaigns over the Pacific, Gulf, and Atlantic basins

Over 470 weather balloons were launched this year!



Indiana University



Valparaiso University



University of Missouri



NC State University



Funding for AR Recon CUSP is sponsored by Ralph through the CW3E FIRO Program with USACE/ERDC

PI: F.M. Ralph, CW3E; Lead Coordinator: A. Michaelis, NCSU
Slide provided by A. Michaelis

AR Recon Coordinated University Sounding Program (AR Recon CUSP)

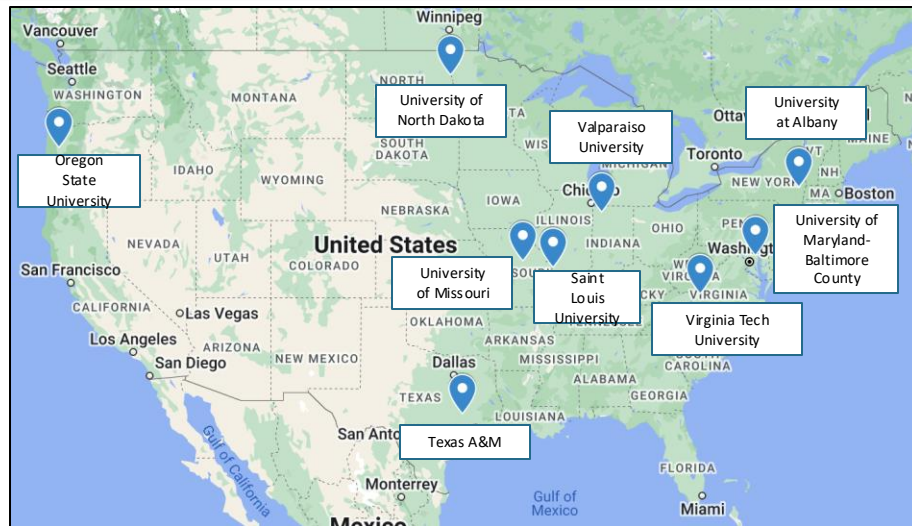


Phase I included **nine universities** across the U.S. to provide land-based upper-air measurements during landfalling atmospheric rivers in coordination with **AR Recon**

Phase I included **10 IOPs** with almost **100 radiosondes** launched from February 3 – March 5, 2025

Over **100 students** across the nine sites participated via official courses, departmental clubs, or “ad hoc” volunteering

Data collected was actively used by **students** in the classroom, **local broadcast stations**, and **National Weather Service** weather forecast offices



Funding for AR Recon CUSP is sponsored by Ralph through the CW3E FIRO Program with USACE/ERDC

*PI: F.M. Ralph, CW3E; Lead Coordinator: A. Michaelis, NCSU
Slide provided by A. Michaelis*

AR Recon Coordinated University Sounding Program (AR Recon CUSP)

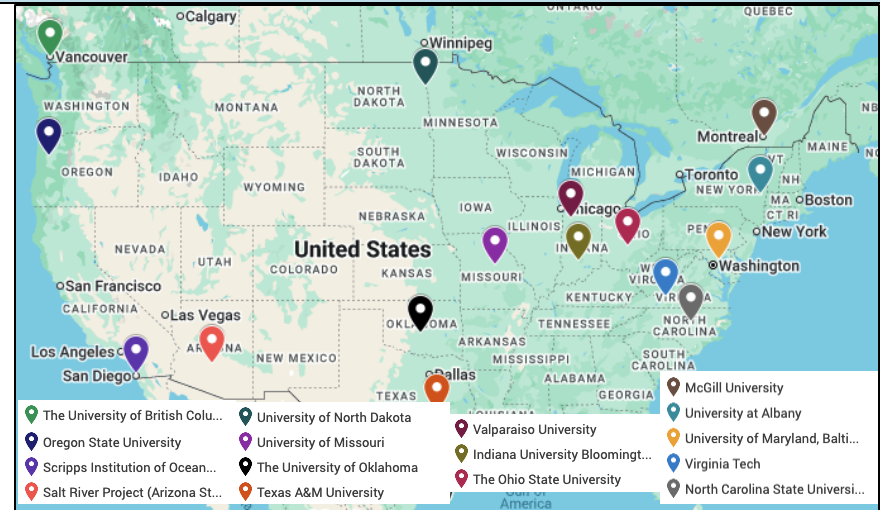


Phase II expanded to **16 universities** across the U.S. and Canada to provide land-based upper-air measurements in coordination with **AR Recon, NURTURE, and NAWDIC** to support the Global AR Recon Program efforts

Phase II conducted **16 IOPs** with **477 radiosondes** launched from January 18 – March 17, 2026

Over **150 students** across the 16 sites participated via official courses, departmental clubs, or “ad hoc” volunteering

Data collected was actively used by **students** in the classroom, **local broadcast stations**, and **National Weather Service** weather forecast offices



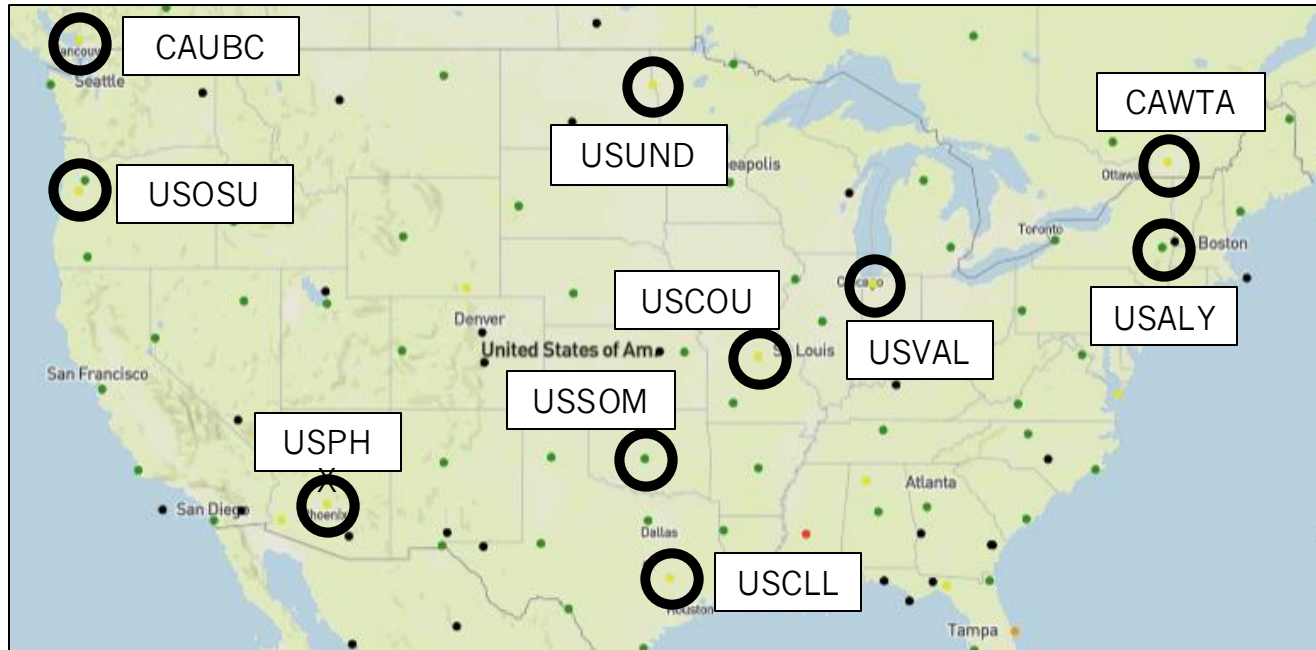
Funding for AR Recon CUSP is sponsored by Ralph through the CW3E FIRO Program with USACE/ERDC

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Slide provided by A. Michaelis*

AR Recon Coordinated University Sounding Program (AR Recon CUSP)



Critical milestone achieved: Improved data assimilation process with data from 14 sites being *routinely ingested* into global NWP models



Snapshot of available **upper-air land observations** used in the 00 UTC February 14, 2026 data assimilation window

https://wdqms.wmo.int/nwp/land_upper-air/six_hour/availability/all/2026-02-14/00

Note: USOHS was assimilated into the 18 UTC window

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Slide provided by A. Michaelis

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New NOAA Aircraft Enhance AR Reconnaissance

“These new state-of-the-art aircraft will greatly enhance NOAA’s ability to gather data critical to hurricane research and forecasting, atmospheric river research and forecasting, climate studies and other missions. Infrastructure investments like this protect both lives and livelihoods.” - NOAA Administrator Rick Spinrad, Ph.D (NOAA press release 7/15/24).



2 new aircraft (G550s) will replace NOAA’s aging GIV. The new aircraft can fly faster, higher, and longer.



Atmospheric Rivers River Reconnaissance, Observations and Warnings Act: Enacted upon President Biden’s signature on 22 December 2023 as part of the 2024 National Defense Authorization Act after approval by the US Senate and House

*F. Martin Ralph, PI (UC San Diego/SIO/CW3E)
Vijay Tallapragada, Co-PI (NOAA/NWS/NCEP)*

<https://www.noaa.gov/news-release/noaa-orders-second-high-altitude-jet-for-hurricane-and-climate-research>; Artist concept of NOAA G550 courtesy Gulfstream. (Image credit: Gulfstream)

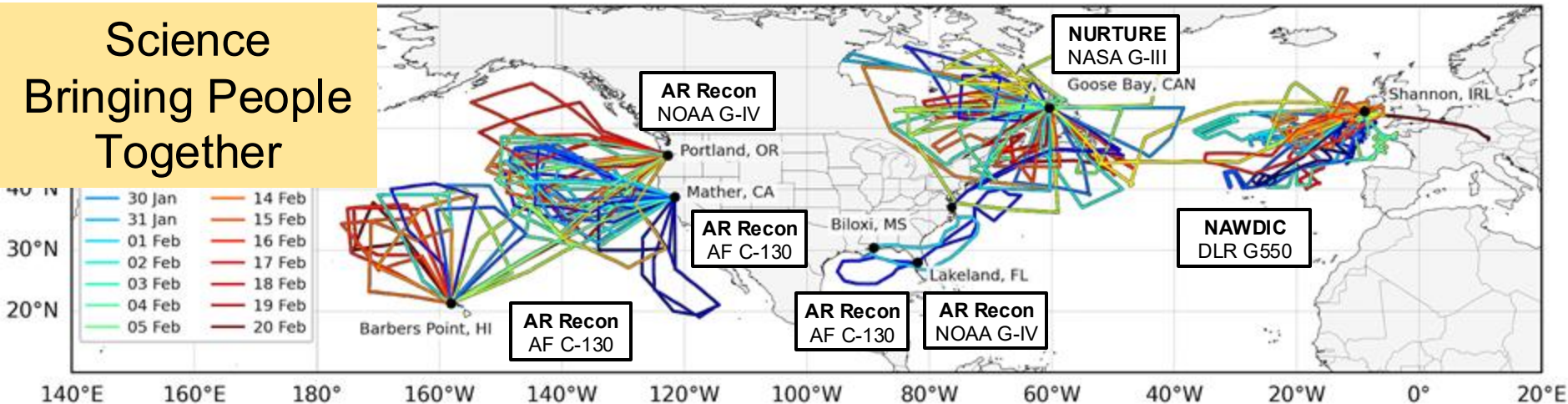
Global Atmospheric River Reconnaissance (GARRP) 2026 Demo

F. M. Ralph, GARRP PI, Vijay Tallapragada GARRP Co-PI

GARRP-Demo 2026 Aircraft IOPs

22 Jan–20 Feb 2026

Science
Bringing People
Together



AR Recon: Atmospheric River Reconnaissance

NURTURE: North American Upstream Feature-Resolving and Tropopause Uncertainty Reconnaissance Experiment

NAWDIC: North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign

Total number of flights: 72

Total deployed dropsondes: 1151



San Diego



Summary

- AR Recon: Operational Research And Operations Partnership will be ongoing for the coming years
- Today: More about AR Recon aircraft, other AR Recon platforms and related observations, satellite opportunities
- Tomorrow: Data impact, science advances (more SAFARI highlights)

