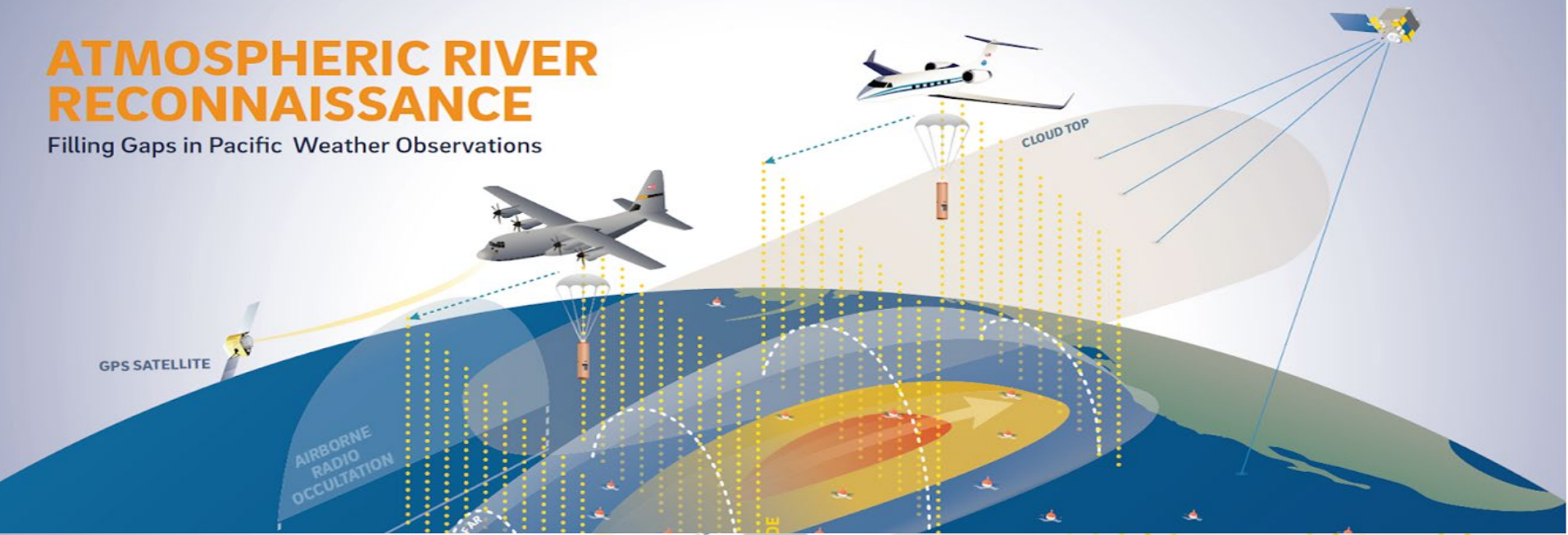


ATMOSPHERIC RIVER RECONNAISSANCE

Filling Gaps in Pacific Weather Observations



Impact of AR Recon (and GARRP) Observations on NCEP Operational GFS Forecasts

Vijay Tallapragada¹, Xingren Wu², Binbin Zhou³, M. M. Nageswararao⁴, Keqin Wu³, Jia Wang⁵, Minghua Zheng⁵, Anna M. Wilson⁵, F. Martin Ralph⁵, Xiujun Wang², Maria Aristizabal³

¹OMD/NWS/NOAA, ²Axiom@OMD/NWS/NOAA, ³Lynker@OMD/NWS/NOAA,

⁴UCAR@OMD/NWS/NOAA, ⁵CW3E, Scripps Institution of Oceanography, UC San Diego



U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service

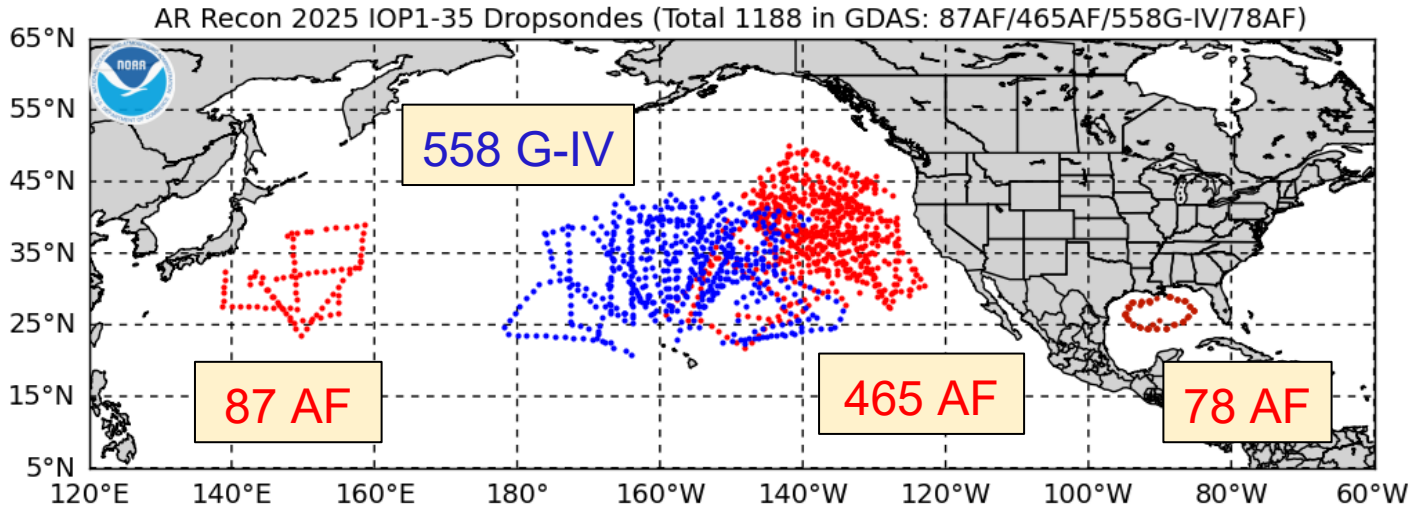
Operational goals for AR Recon at NCEP

- Overarching goal: improve operational predictions of land-falling atmospheric rivers and their impacts globally
- Enhance the use of aircraft observations in modeling and data assimilation
- Design and develop ensemble based objective sampling strategies
- Run (near) real time data denial experiments
- Improve verification techniques

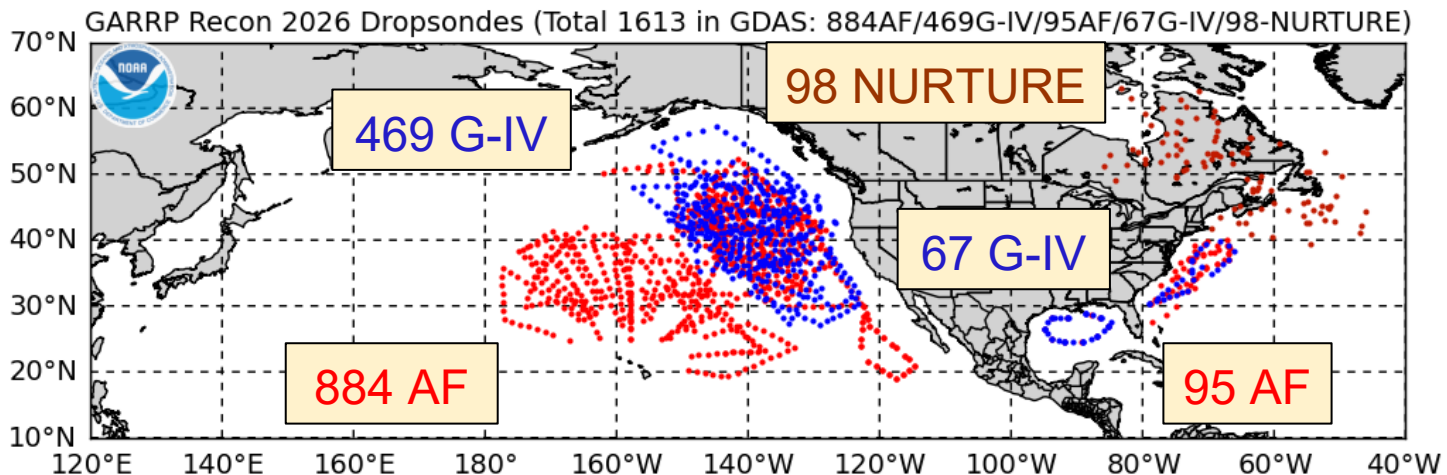
Outline

- Overview of AR Reconnaissance
- Research and Operations Partnership for AR Recon
- NCEP's contributions to GARRP
- Strategies for filling data gaps associated with ARs
- Impact of dropsonde and drifting buoy data on NCEP operational GFS
- Current progress and future work

AR Recon WY2025 Dropsondes in GFS DA



GARRP WY2026 Dropsondes in GFS DA



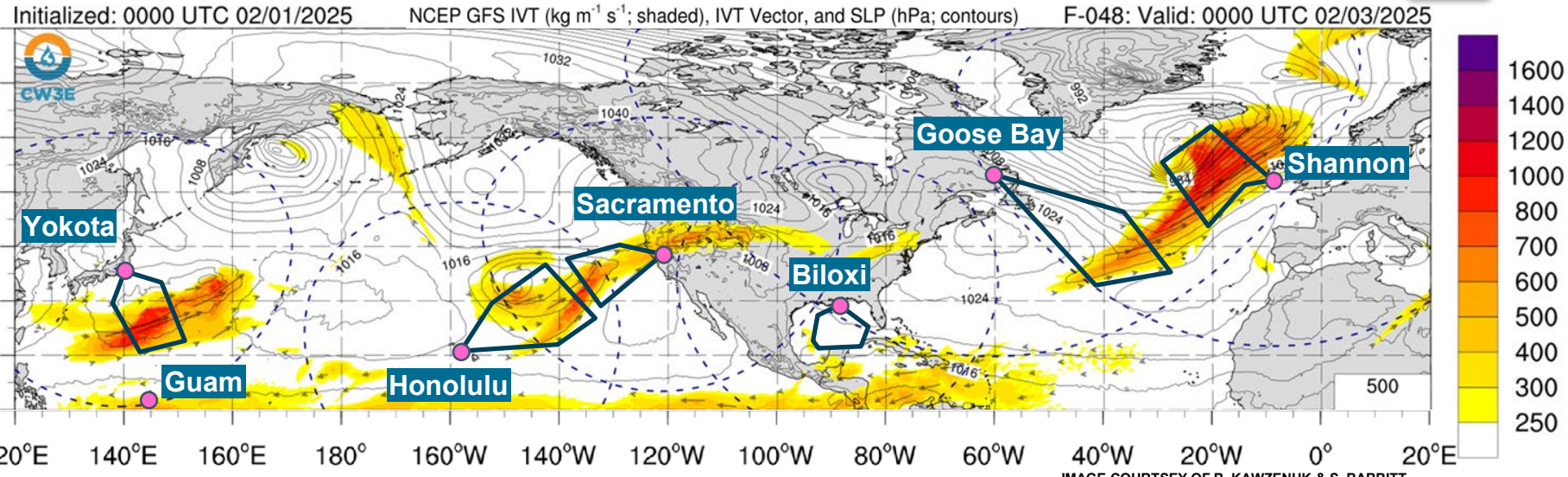
AR Recon 2025-2026 Season

Northern Hemispheric GARRP* Demo

F. M. Ralph, AR Recon PI, Vijay Tallapragada Co-PI



West Pacific  Cent/East Pacific   Gulf/East Coast  High Latitude  East Atlantic 



Command Center
La Jolla, CA



Western Pacific
USAF C-130
Jan 2024: Guam
Jan 2025: Yokota, JPN
Jan 2026: Yokota, JPN

Central/East Pacific
NOAA G-IV & USAF C-130
Nov-Mar each year
On Station Jan-Feb
C-130: Sacramento, CA
G-IV: Honolulu, HI

Gulf/East Coast
USAF C-130
Nov-Mar each year
upon request
C-130: Biloxi, MS

Western Atlantic
NASA G-III
12 Jan – 6 Feb 2026
Goose Bay, CAN
Future flights (2027) by
NASA B777

High Latitude
G-550 & ATR42
12 Jan – 20 Feb 2026
Shannon, Ireland
G-550: German HALO
ATR42: French SAFIRE

Northern Hemispheric GARRP

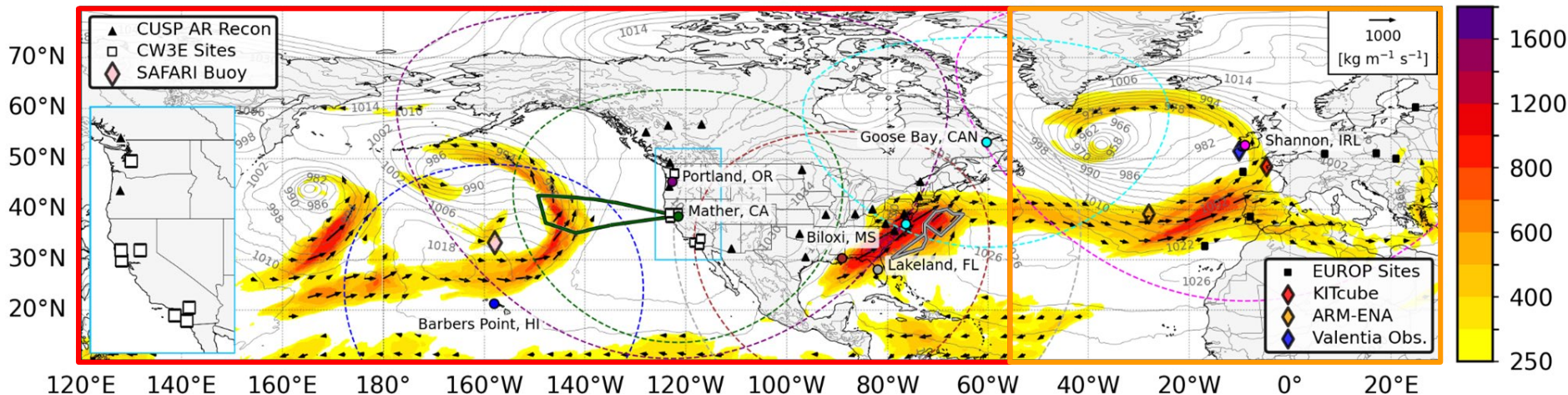
F. M. Ralph, AR Recon PI, Vijay Tallapragada Co-PI
25 Jan 2026



ECMWF initialized 0000 UTC 25 Jan 2026

Valid: 0000 UTC 26 Jan 2026

Valid: 1200 UTC 26 Jan 2026



AR-Recon

W ATL (C-130)
6 Jan - 5 Feb
Biloxi, MS

W ATL (GIV)
6 Jan - 5 Feb
Lakeland, FL

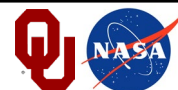
C PAC (C-130)
6 Jan - 5 Mar
Barbers Point, HI

NE PAC (G-IV)
6 Jan - 1 Feb
Portland, OR

E PAC (C-130)
6 Jan - 5 Feb
Mather, CA



NURTURE



NW Atlantic (G-III)
26 Jan - 6 Feb
Goose Bay, Canada



NAWDIC



NE Atlantic (HALO)
13 Jan - 20 Feb
Shannon, Ireland



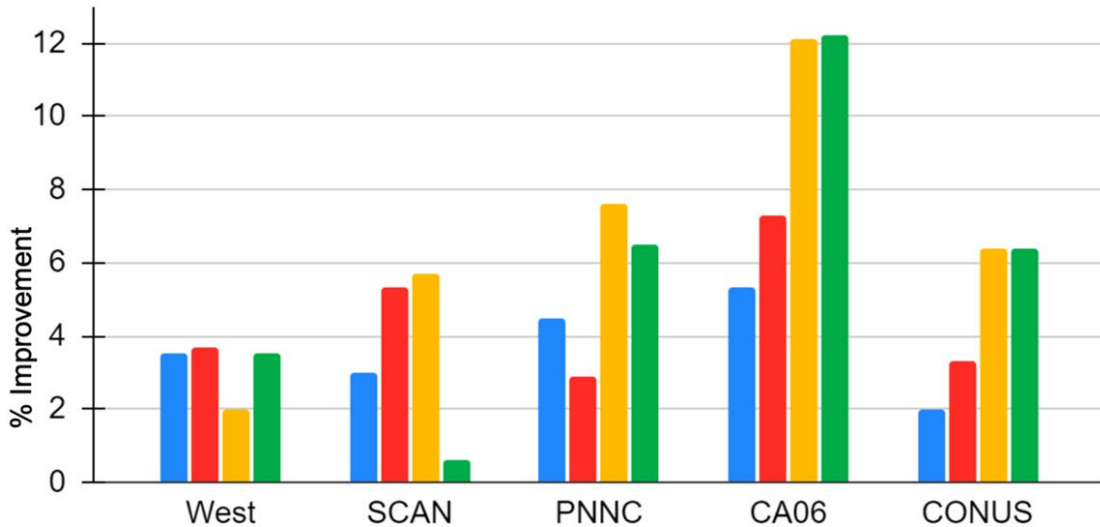
Near Real-Time Data Deny Experiments with NCEP Operational GFS

- ARR near real-time data denial
 - CTRL – operational GFS, assimilate dropsonde and HDOBs data
 - DENY – the same setting as operational GFS, but deny dropsonde and HDOBs data



AR Recon 2022-23 Impact on Precipitation Forecasts 72-hr Forecast Improvement Ctrl vs. Deny

■ 0.1" ■ 0.5" ■ 1" ■ 2.5"



Largest improvements over the California Domain for the heavier precipitation amounts

On average, **12% improvement** equates to skill expected **8 years in the future.**

Presentation by V. Tallapragada

AR Recon Workshop
June 2023
@ECMWF

Not only is skill improved over West Coast, but also over western U.S. and CONUS! Regionally upwards of 12% improvement!



NATIONAL WEATHER SERVICE

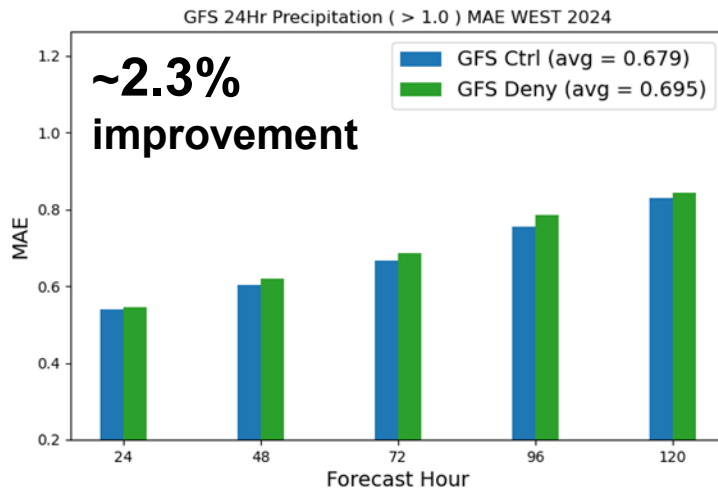
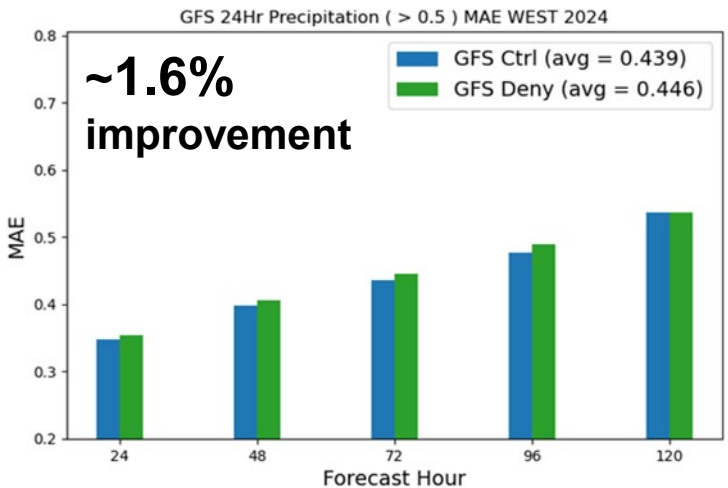
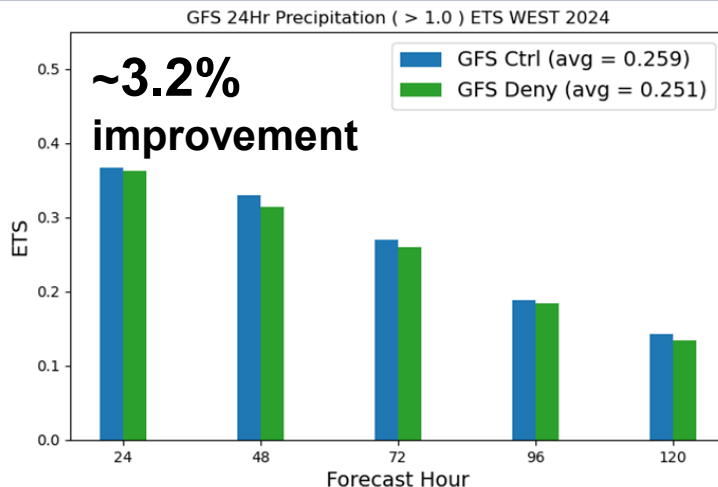
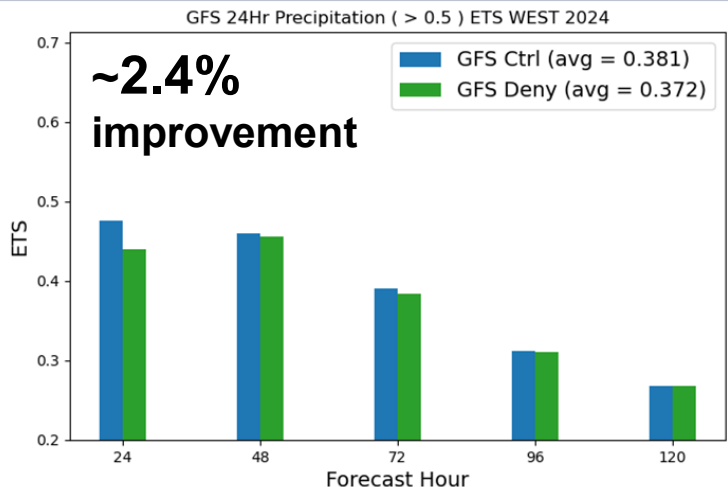
Building a Weather-Ready Nation // 14



AR Recon precipitation (>0.5 in)

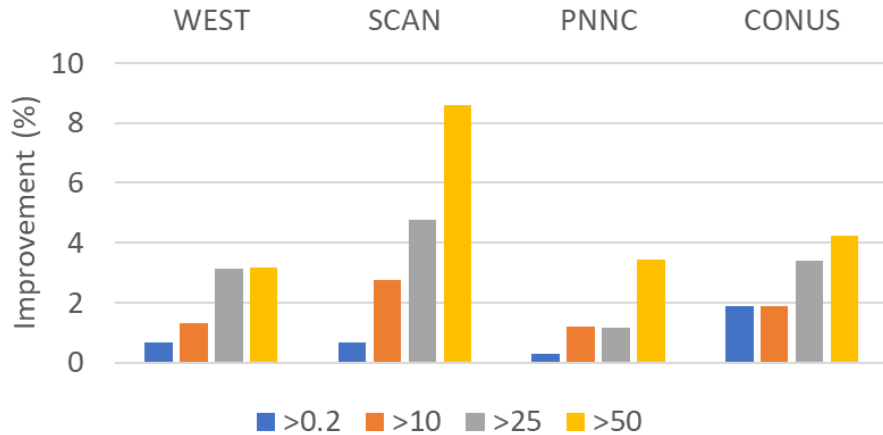
AR Recon precipitation (>1.0 in)

**WY2024
ARR 40 IOPs
WEST**

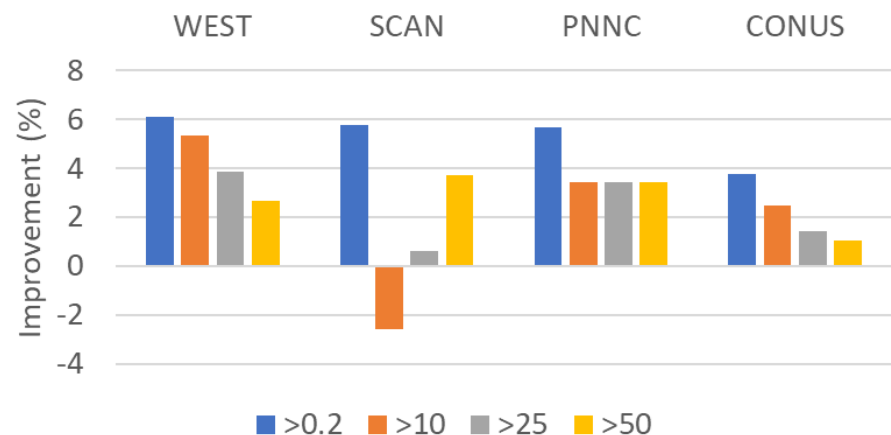


AR Recon WY2025 Impact on Precipitation Forecast Improvement (%): GFS vs DENY

48-hr Fcst QPF Improvement GFS vs Deny



120-hr Fcst Improvement GFS vs Deny

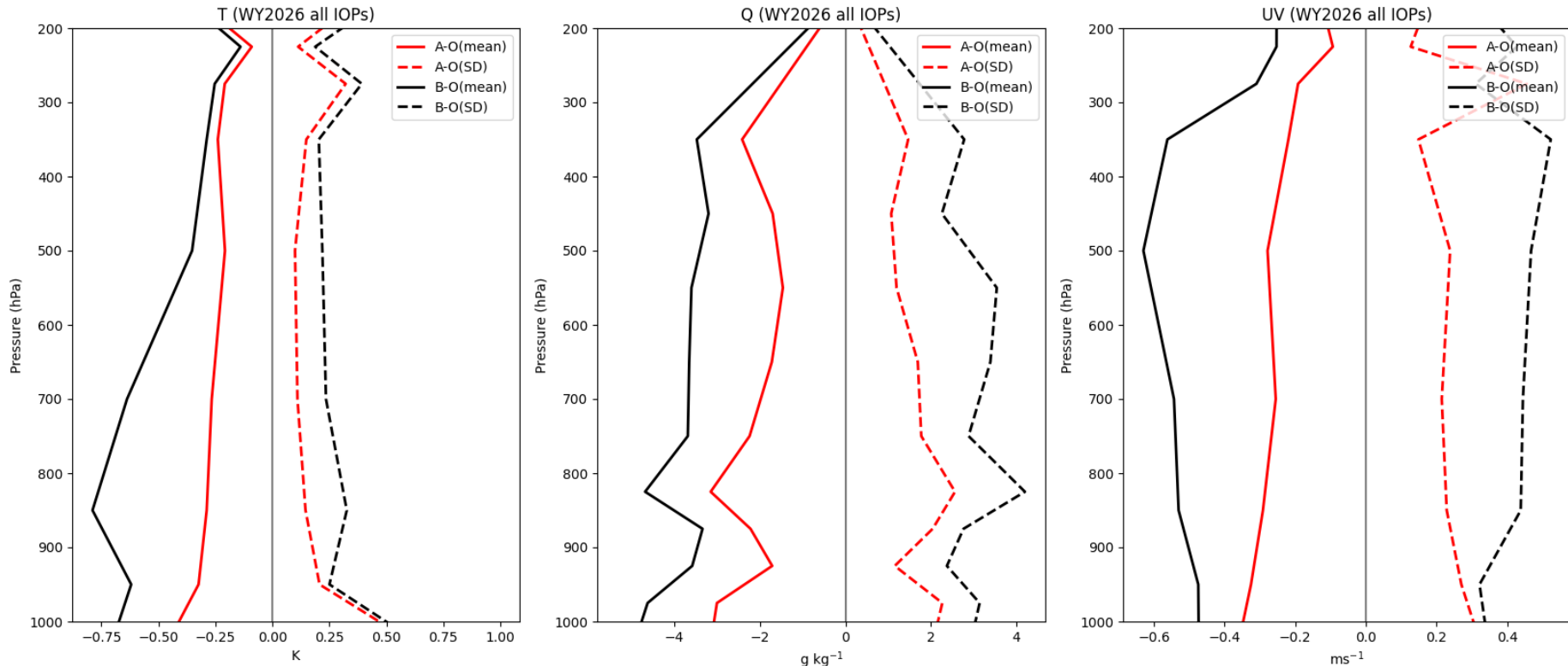


West Coast (**WEST**): 107-127W, 28-49.5N
 Southern California, Arizona, New Mexico (**SCAN**): 95-122W, 28-39N
 Pacific Northwest and Northern California (**PNNC**): 117-125W, 36-49.5N
CONUS

Dropsonde data improved GFS precipitation forecasts

GFS DA with Dropsondes data during WY2026

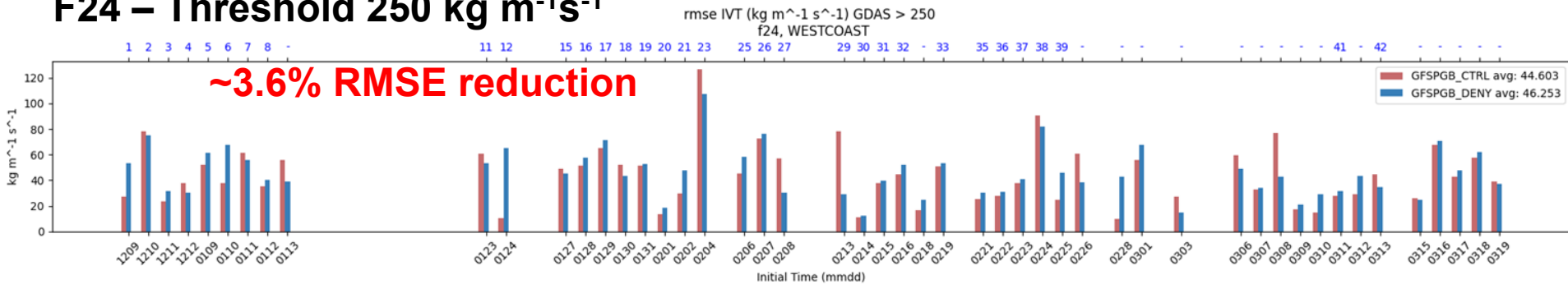
Mean of (A-O) and (B-O) for T, Q and UV during 2025 Dec 9 and 2026 Mar 13 from GFS



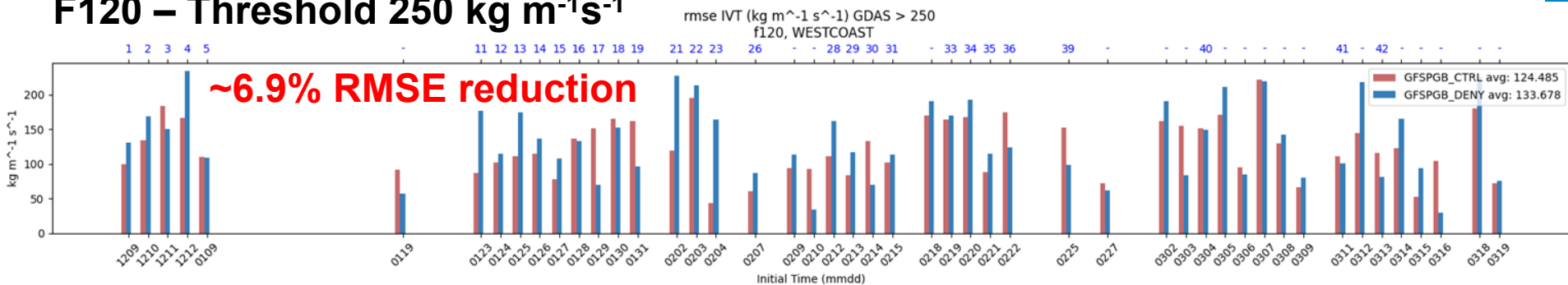
Improved analysis in T/Q/UV with dropsonde obs

AR Recon WY 2026 U.S. WEST Coast IVT Landfall RMSE (ref GDAS)

F24 – Threshold $250 \text{ kg m}^{-1} \text{ s}^{-1}$

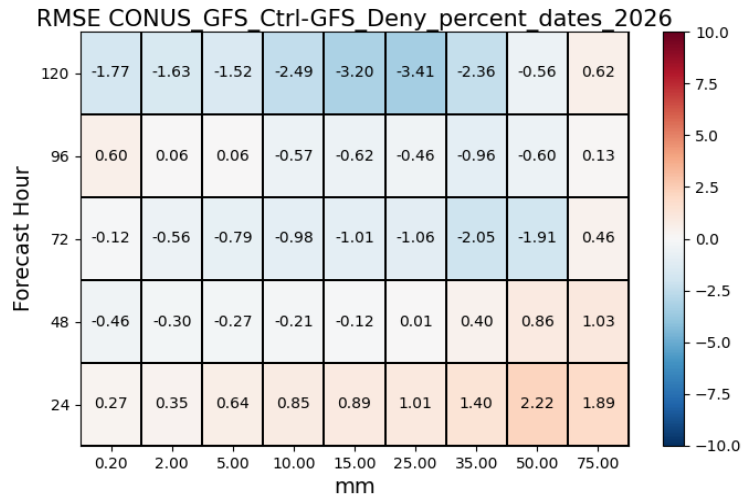
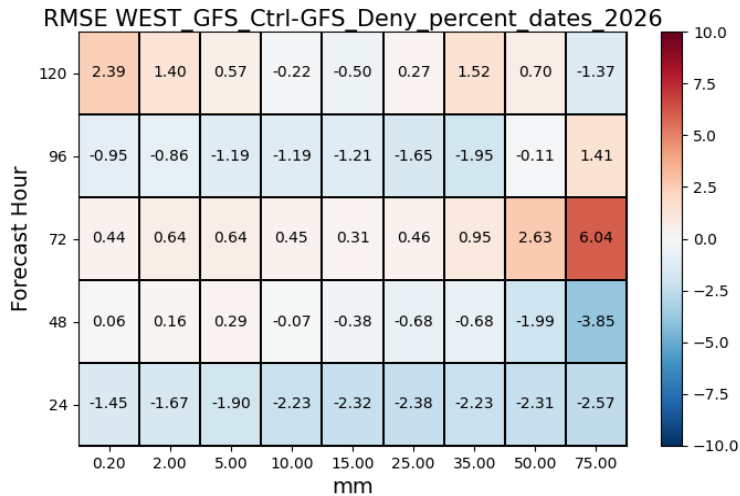


F120 – Threshold $250 \text{ kg m}^{-1} \text{ s}^{-1}$

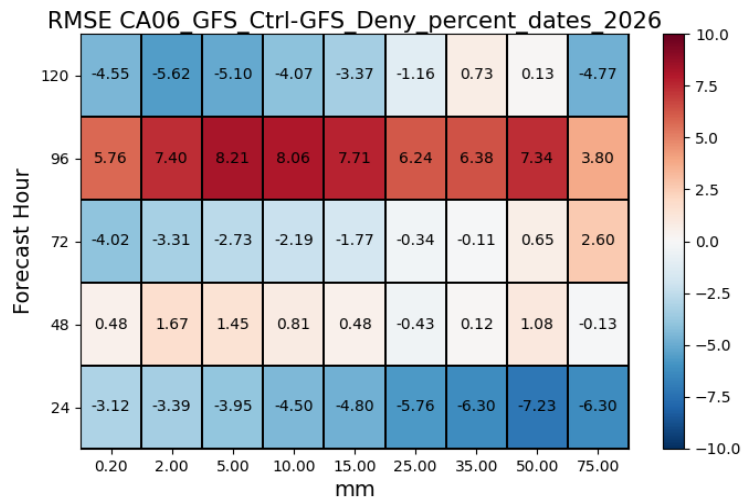
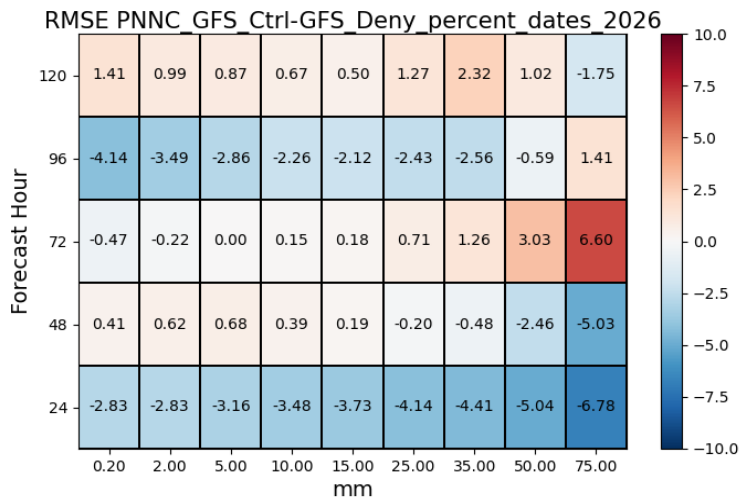


WEST/CONUS PNNC/CA06

24-h
precipitation
RMSE
difference (%)
between GFS
and Deny (ref.
Stage IV).



Blue indicates
a reduction in
RMSE,
meaning the
GFS forecast
is improved
through
dropsonde
assimilation.

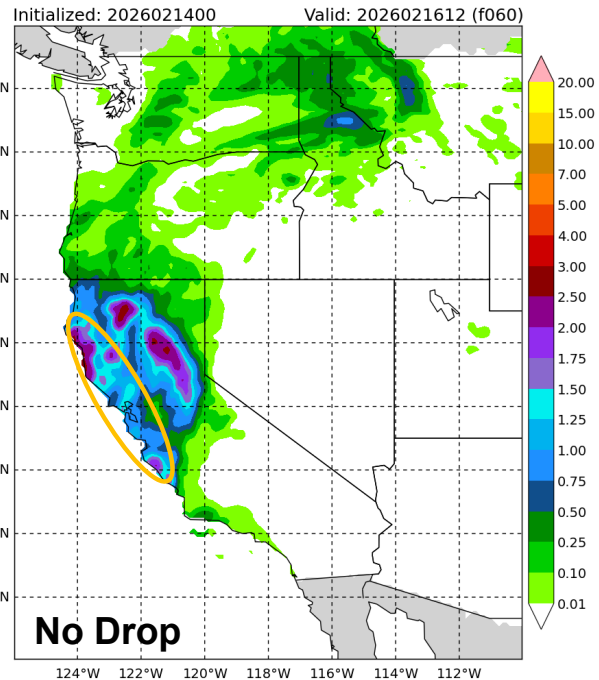
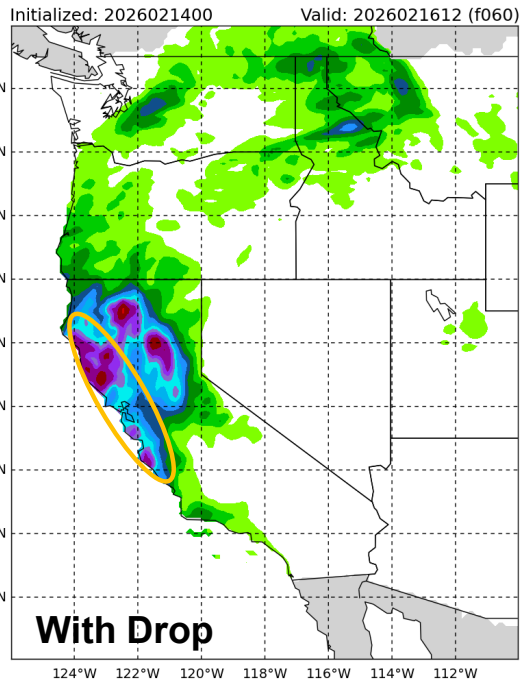
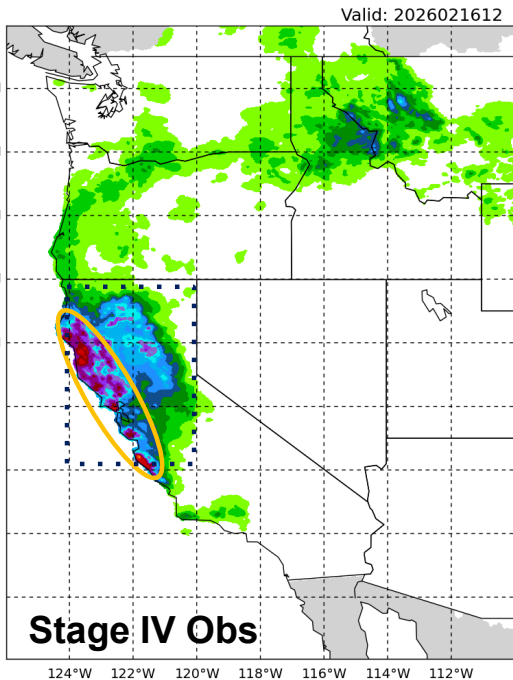


IOP 30 case: 00Z 14 Feb 2026 forecast of 24-hour precipitation accumulation (12–36 h) – modest improvements in the short-range

ST4 24h Total Precipitation (inches)

GFSv16 24h Total Precipitation Ctrl (inches)

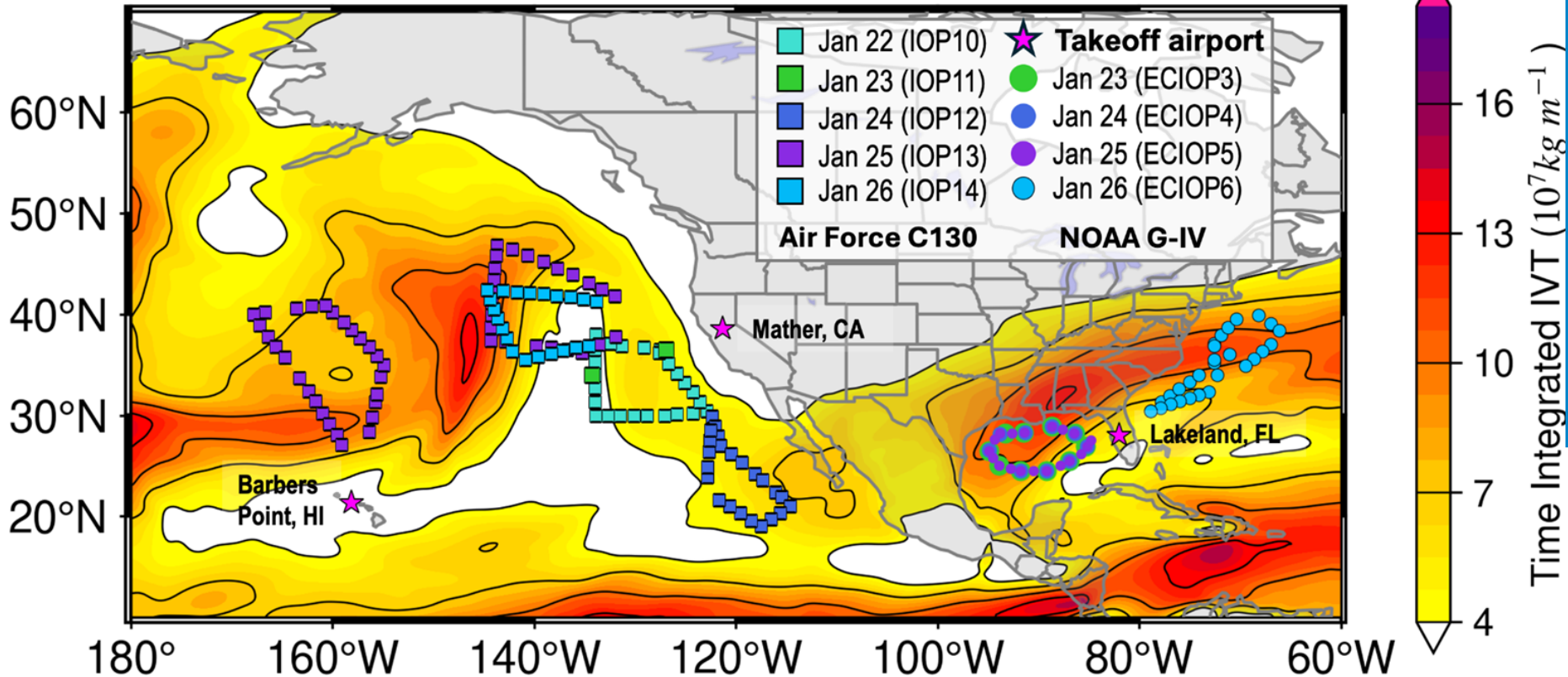
GFSv16 24h Total Precipitation Deny (inches)



Assimilating dropsonde observations reduces the mean absolute error of the precipitation forecast by approximately 17% over the selected region (dotted box).

AR Recon for Winter Storm Jan 2026: Dropsondes

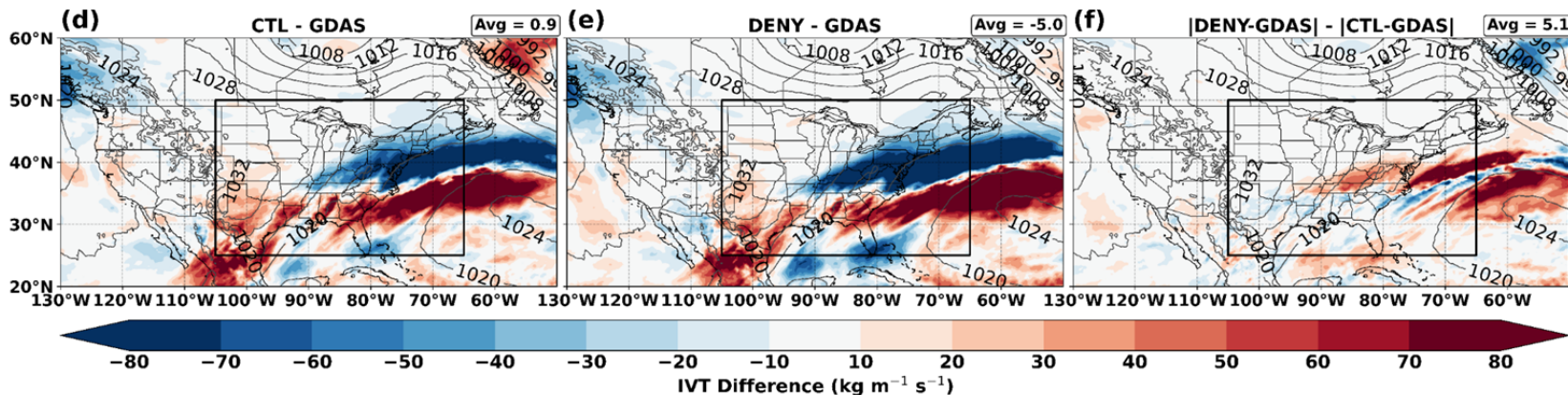
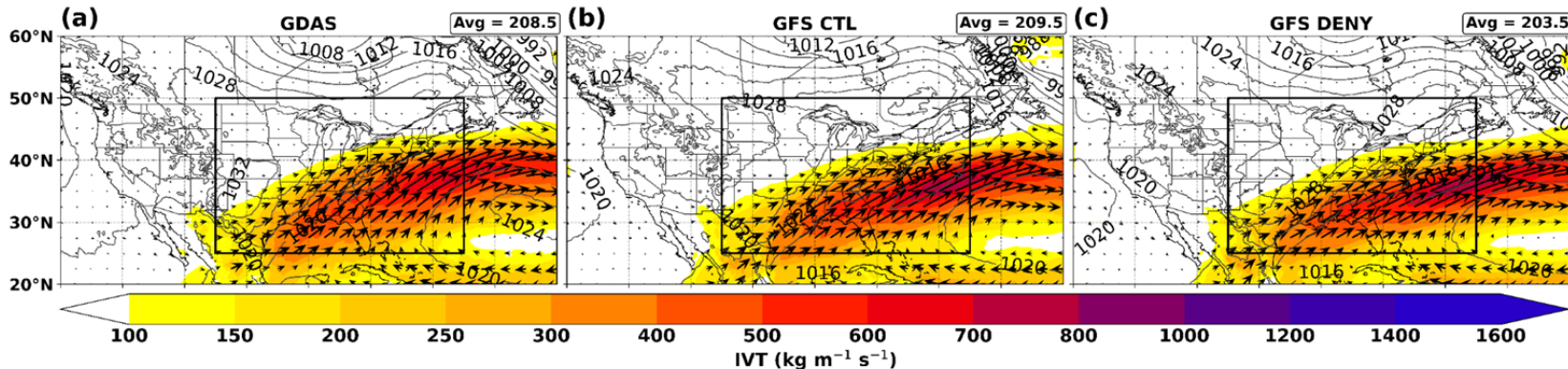
00 UTC 22 Jan - 00 UTC 26 Jan 2026



AR Recon for Winter Storm Jan 2026: IVT Forecast

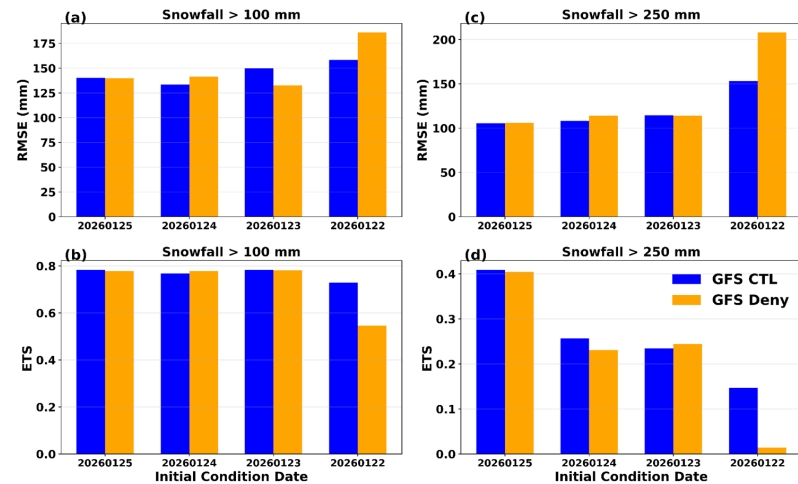
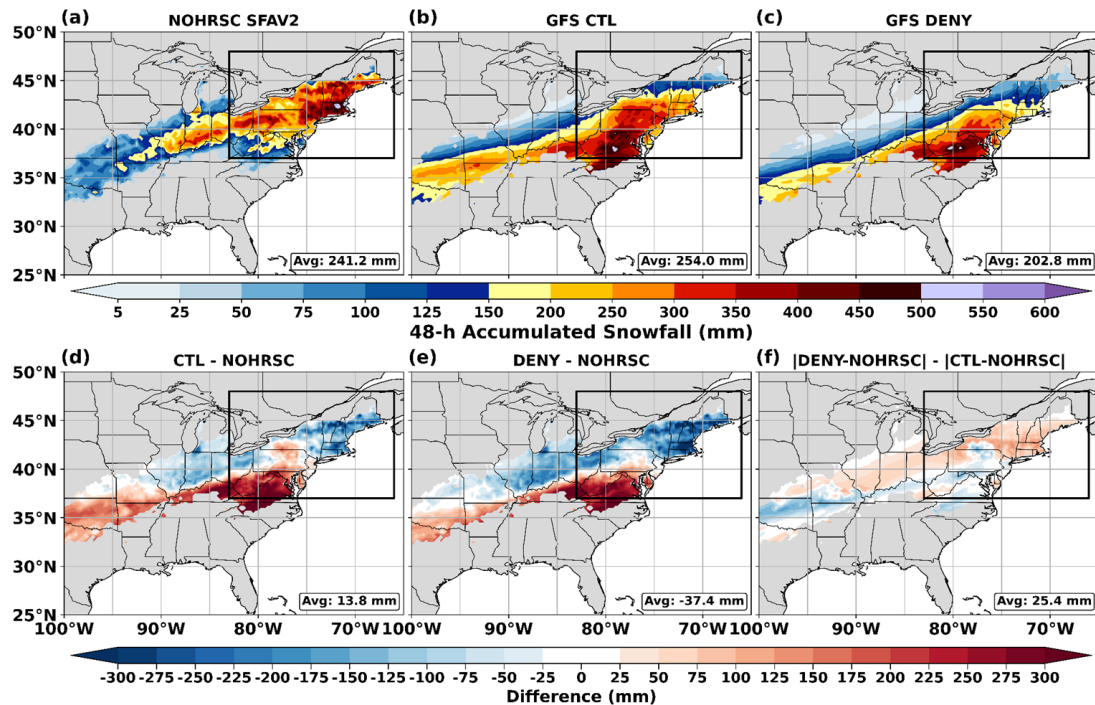
Init: Jan 22, 2026; vrfy: Jan 25-27, 2026

Mean IVT (shading), Mean IVT Vectors, Mean SLP (contours) | Initial: 2026012200 | Valid: 2026012500-2026012700

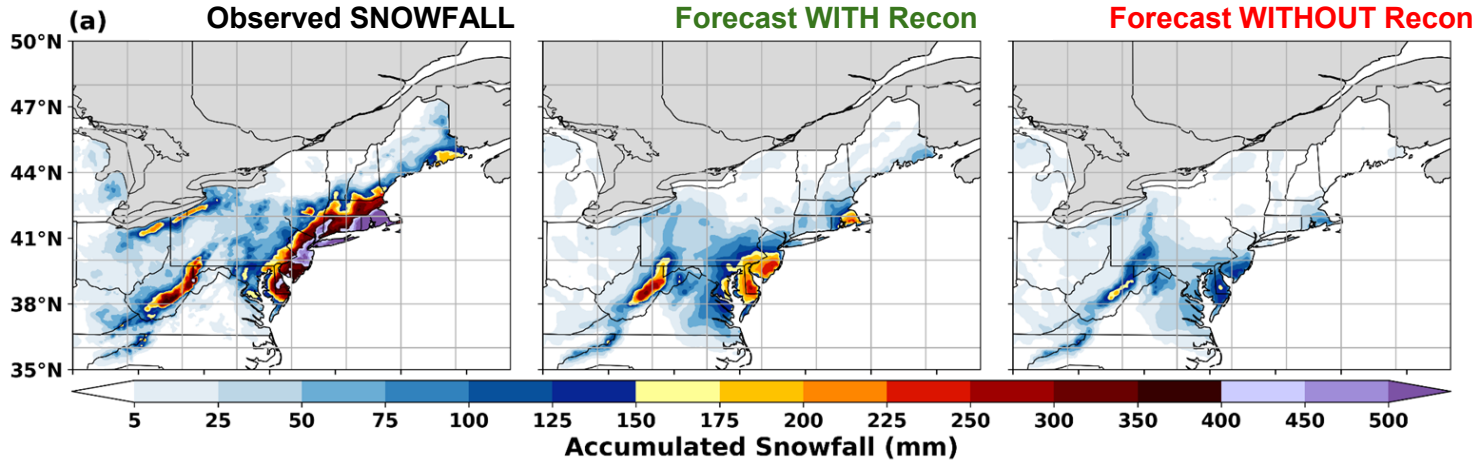


AR Recon for Winter Storm Jan 2026: Snow Forecast

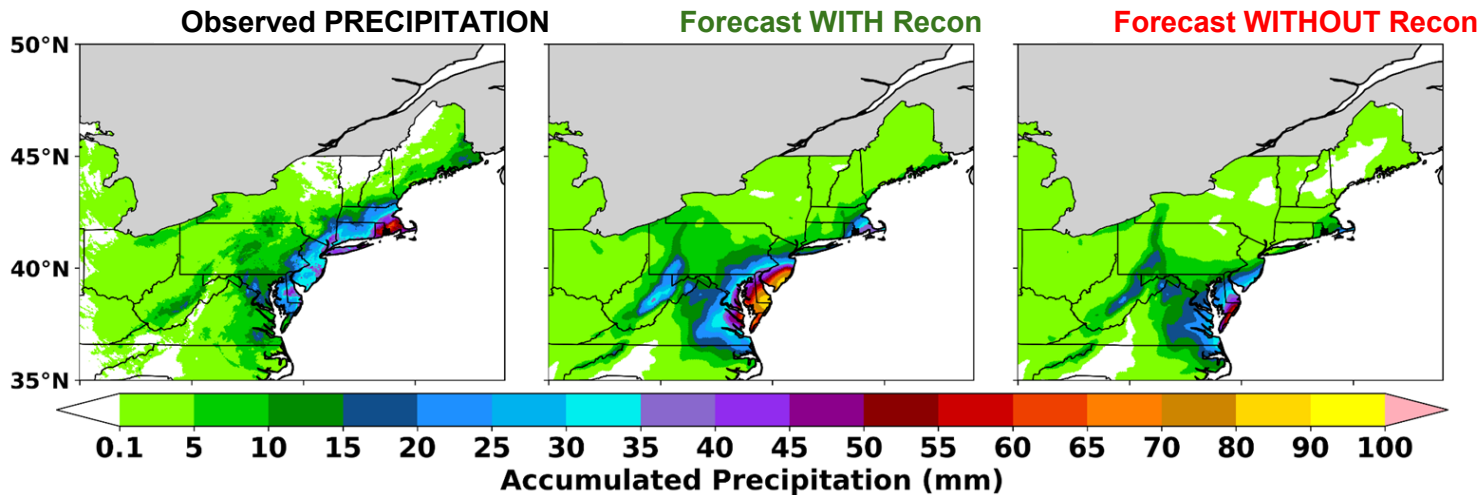
Init: Jan 22, 2026; vrfy: Jan 25-27, 2026



Init: 2026021900 | Valid window: 20260Sunday afternoon - Monday night, Feb 22-23



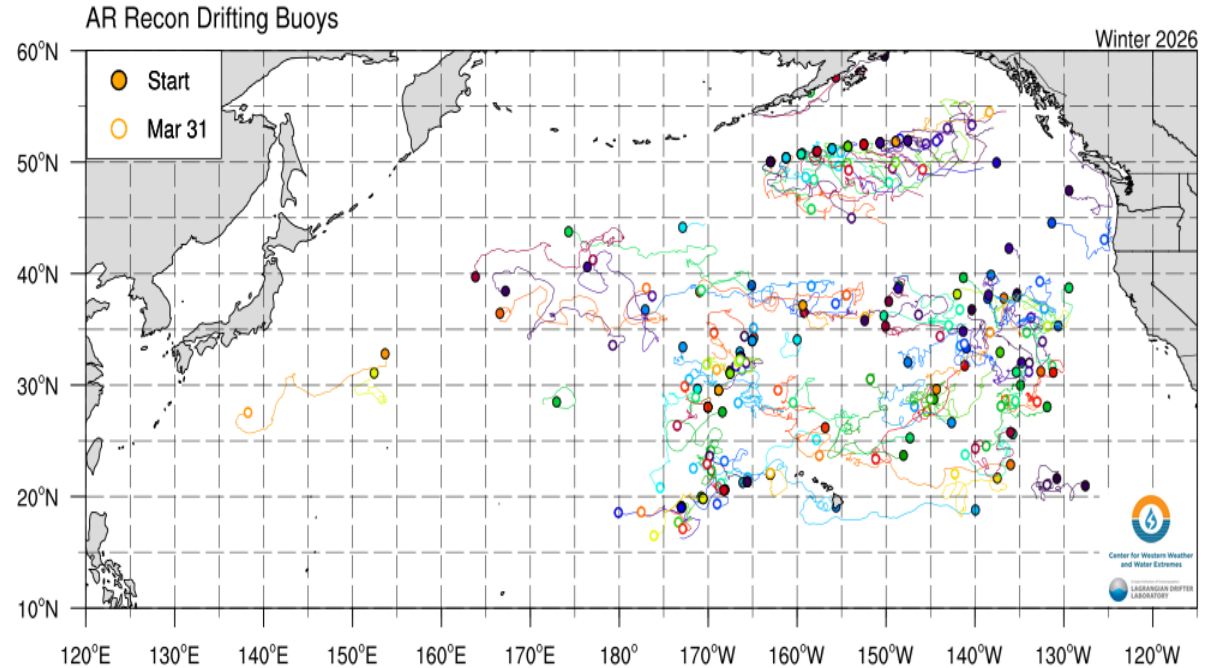
Init: 2026021900 36h Accumulated Precipitation (mm) Valid: 2026022218-2026022406



AR Recon
for Winter
Storm Feb
2026: Snow
and Precip
Forecast
Init: Feb 19,
2026; vrfy:
Feb 22-24,
2026

New in 2026: Drifter Data Denial Experiments with the NCEP Operational GFS

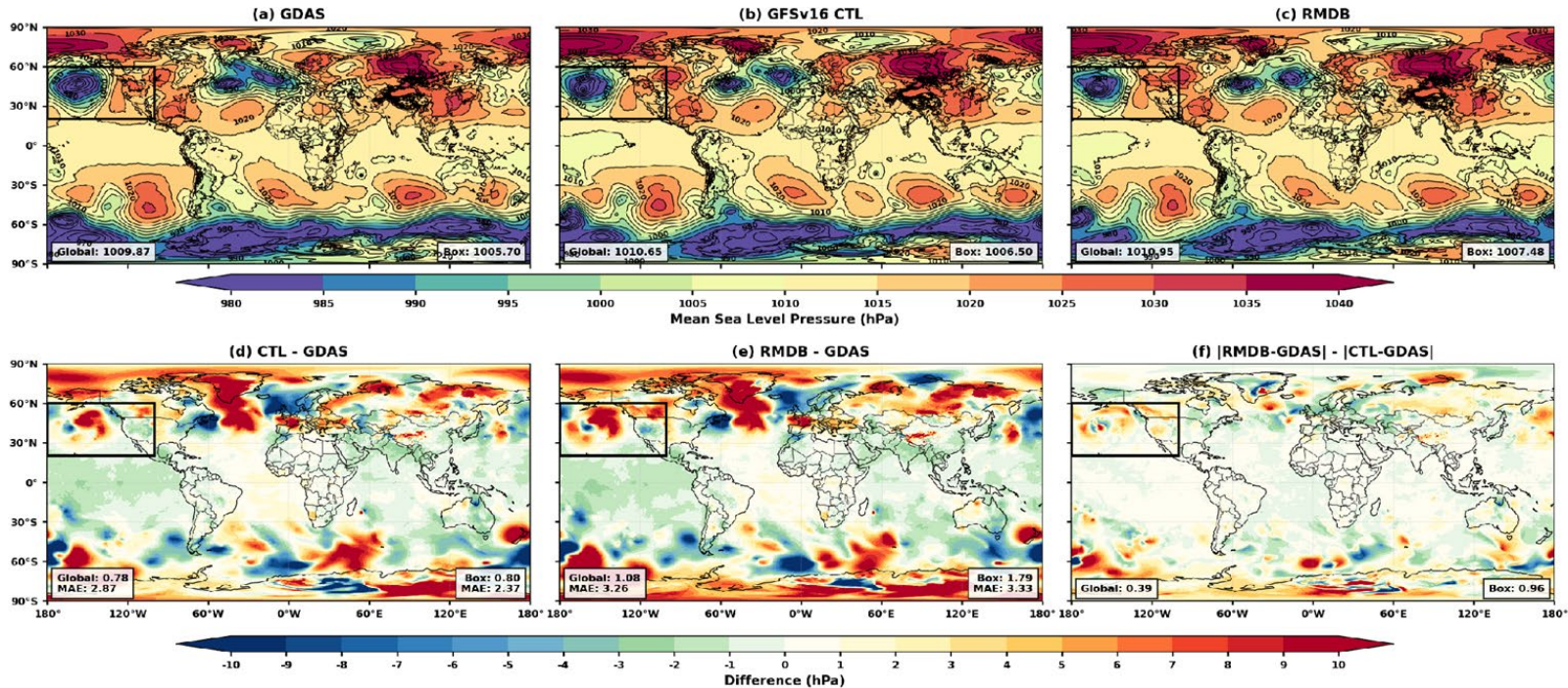
- **CTRL** – operational GFS, assimilate drifter data
- **RMDB** – Same configuration as the operational GFS, but with ALL drifting buoy observations removed from GFSv16 assimilation
- **Dec 9 2025 - Feb 28 2026**



Mean Sea Level Pressure — Spatial Comparison

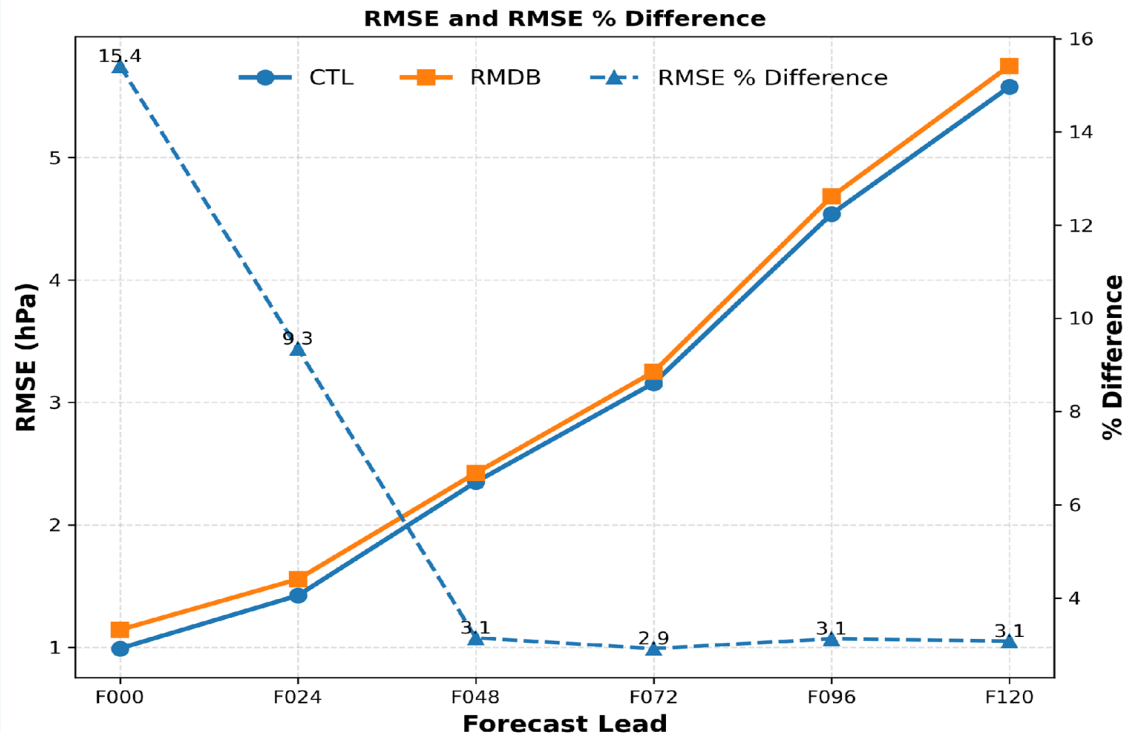
Init: Jan 29 2026;
vrfy: Feb 3 2026

Mean Sea Level Pressure | Initial: 2026012900 | F120 | Valid: 2026020300



- Removing drifter buoys degrades Box MAE by +40% (2.37→3.33 hPa) — nearly double the global impact — confirming buoys are especially critical in this region.

MSLP RMSE and Relative Difference (%) as a Function of Forecast Lead Time










F000: RMDB 15.4% worse than CTL

Difference narrows to ~3% at F048+

Key Finding: Buoys most critical at analysis time & short-range leads

GFS v17: Fully Coupled UFS Weather Model

Possibly the most complex single upgrade in GFS history.

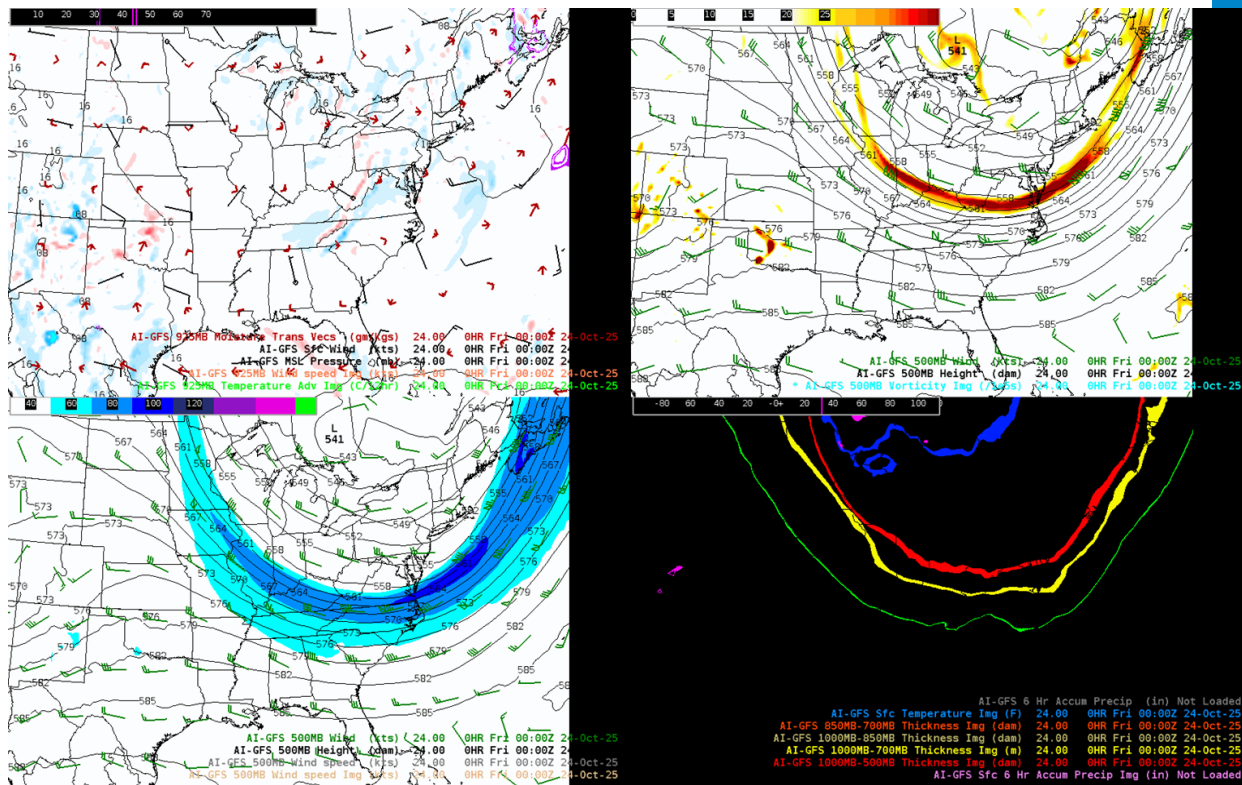
-  Coupled model.
-  Weakly and strongly coupled DA.
-  GSI updates including SDL.
-  JEDI for observations and algorithms.
-  New observation processing.
-  New workflow.
-  Massive data volume increase.

Planned for operations in late 2026.



AI/ML Modeling at NWS: EAGLE → AIGFS, AIGEFS, and Hybrid GEFS

- Moved from Experimental to **Operational on Dec. 17, 2025**
- Adopt new names appropriate for each application
 - **EAGLE Solo** → AI Global Forecast System [**AIGFS**]
 - **EAGLE Ensemble** → AI Global Ensemble Forecast System [**AIGEFS**]
 - Hybrid AIGEFS + GEFS [**HGEFS**], a 62-member AI + physical ensemble



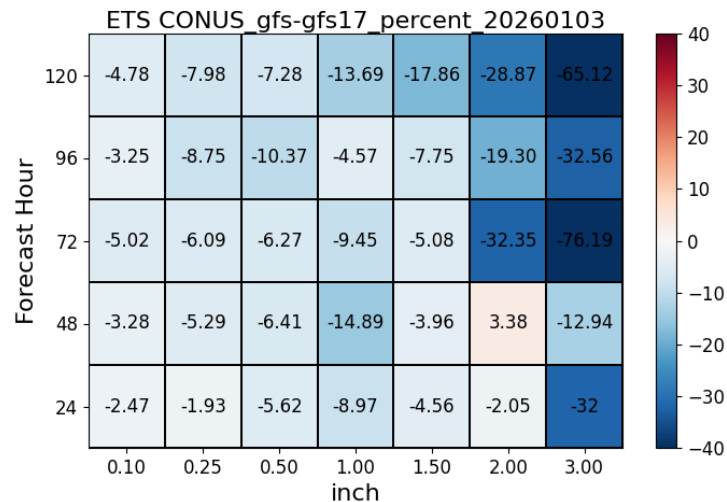
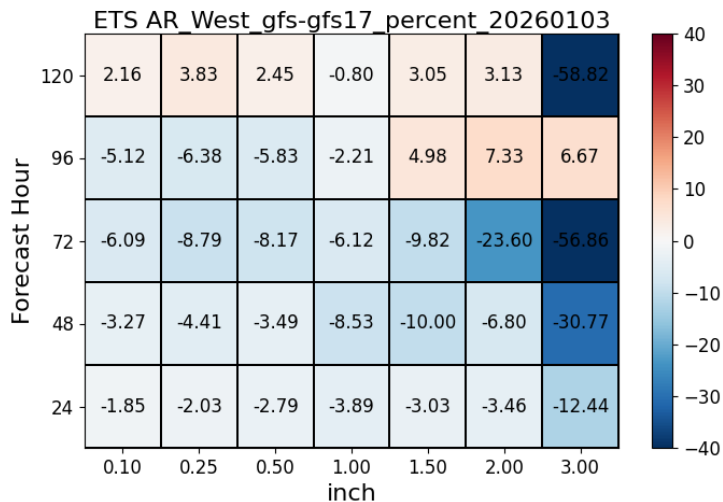
New fields: moisture transition vectors, 500MB height (dam), vorticity, 850-700mb thickness (mg).

New in 2026: GFSv17 and AIGFS for ARs

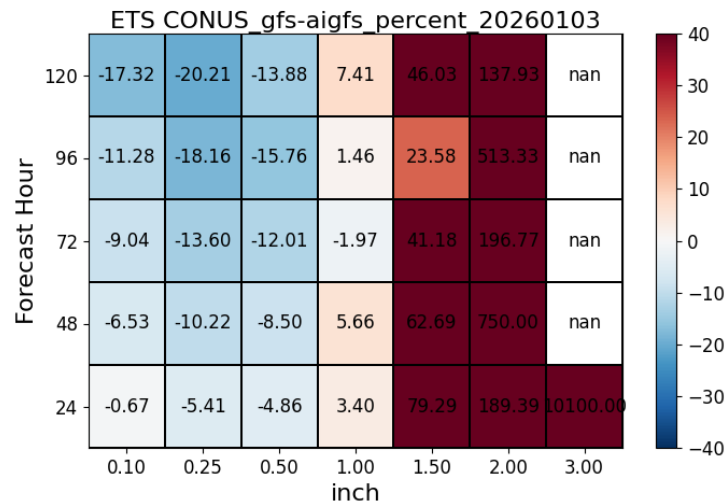
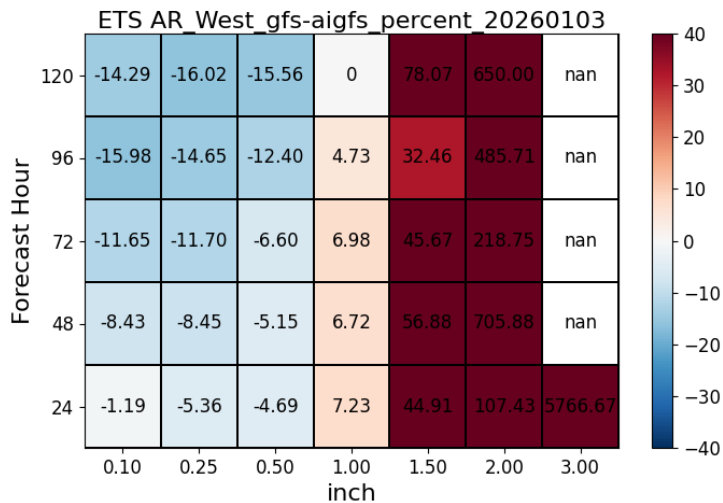
- **GFSv17: Fully coupled atmosphere–ocean–ice–wave–land system with updated physics**
- **AIGFS:**
 - AIGFS operates purely on pattern recognition from historical data (typically about 40–50 years of reanalysis data). It may not "understand" the physical laws governing atmospheric saturation or sudden convective instability.
 - Heavy precip events are rare. So there are still not enough training data for heavy precip events in the current AIGFS training dataset.
 - AIGFS was trained over larger grids, and may not capture the smaller scaled heavy precip events.
- **Precipitation forecast performance relative to GFSv16 (U.S. West Coast and CONUS)**

WEST/CONUS

24-h
precipitation
ETS difference
(%) between
GFSv16/GFSv17
and
GFSv16/AIGFS
(ref. CCPA).



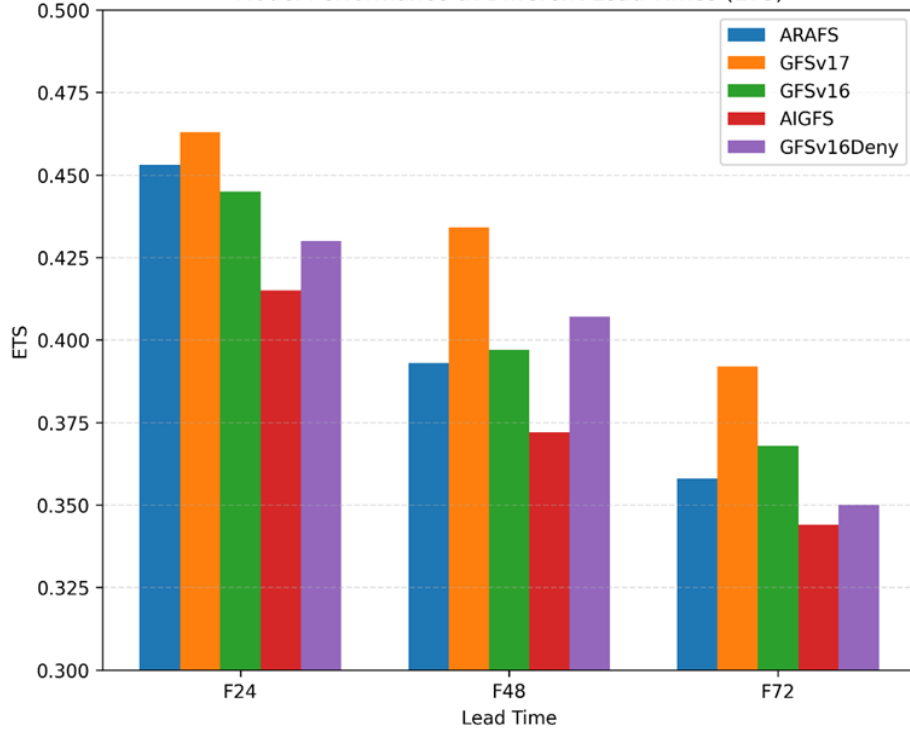
Blue indicates
higher ETS
(improved
forecast skill)
for GFSv17 or
AIGFS relative
to GFSv16.



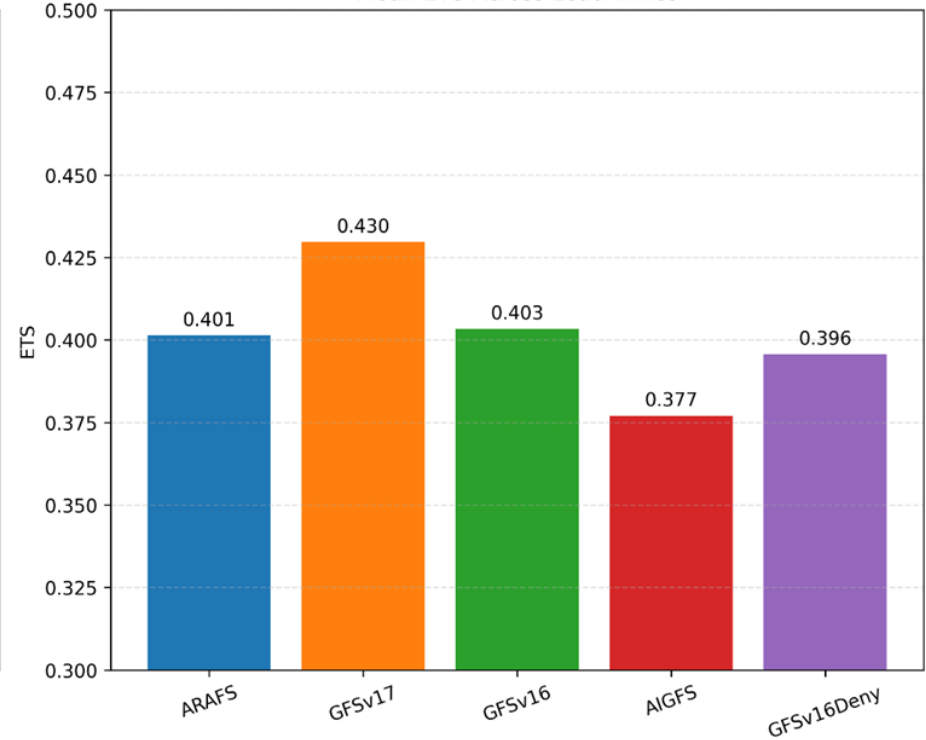
AR Recon Jan–Mar 2026 U.S. West

24-hour Accumulated Precipitation ETS (1-inch Threshold)

Model Performance at Different Lead Times (ETS)



Mean ETS Across Lead Times



Summary and Future Plans

- AR Recon dropsonde observations enhance the GFS analysis, resulting in considerable improvements in GFS forecast performance along the U.S. West Coast - especially for precipitation forecasts.
- The assessment of impact of drifting buoy indicate modest impact on GFS MSLP forecasts.
- The new fully coupled GFSv17 will be applied for future AR case studies.
- AIGFS still can't perform well for precipitation forecasts - more work needed there.
- Continued evaluation and optimized integration of AR and GARRP Recon data and other innovative datasets are expected to further enhance GFS forecast skill.

A satellite view of Earth from space, showing the Americas and the Atlantic Ocean. The word "Questions?" is overlaid in white text in the center of the image.

Questions?