Unifying Targeted Aircraft Reconnaissance Observations for Improving Atmospheric River and Winter Storm Forecasts

NATIONAL WEATHER SERVICE

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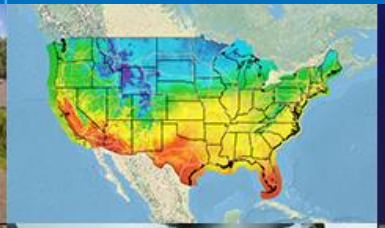
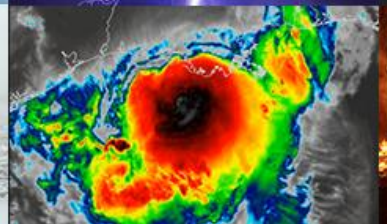
AR Recon Workshop, ECMWF, June 26-29, 2023







Outline

- AR Reconnaissance in the context of Operational Modeling and Data Assimilation at NCEP: **Why is it important?**
- Impact of dropsonde data on NCEP operational GFS: **What are the benefits?**
- **Unifying Targeting Strategies** for Aircraft based Recon for ARs and Winter Storms
- **PPGC and SAB Report: NOAA's New Project:** Water in the West, Phase 1: ARs

Atmospheric River Reconnaissance Background (2016-2023+)

AR RECON
Research And Operations Partnership

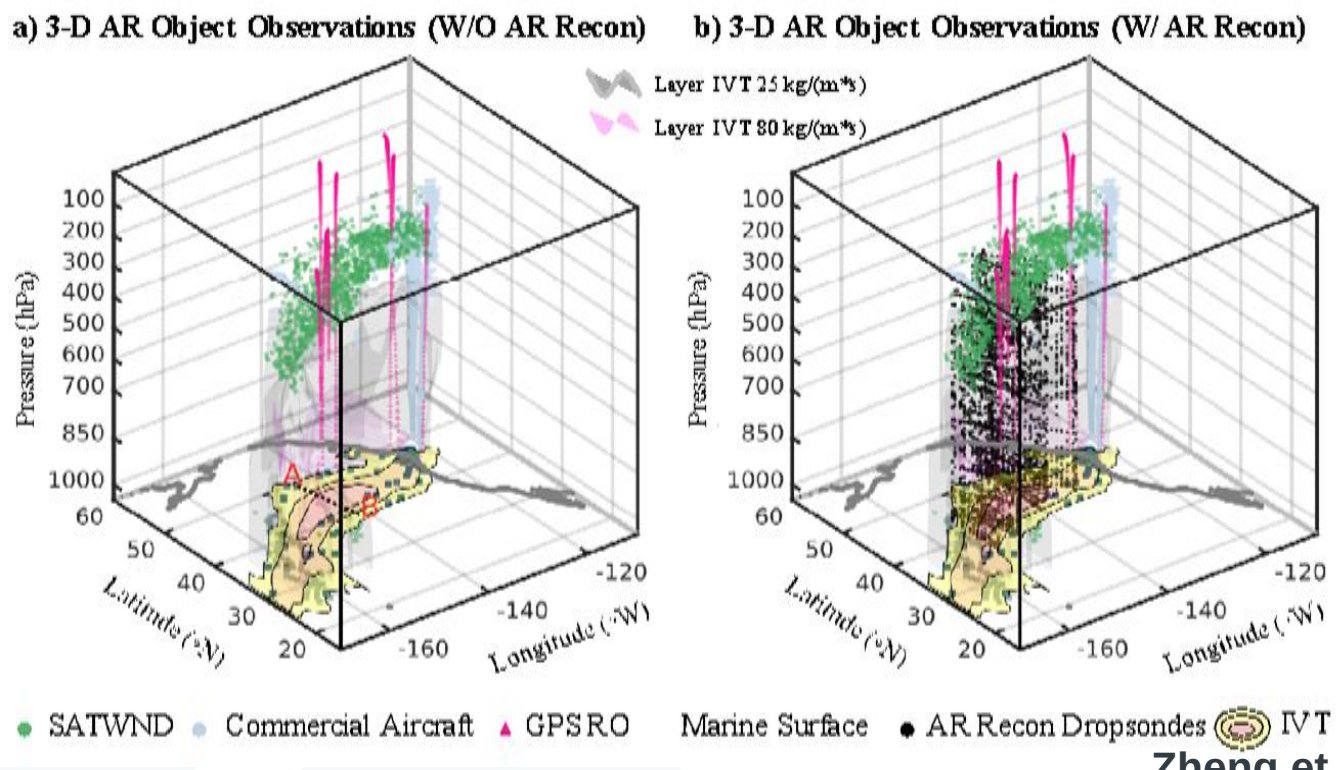
OVERARCHING GOAL

Atmospheric River Reconnaissance Strives to Improve Predictions of Land-falling Atmospheric Rivers and Their Associated Impacts in the Western U.S.

- Has transitioned from field demonstration to an **operational requirement through NWSOP**
- Organized and led as a **Research And Operations Partnership**
- Uses Air Force C-130s and the NOAA G-IV; uses dropsondes, flight level data, airborne radio occultation, pressure-enabled drifting buoys
- Flight planning and calling of missions is carried out by a diverse team of scientists and forecasters
- “Steering committee for modeling and data assimilation” enables multi-agency impact assessments
- Robustness of results are established through scientific peer-review

F. Martin Ralph (UCSD/SIO/CW3E) - PI
Vijay Tallapragada (NWS/NCEP) - Co-PI
Anna Wilson (UCSD/SIO/CW3E) - Coordinator

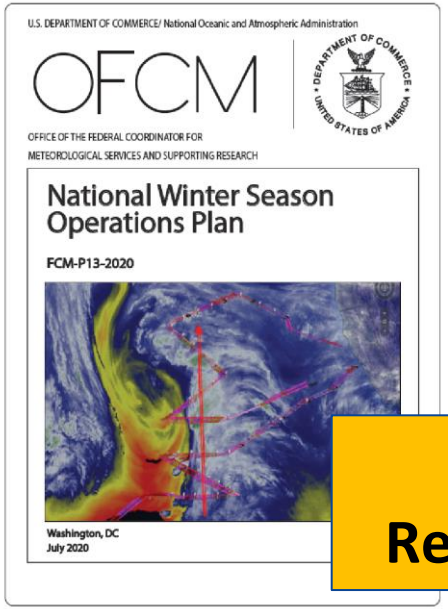
DATA GAPS FOR AR: OBSERVATION DENSITY ANALYSIS



Zheng et al. 2020 (BAMS)

National Winter Season Operations Plan Includes AR Reconnaissance Off the U.S. West Coast Starting in 2020

In Spring 2019, the interagency group that develops the NWSOP approved incorporation of AR Recon as a leading priority for addressing gaps in west coast storm prediction, specifically targeting ARs and their vicinity over the Pacific with NOAA and Air Force Recon capabilities.



Cover Image: AR Recon tracks (AFRC/53 WRS WC-130J aircraft) from 24 February 2019 on GOES-17 water vapor imagery (warm colors delineate dry air and white/green colors delineate cold clouds). White and brown icons indicate dropsondes. The red arrow indicates the AR axis.

Foreword

The purpose of the National Winter Season Operations Plan (NWSOP) is to coordinate the efforts of the Federal meteorological community to provide enhanced weather observations of severe Winter Storms impacting the coastal regions of the United States. This plan focuses on the coordination of requirements for winter season reconnaissance observations provided by the Air Force Reserve Command's (AFRC) 53rd Weather Reconnaissance Squadron (53 WRS) and NOAA's Aircraft Operations Center (AOC).

The goal is to improve the accuracy and timeliness of severe winter storm forecasts and warning services provided by the Nation's weather service organizations. These forecast and warning responsibilities are shared by the National Weather Service (NWS), within the Department of Commerce (DOC) and the National Oceanic and Atmospheric Administration (NOAA); and the weather services of the United States Air Force (USAF) and the United States Navy (USN) , within the Department of Defense (DOD).

Within the organizational infrastructure of the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), the Working Group for Winter Season Operations (WG/WSO) is responsible for maintaining the plan. This year marks the 35th edition of the National Winter Season Operations Plan (NWSOP).

The national winter season mission is a team effort, and as we strive to be a "Weather-Ready Nation," the effective coordination of the Federal agencies involved, local emergency managers

AR Recon represents a Research And Operations Partnership

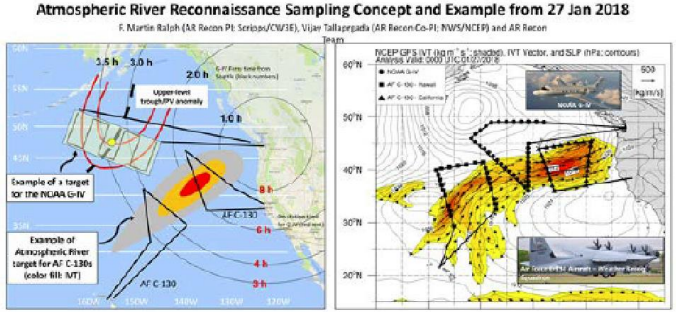


Figure 1-1. Atmospheric river reconnaissance targeting concept and example using 3 aircraft, executed on 27 Jan 2018. In addition, moist adjoint method is used to identify regions of large initial condition error impacts, which largely match the location of the AR.

raft operations may begin as early as five days prior
ndfall. The frequency of flights during operations is
eeds of forecast models, however, may include up to
ture centered around 0000 UTC. During operations,
or at UCSD/SIO/CW3E identifies important AR
nd data collection requirements via either the NWS
ector, EMC representative or WPC representative to
EP Central Operations. CARCAH works with the SDM to determine the ability of reconnaissance units to meet requirements, considering the availability of resources with mission requirements and incorporates tasked requirements into the Winter Season Plan of the Day (WSPOD).

AR Recon in Numbers: 2016-2023

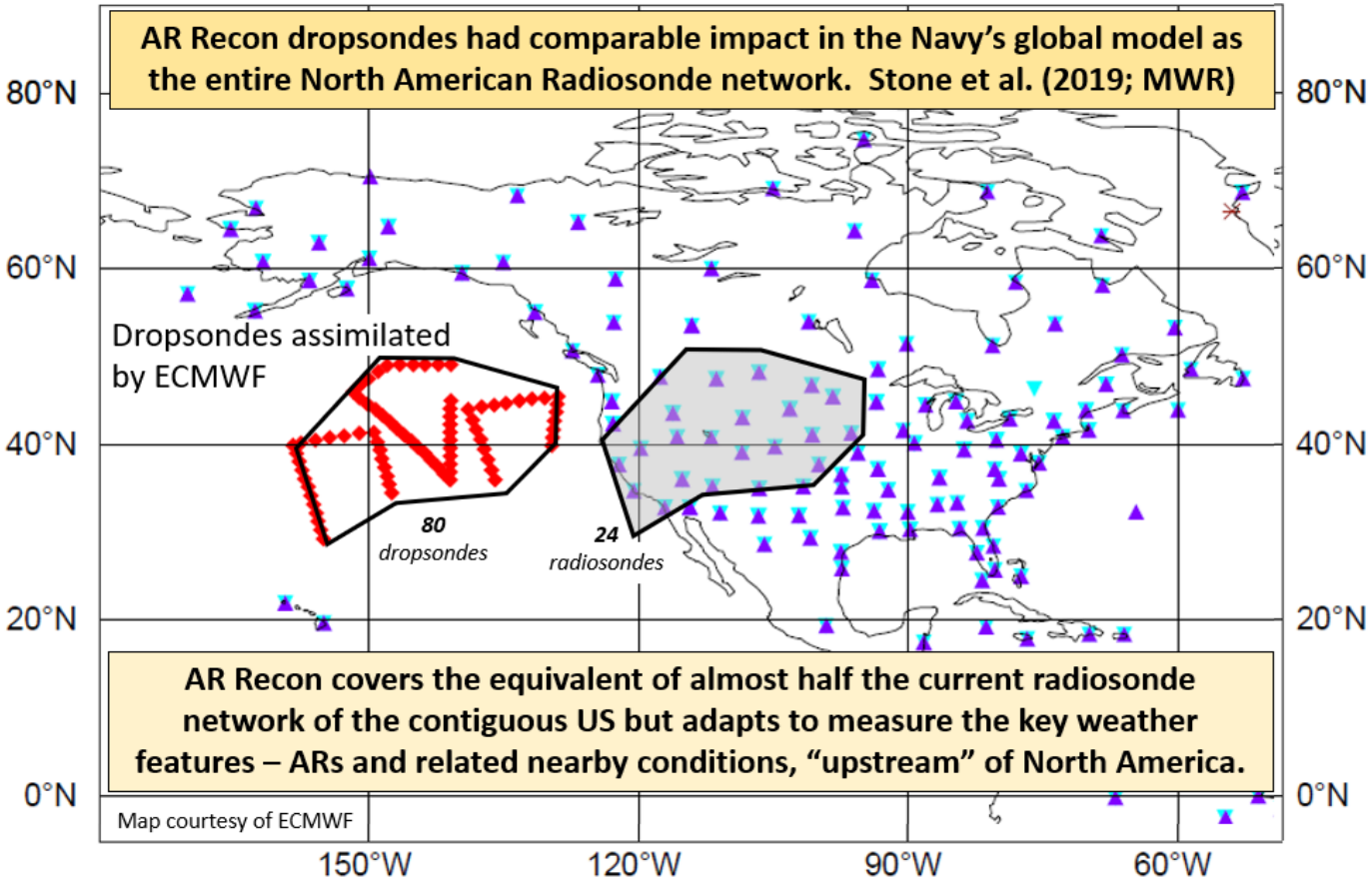
Summary | 2023 | 2022 | 2021 | 2020 | 2019 | 2018 | 2016

Date	IOPs	Flights	AF C-130J	AF C-130J	NOAA G-IV	Assimilated Drops (18/00/06 UTC)*		
			Dropsondes (Bad drops) / Flight hours			NCEP	ECMWF	Navy
2023 Totals	39	51	825 (66) / 283.8		555 (47) / 132	22 / 1207 / 10		20 / 844 / 0
2022 Totals	25	32	465 (41) / 177.3	27 (3) / 10.1	310 (12) / 79.6	0 / 742 / 0	123 / 451/ 0	0 / 685 / 0
2021 Totals	29.5	46	613 (72) / 216.9	103 (4) / 34.7	563 (65) / 137.9	20 / 1029 / 13	102/906/0	20 / 1098 / 21
2020 Totals	17	31	177 (17) / 68.3	231 (16) / 97.5	409 (23) / 105.3	3/620/5	66/559/0	3/456/3
2019 Totals	6	11	169 (17) / 54.5	122 (10) / 41.4		0/262/2	17/244/0	256
2018 Totals	6	13	131 (2) / 47.1	125 (5) / 46.6	115 (3) / 24.6	2/333/0	311	333
2016 Totals	3	6	155 / 33.4	115 / 31.3		157		

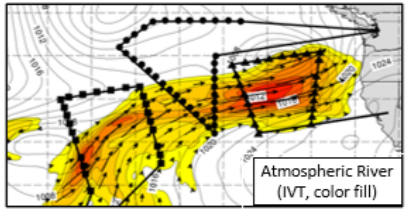
Atmospheric River Reconnaissance Example– 2018 (0000 UTC 27 Jan)

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

AR Recon dropsondes had comparable impact in the Navy's global model as the entire North American Radiosonde network. Stone et al. (2019; MWR)

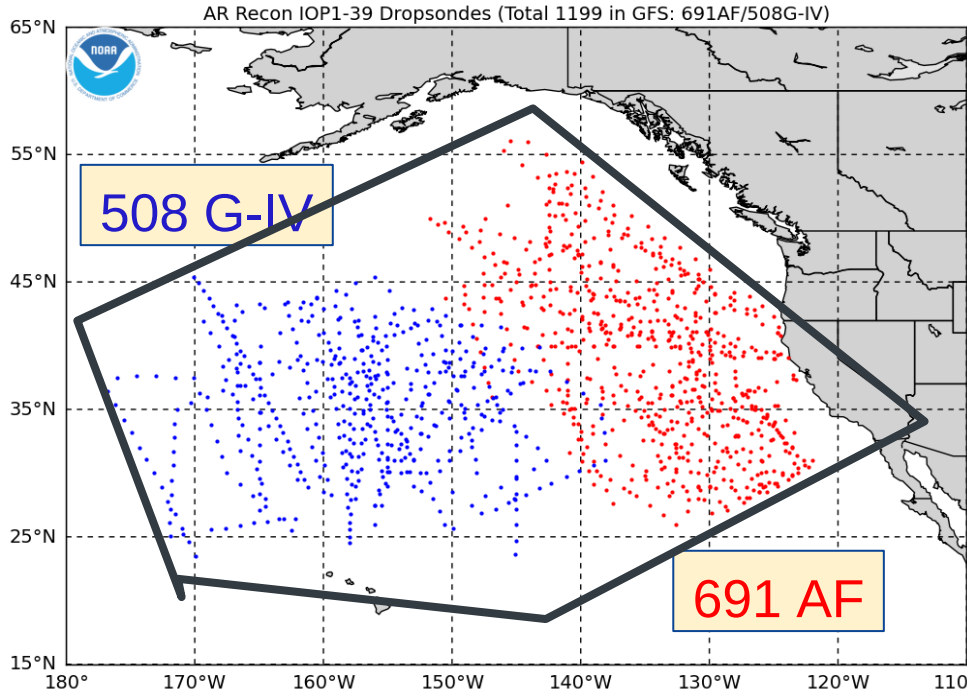


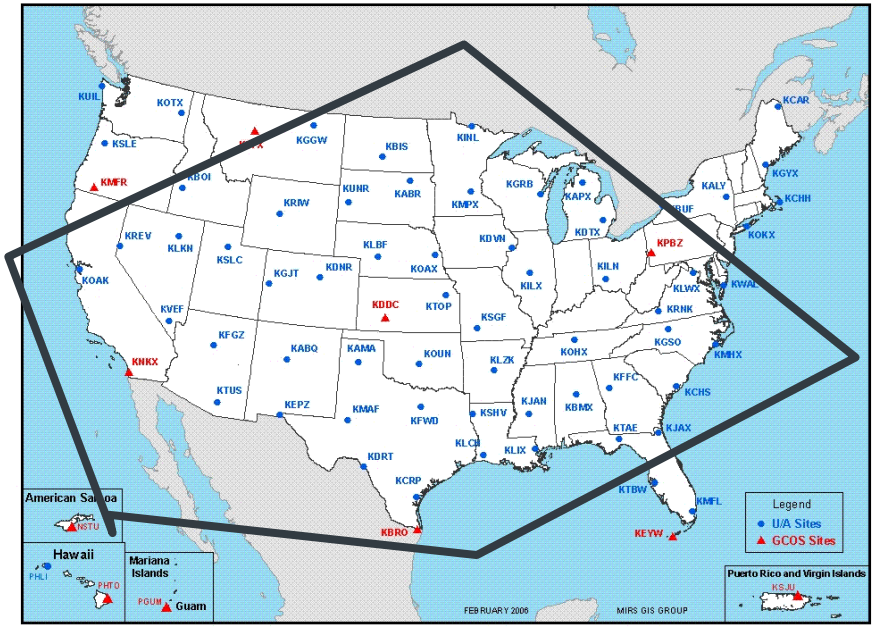
AR Recon covers the equivalent of almost half the current radiosonde network of the contiguous US but adapts to measure the key weather features – ARs and related nearby conditions, "upstream" of North America.



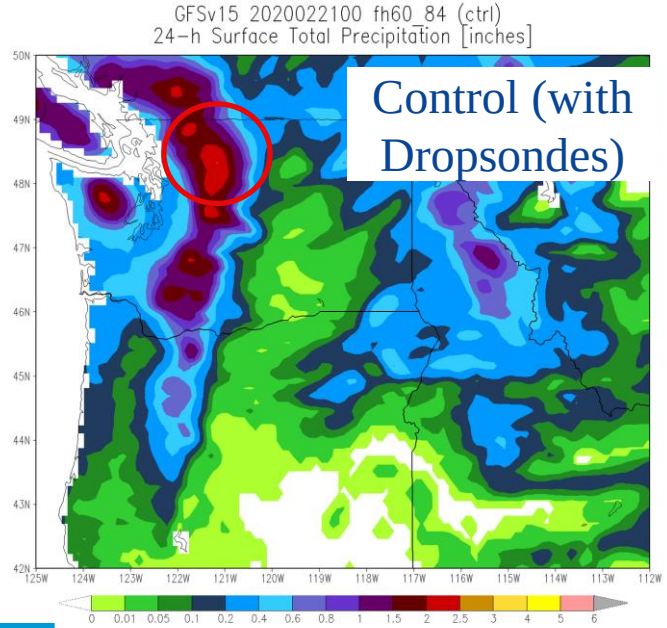
"The 24-h global forecast error reduction from the reconnaissance soundings can be comparable to the reduction from the North American radiosonde network for the field program dates that include at least two flights."
(Stone et al. (2019; MWR)

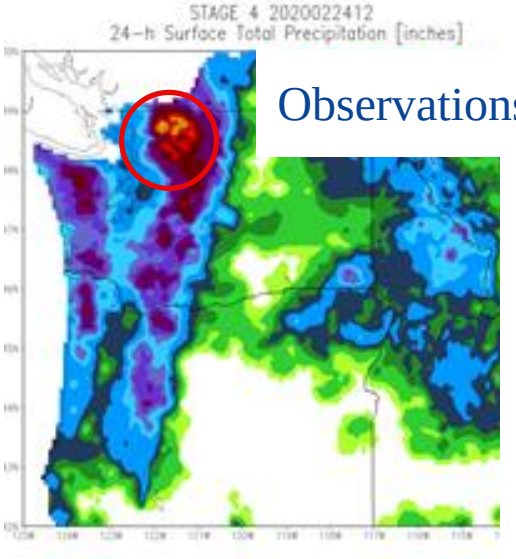
2022-2023 AR Recon IOP 1-39 dropsondes

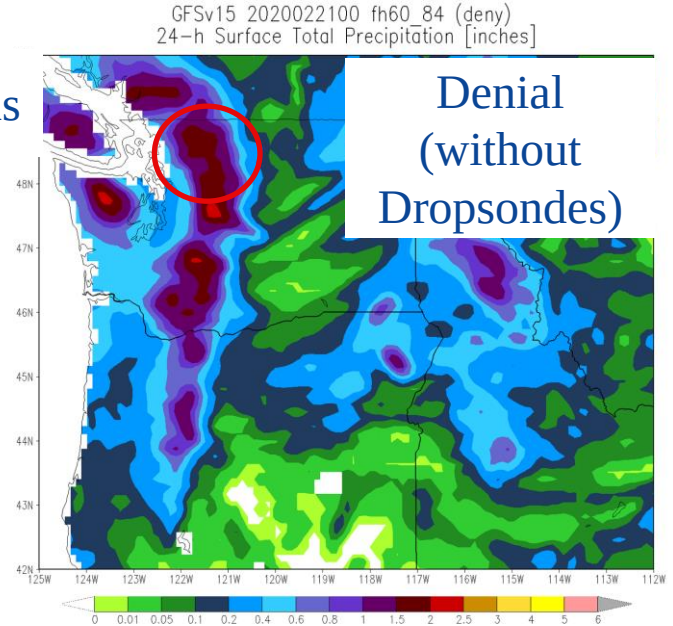




GFSv15 PRECIP: 24-h total – 2020 February 23 12Z-February 24 12Z (72-hr forecast)







AR Recon helped better predict the intense precipitation amounts

AR 2020 Dropsonde Impact Precipitation threat score

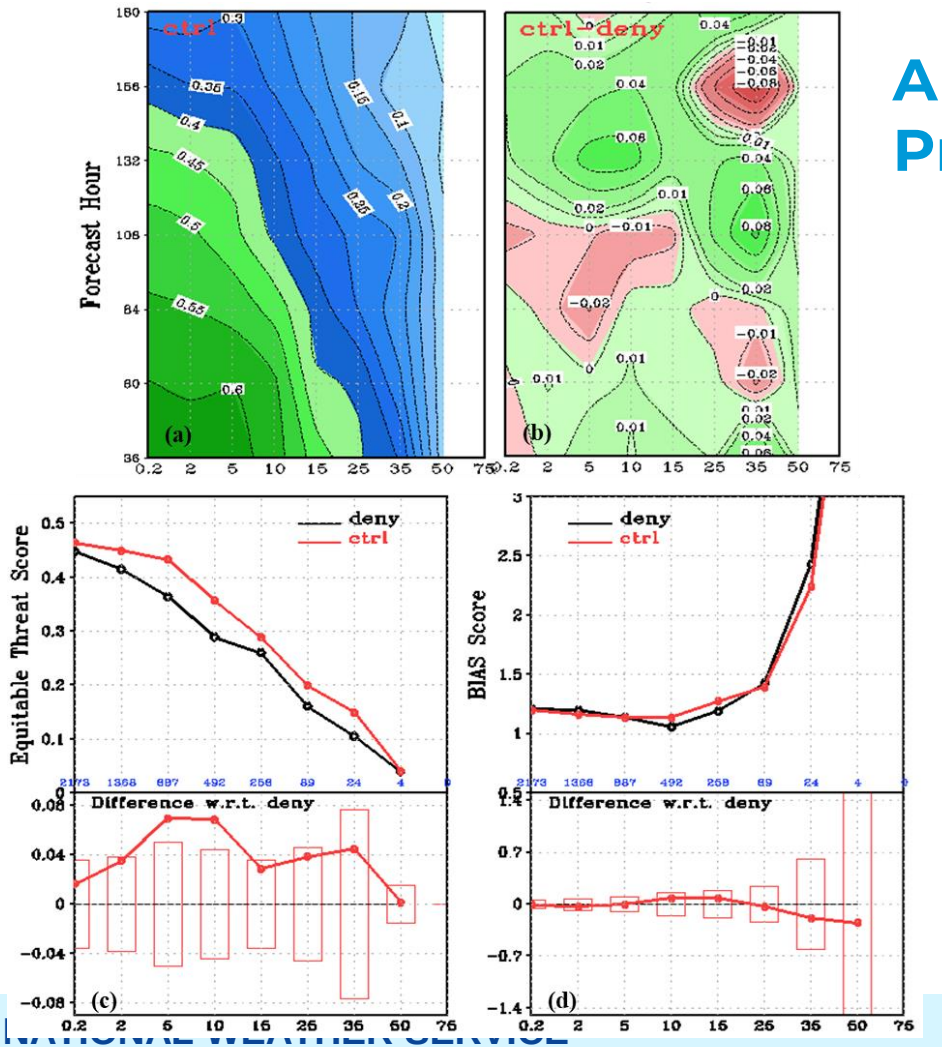


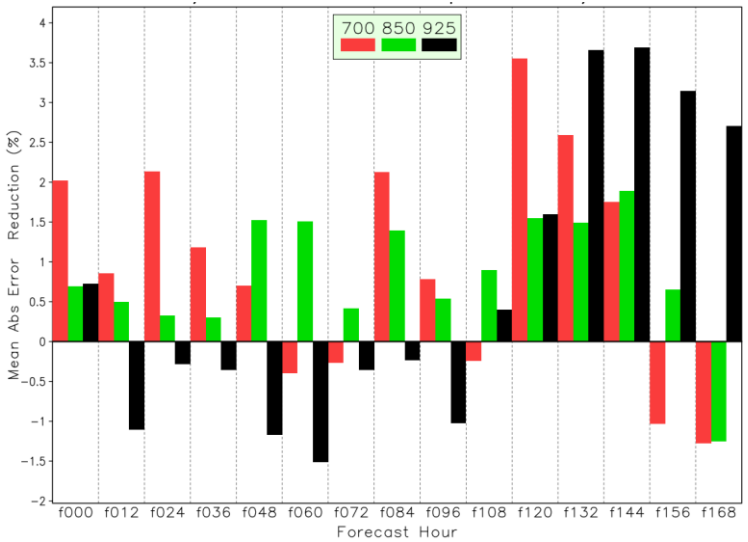
Fig. 9. (a) CTRL threat score for the experimental period. (b) CTRL-DENY difference for 36-180 h precipitation forecasts over the US West Coast region (approximately 32-49.5N, 115-125W) for the AR2020 experimental period. The score is for 0.2-75 mm/day precipitation thresholds for 24-h accumulations. Positive impact is green and negative impact is red. (c) 108-132 h forecast averaged CTRL (red) and DENY (black) threat scores and CTRL-DENY differences. (d) as in (c) but for bias scores. Differences outside the vertical boxes indicate statistical significance at the 99% level.

Lord et al. 2023, WAF

Data Impact Experiment Results from 2020 AR Recon

Lord, S.J., X. Wu, V. Tallapragada and F.M. Ralph, 2022: The Impact of Dropsonde Data on the Performance of the NCEP Global Forecast System During the 2020 Atmospheric Rivers Observing Campaign. Part 2: Dynamic Variables and Humidity. *Weather and Forecasting. Final revision*

- **Focus on relatively large scale statistics for dynamic variables like IVT, MSLP, GPH, winds and humidity (PNA, US West coast)**
- **17 IOPs in 2020 showed overall improved statistics for wind and moisture profiles when dropsonde data is assimilated into the NCEP Operational GFS**
- **The positive dropsonde data impact on precipitation forecasts over U.S. West Coast domains appears driven by improved low-level moisture fields**

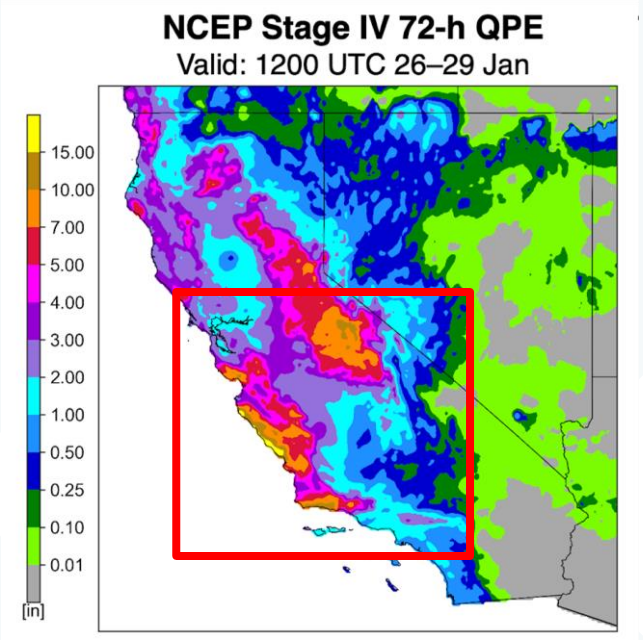


Average MAE reduction (%) over 17 IOP cases for 12-168 h relative humidity forecasts at 700/850/ 925 hPa, verified against ECMO analyses.

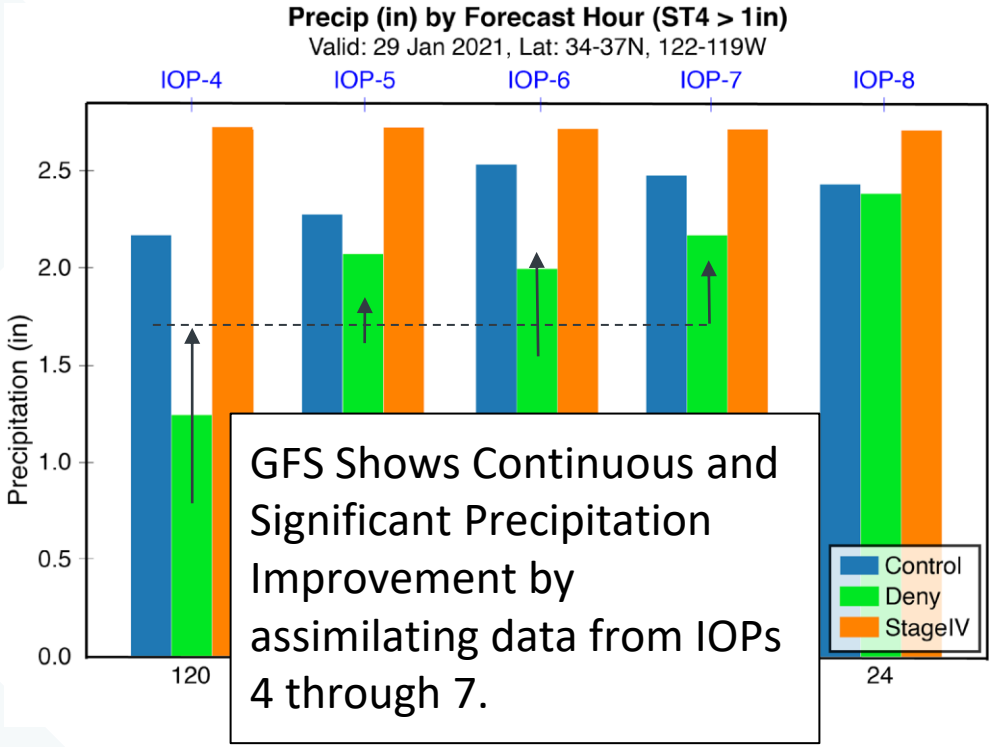
AR Recon 23-28 Jan. 2021 Sequence: *Example of Impact*

AR Recon Data Denial Experiments

V. Tallapragada, F.M. Ralph, X. Wu, M. Zheng



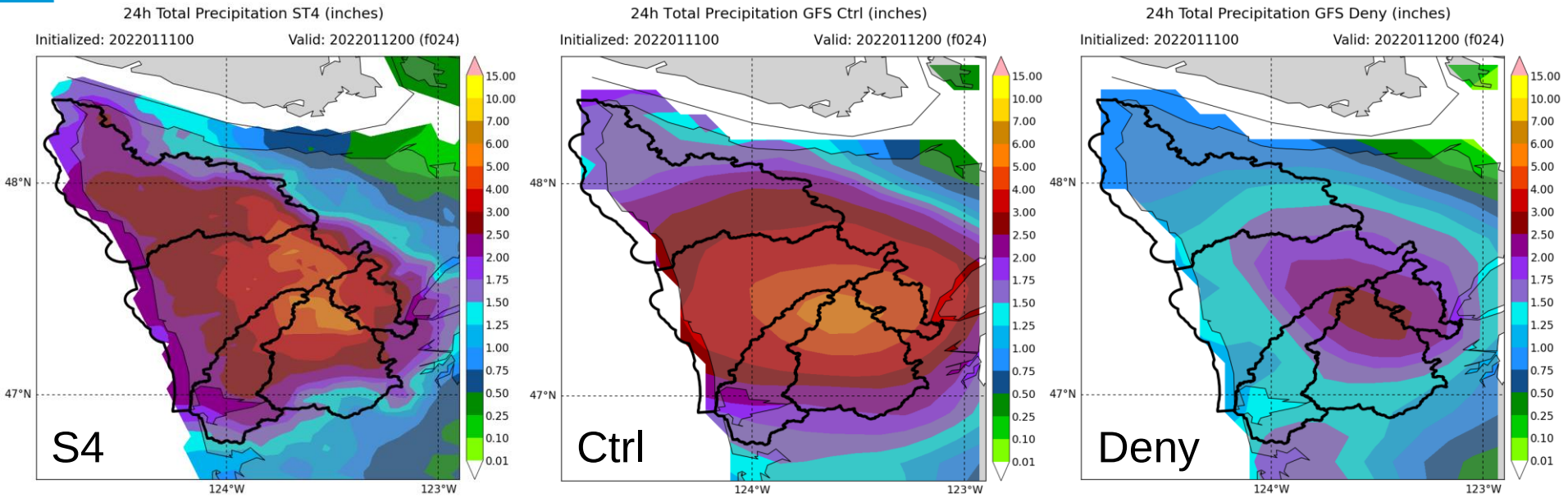
GFS precipitation forecast error at 120h (5-day) lead time ***with drops*** is equivalent to the 48h (2-day) error without drops.



GFS Shows Continuous and Significant Precipitation Improvement by assimilating data from IOPs 4 through 7.

ARR 2022 IOP 1 (Jan 11) Impact from GFSv16 Forecast

24-h precipitation 00Z Jan 11 to 00Z Jan 12

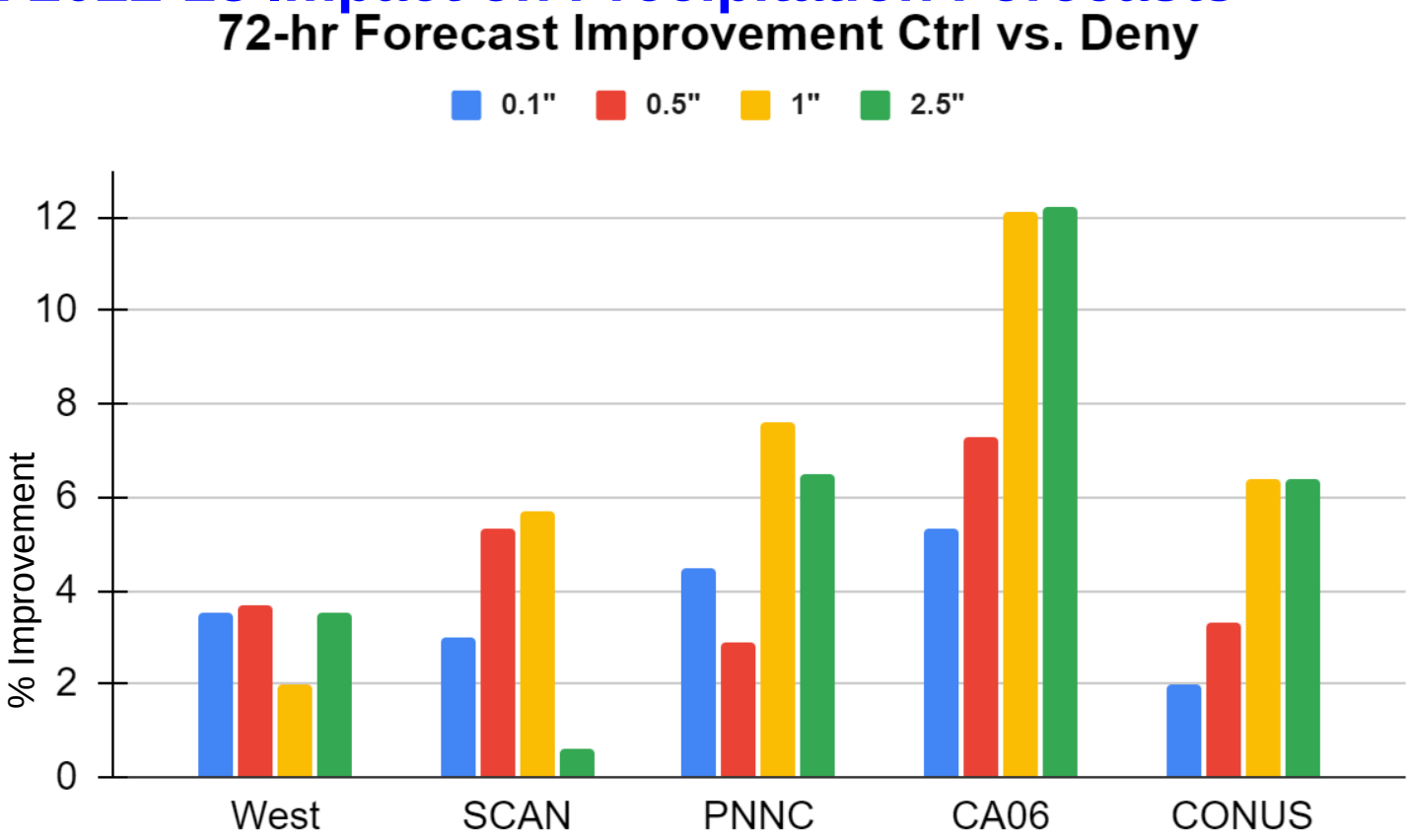


AR Recon flight substantially reduced errors in the 24-48 hours lead-time forecast of heavy precipitation (in WA). The maximum precipitation in the data denial experiment is less than half of the observed maximum precipitation (~6 inches) in this case.

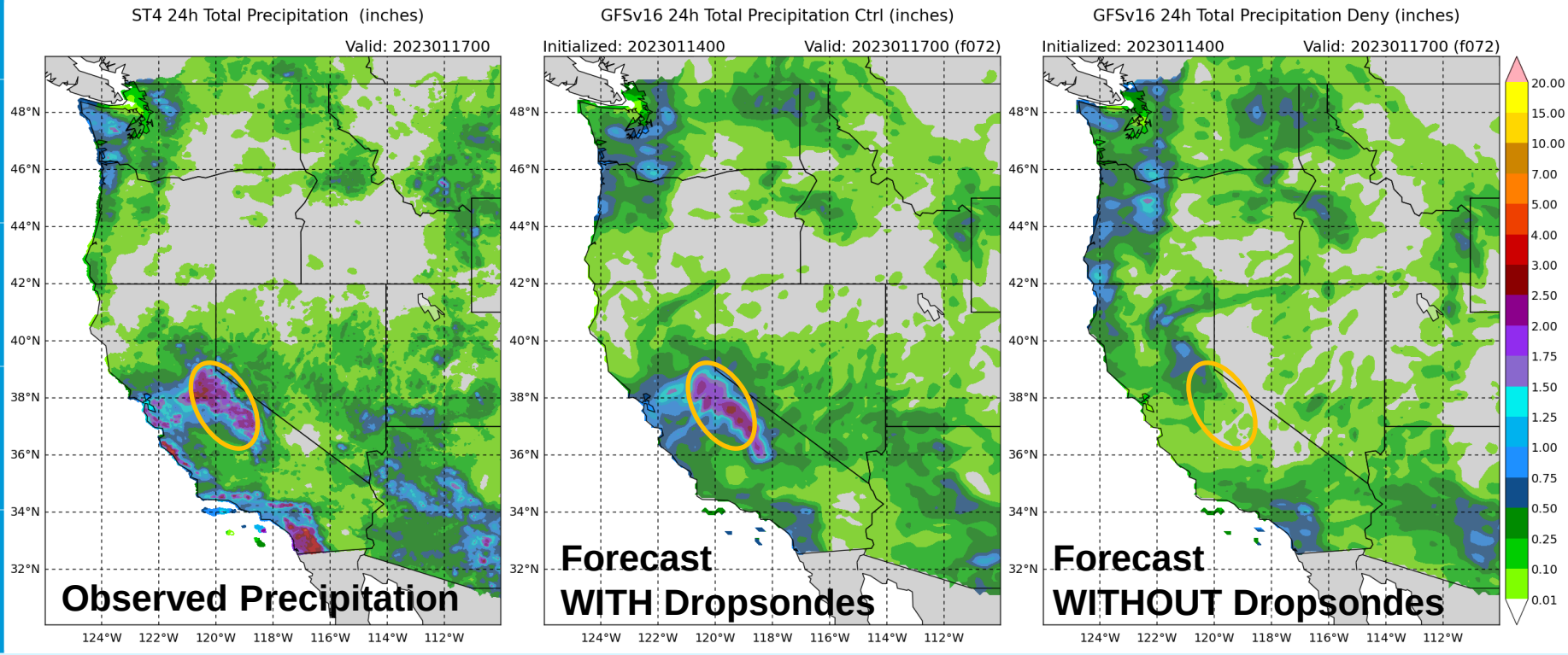
AR Recon 2022-23 Impact on Precipitation Forecasts

Largest improvements over the California Domain for the heavier precipitation amounts

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



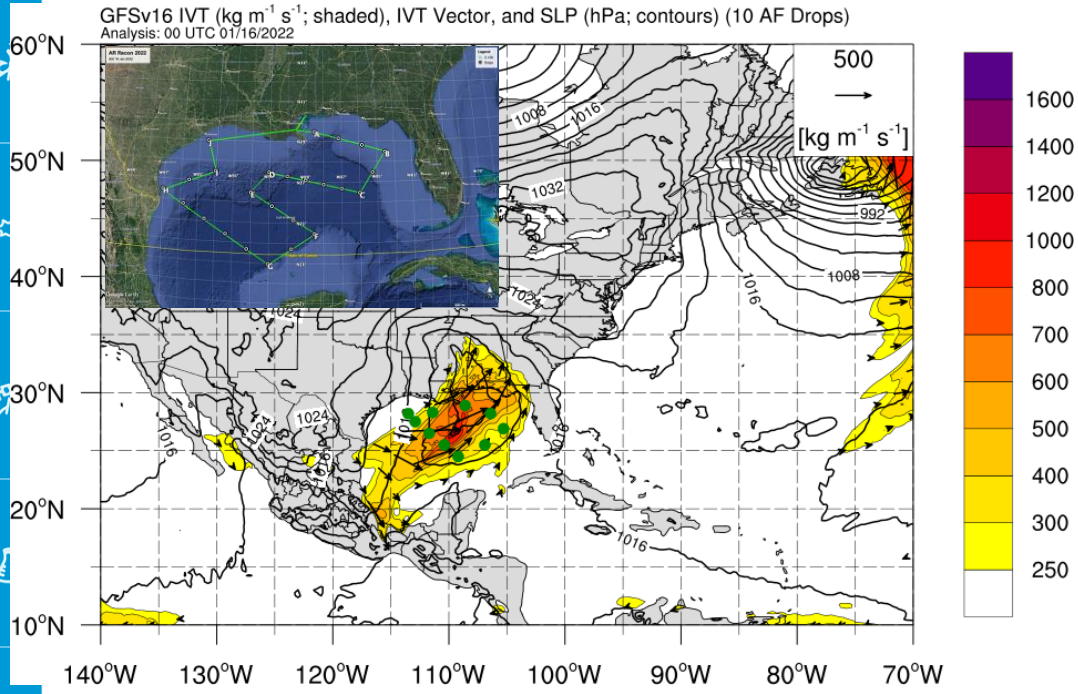
Case Study: IOP 14 (00Z Jan 14)
72-hour forecast, verify at 00Z Jan 17

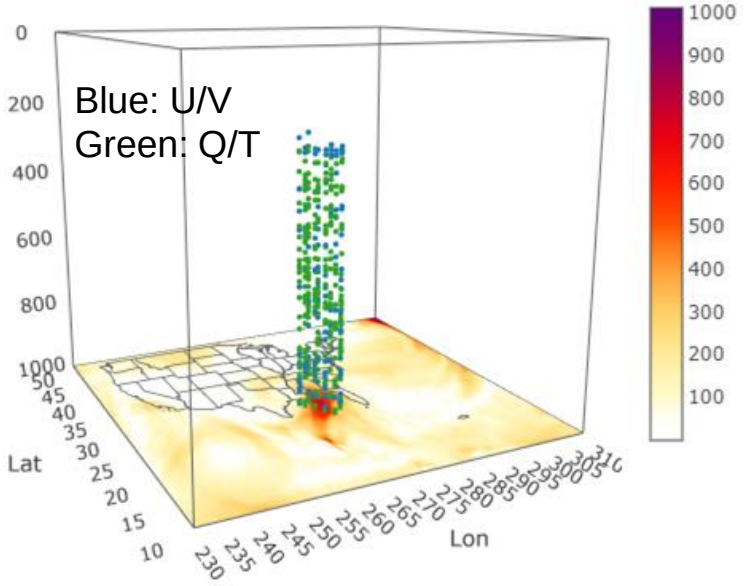


Unifying Sampling Strategies for ARs in the Pacific and Winter Storms impacting Gulf and East Coast

Demo Flight Plan for WSR 00Z 16 Jan 2022

WSR 1 – 00Z 16 Jan 2022
(Fixed track with 10 Drops)



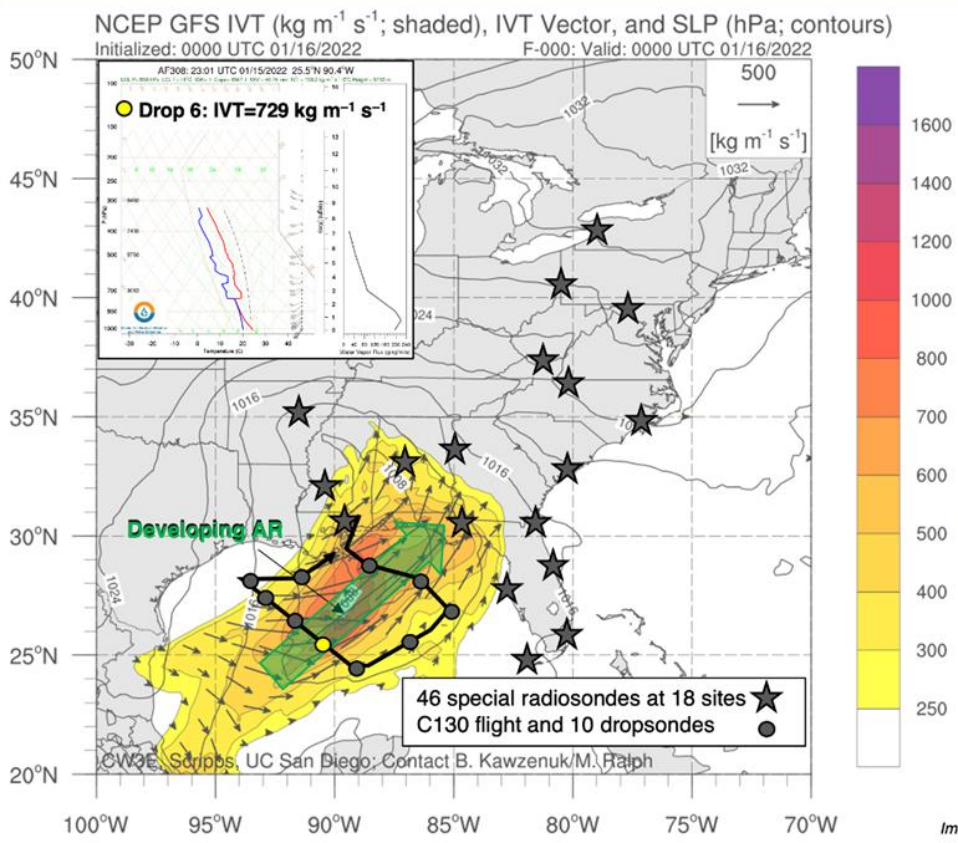


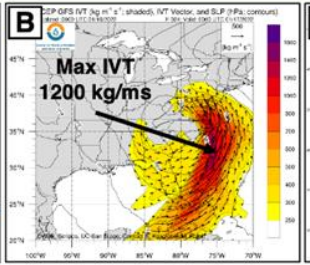
WSR1 (1/16/2022)	T	Q	UV
Data Assimilated	267	233	197
Data Monitored	10	26	0
Data Rejected	0	0	0
Total counts	277	259	197

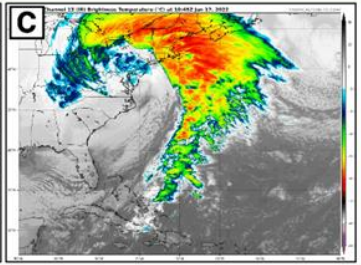
AR Recon EC-IOP1: 16 January 2022 | Major East Coast Winter Storm

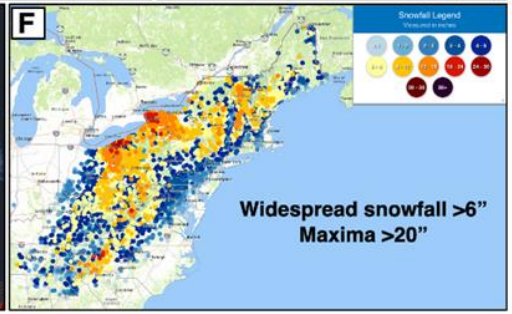
AR Recon Team (CW3E/NCEP/USAF and others) partnered with NWS/NCEP and Regional offices to propose and implement additional radiosonde and aircraft observations in Eastern US and Gulf of Mexico, using lessons from the West Coast, ahead of a major East Coast Winter Storm with the goal to reduce uncertainty in predicting the development and evolution of the storm.

AR Recon: http://cw3e.ucsd.edu/arrecon_overview/ | F. M. Ralph (PI; UC San Diego/SIO/CW3E) & V. Tallapragrada (co-PI: NOAA/NWS/NCEP)









A: Winter storm necessitated winter storm watches and warnings up and down East Coast
B: AR intensified into an ***Extreme*** AR4 with IVT magnitudes >1200 kg m^{-1} s^{-1}
C: Storm contained a robust warm conveyor belt as it tracked into Northeast US
D: Narrow cold frontal rainband (NCFR) in Florida produced severe weather (7 tornadoes)
E: NCFR contained gap-and-core convective structure as it propagated north with heavy stratiform precipitation at the terminus of the AR over Mid-Atlantic; strong onshore flow later produced severe wind reports in NJ/NY and coastal flooding through New England
F: Mesoscale banding on the west side the storm and orographic enhanced precipitation in the AR produced widespread snowfall from Georgia to Maine.

Image credits: CW3E, PivotalWeather.com, TropicalTidbits.com, RadarScope, and NOAA/NWS; Prepared by J. Cordeira & F. M. Ralph

Developing Custom Tracks for Winter Storm Reconnaissance in the Gulf of Mexico and Western North Atlantic as part of Atmospheric River Reconnaissance

Chairs:

Vijay Tallapragada, *NOAA/NWS/NCEP/EMC*

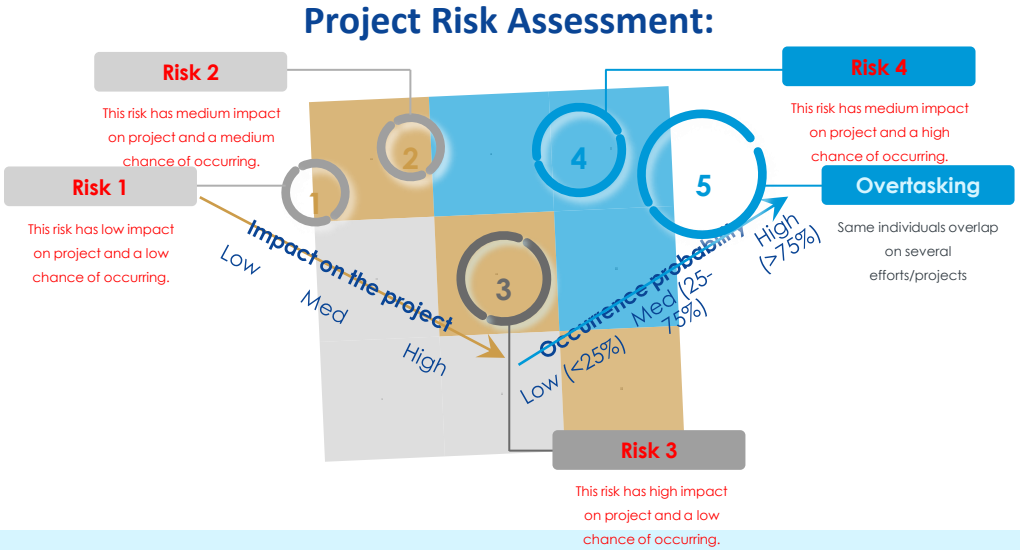
Anna Wilson, *Center for Western Weather and Water Extremes at Scripps Institution of Oceanography*

Courtesy: Chris Dyke, Chief, US AFRS Weather Operations

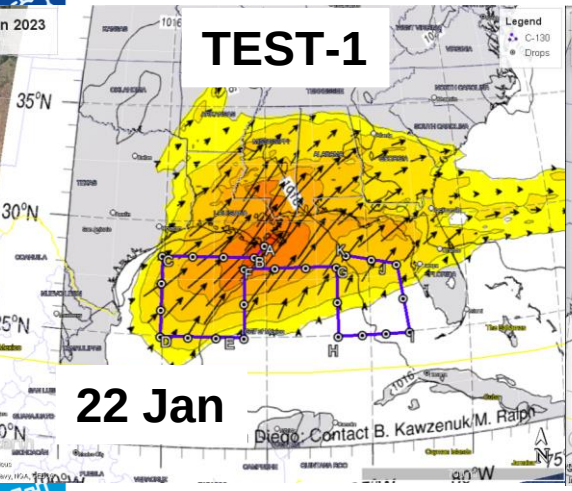
Project Overview

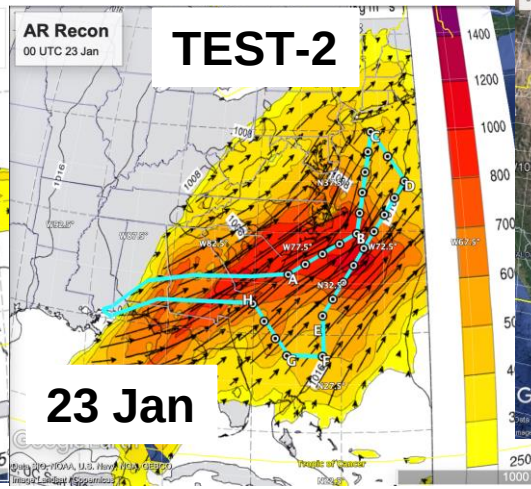
Goal: Using West Coast Atmospheric River Reconnaissance as a model, including its framework as a Research and Operations Partnership, prepare and establish new methods, targeting techniques based on forecast sensitivities, and coordination protocols to execute customized track missions over the western North Atlantic and Gulf of Mexico.

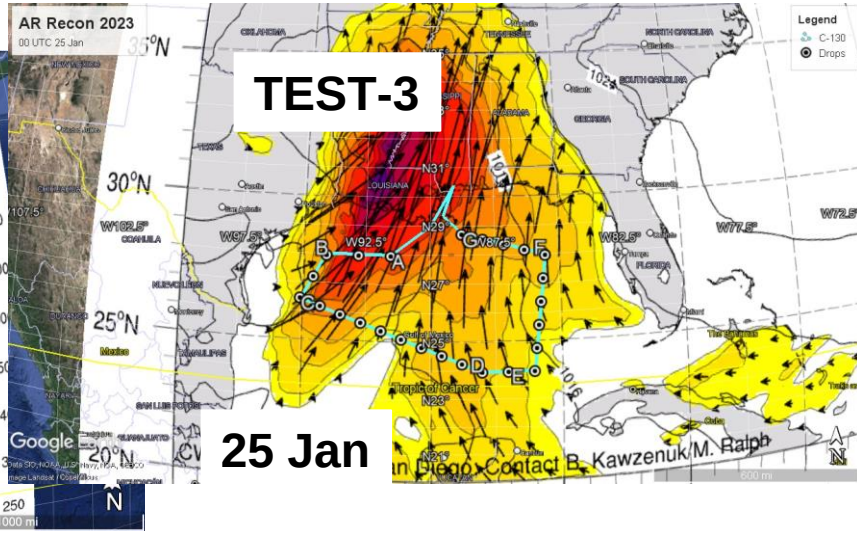
- Implementation will be in 3 phases:
  - Phase 1: Aircraft Implementation
  - Phase 2: Aircraft Optimization
  - Phase 3: Impact Optimization
- Each phase will have at least one deliverable:
  - Phase 1: Refined SOP (version 2)
  - Phase 2: Updated NWSOP
  - Phase 3: Winter Season Sensing Strategy Document

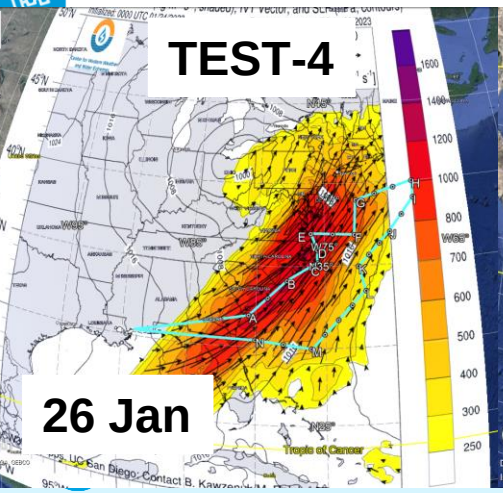


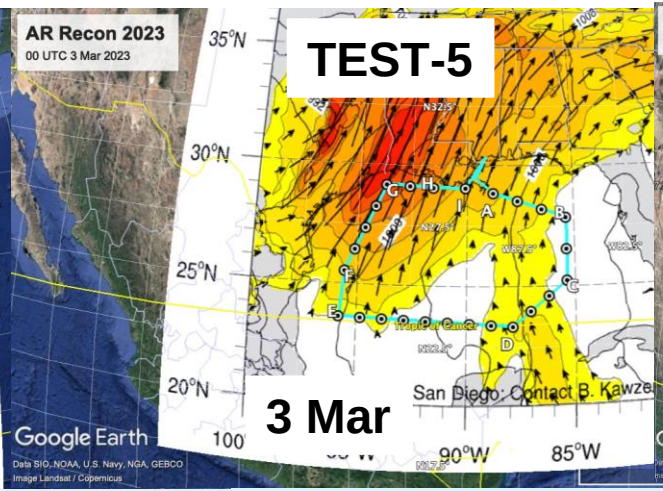
Flight Plans: WSR TEST 1-6

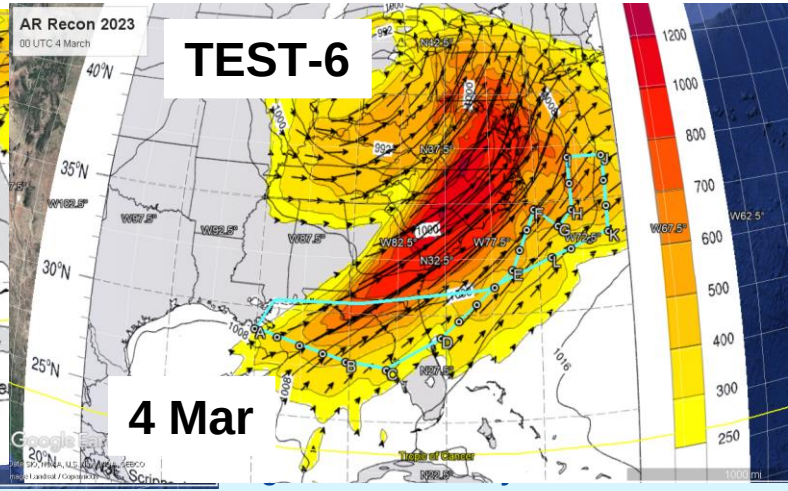






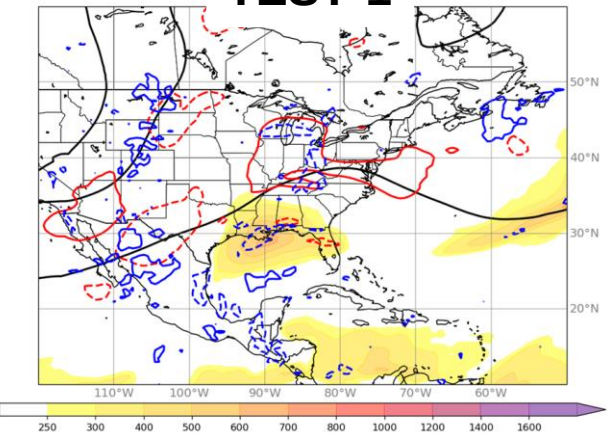




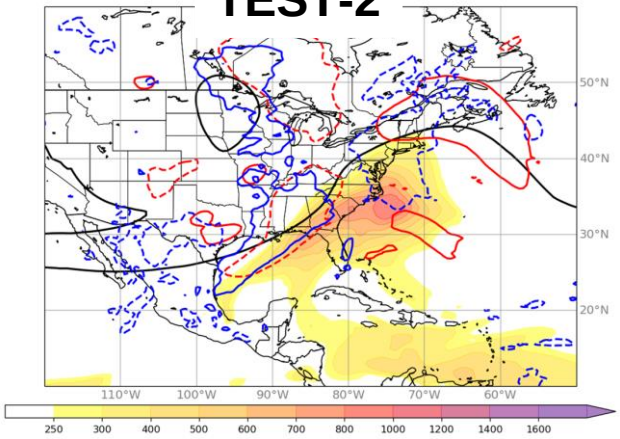


Summary plots - GEFS/CMC ensemble sensitivity products: TEST 1-6

TEST-1



TEST-2



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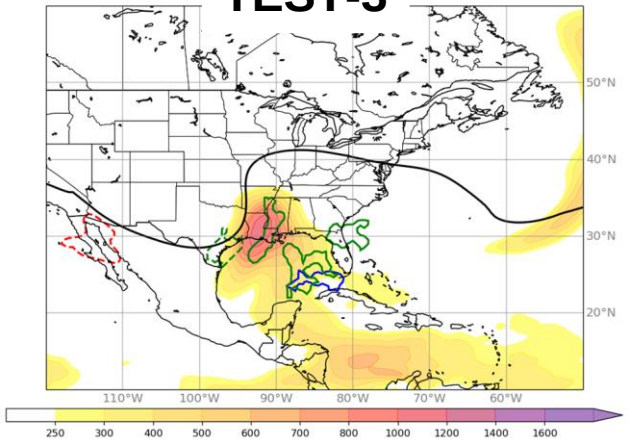
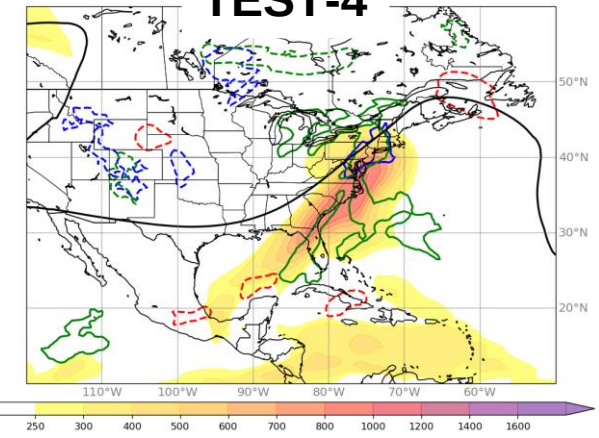
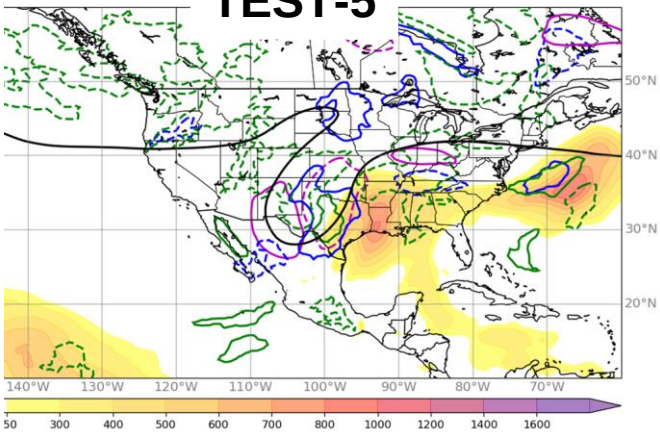


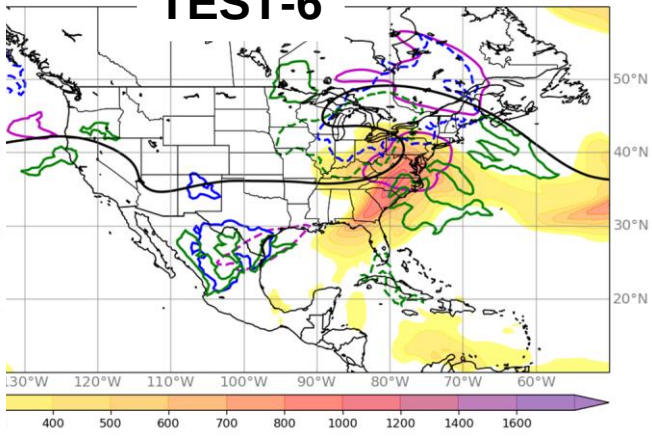
TEST-4



TEST-5



TEST-6



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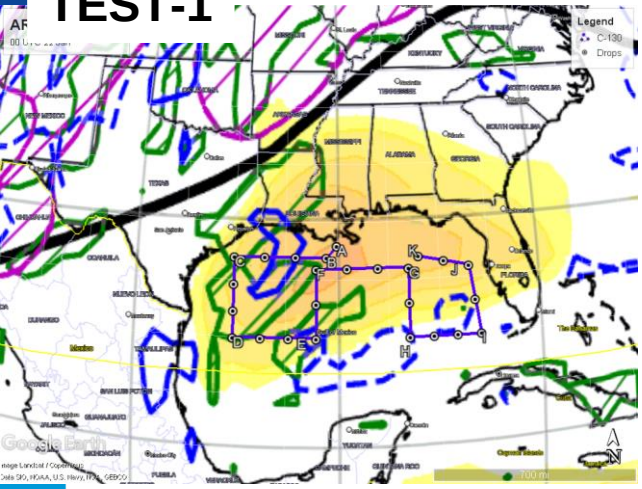

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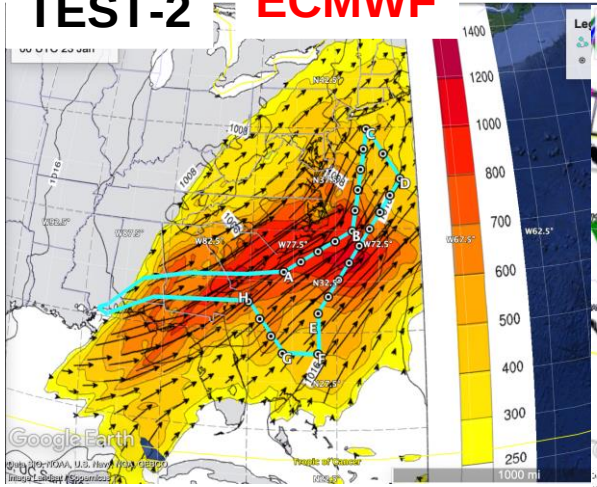

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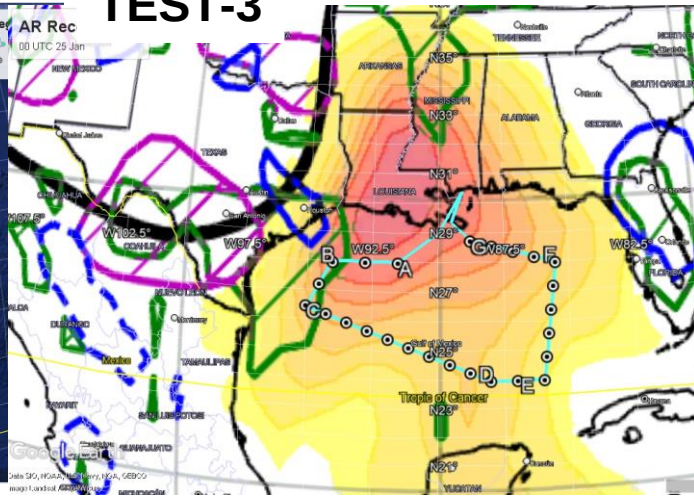

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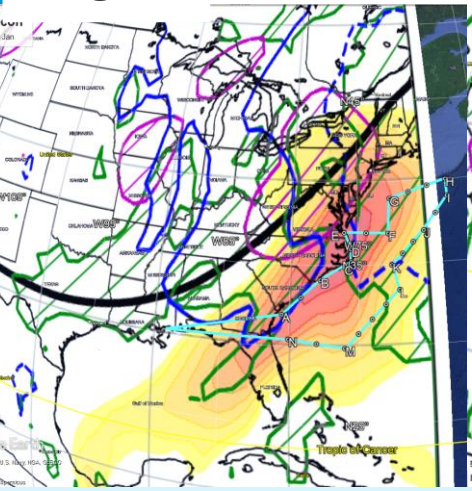

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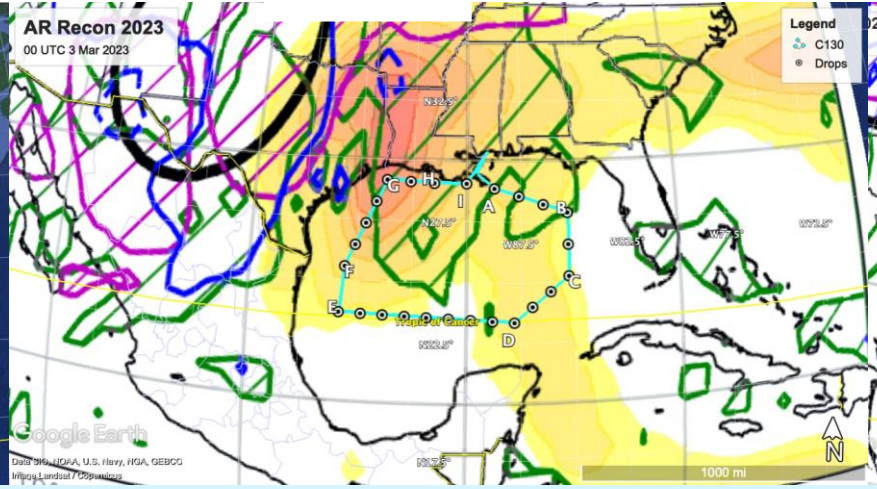
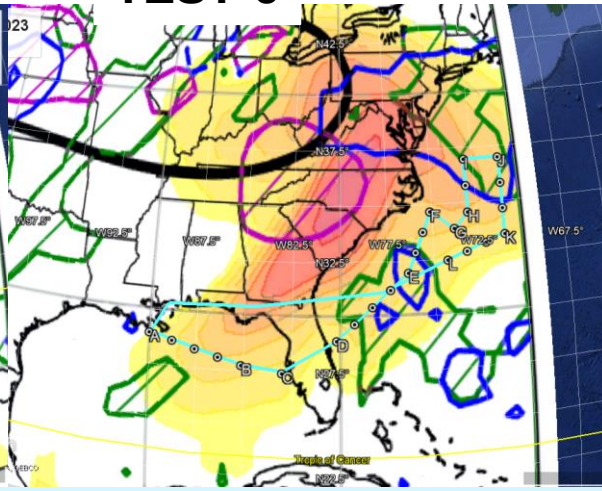
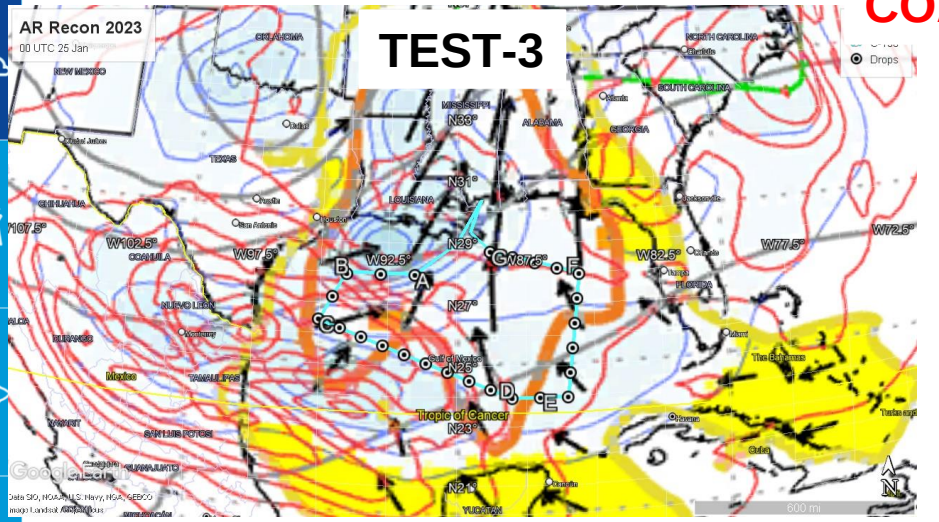
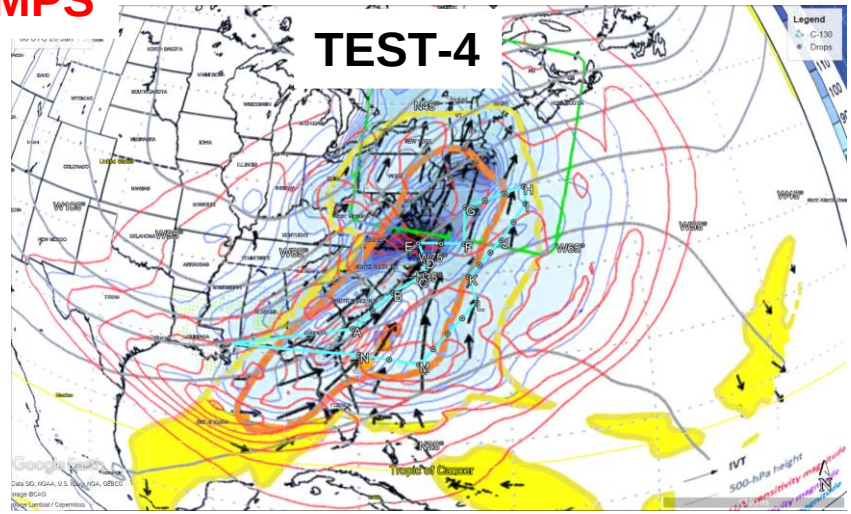


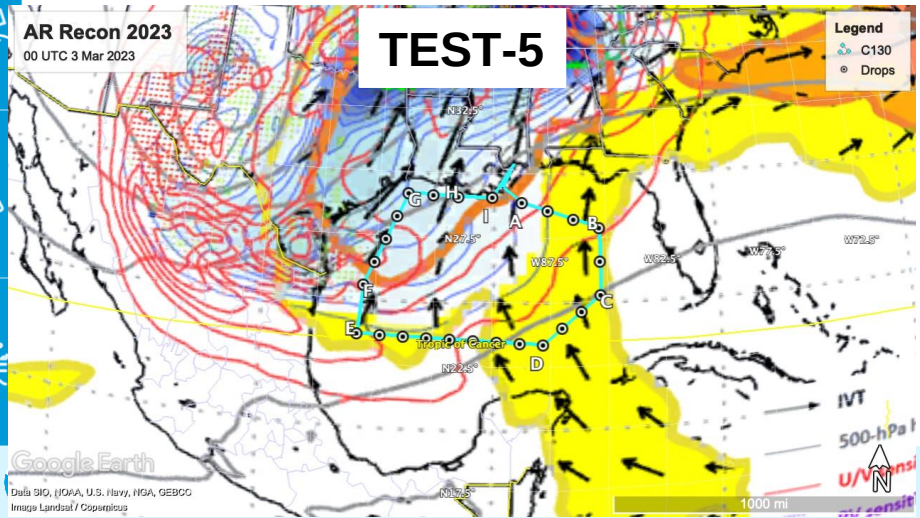
TEST-6

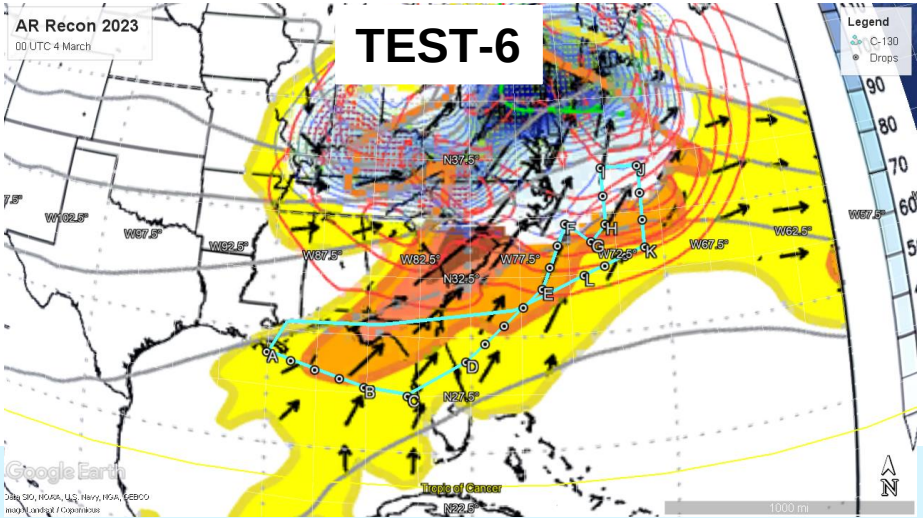


COAMPS


AR Recon 2023
00 UTC 25 Jan
TEST-3
Legend
C-130
Drops
Tropic of Cancer
Google Earth

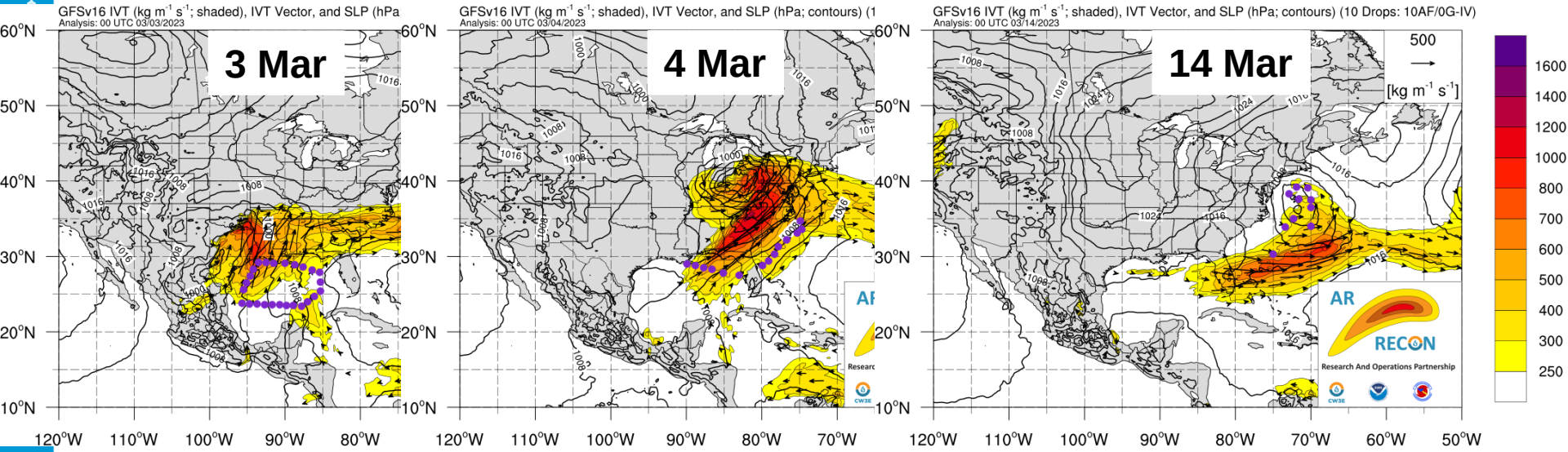

TEST-4
Legend
C-130
Drops
Tropic of Cancer
IVT
500-hPa height


AR Recon 2023
00 UTC 3 Mar 2023
TEST-5
Legend
C130
Drops
Tropic of Cancer
IVT
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
1000 mi


AR Recon 2023
00 UTC 4 March
TEST-6
Legend
C-130
Drops
Tropic of Cancer
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
1000 mi

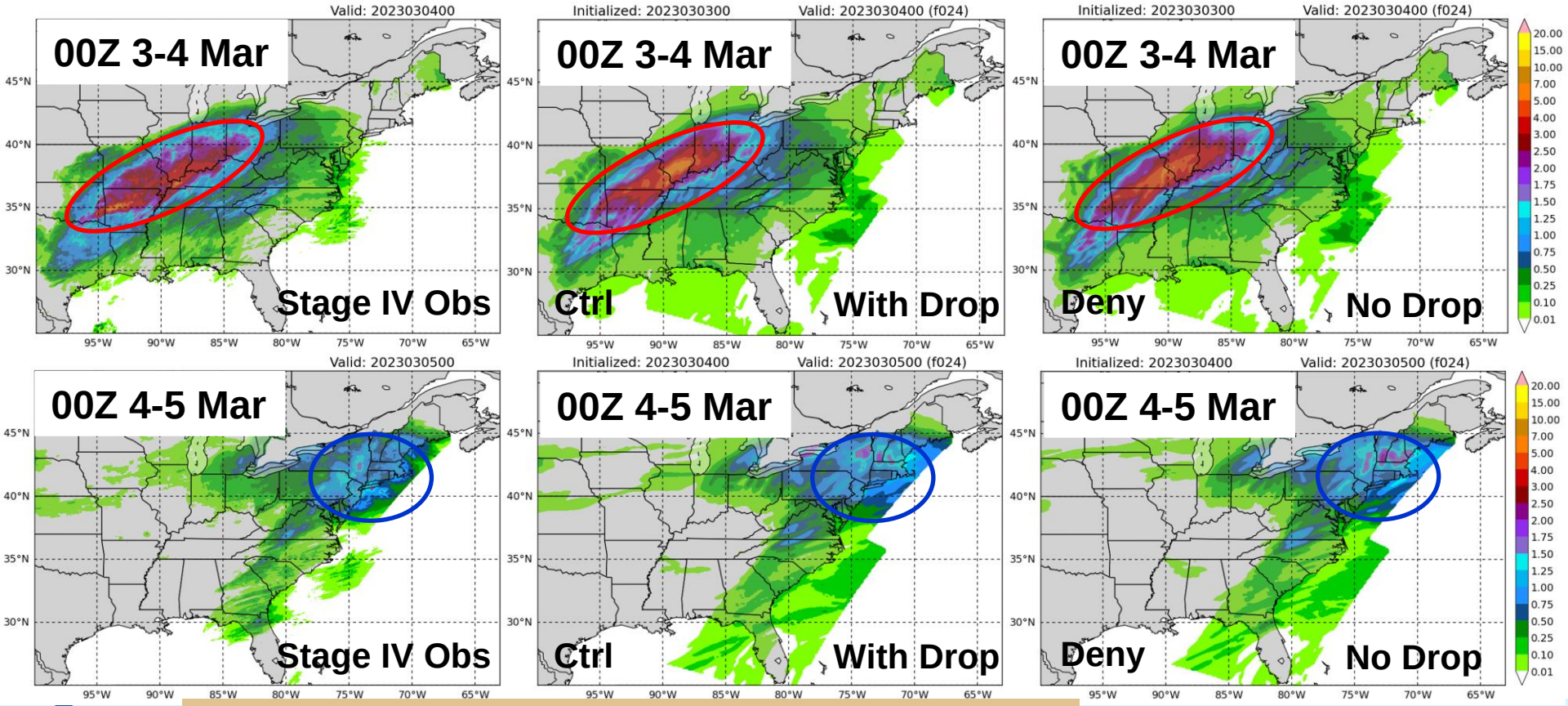
WSR Flights: Mar 3, 4, 14 (00 UTC), 2023

Based on two custom tracks (3 & 4 Mar) and one fixed track (14 Mar)



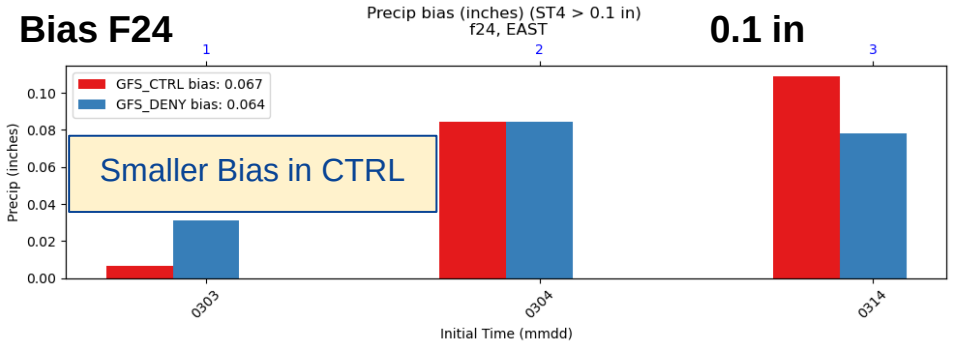
WSR Cases: TEST 5&6 (00Z 3/4 Mar)

GFS 24-hour forecast, verify at 00Z 4/5 Mar - 24-h total precipitation



Slightly improved forecast in Ctrl with dropsondes DA

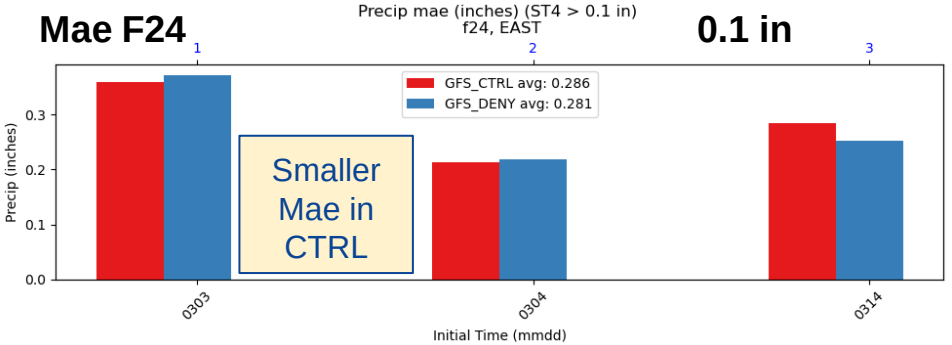
Bias F24



0.1 in

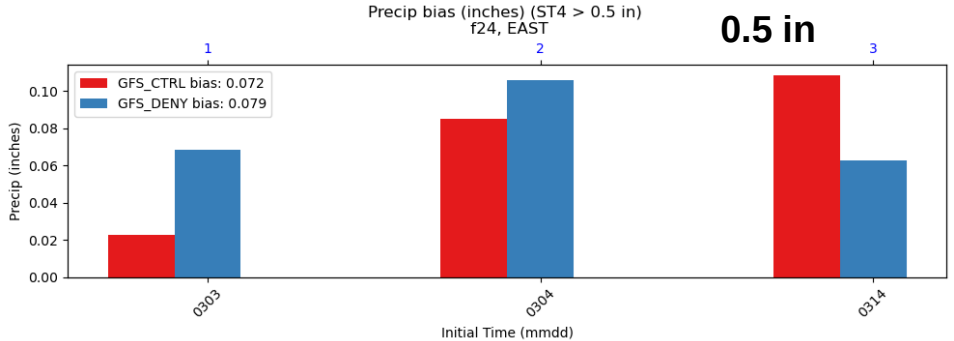
Smaller Bias in CTRL

Mae F24

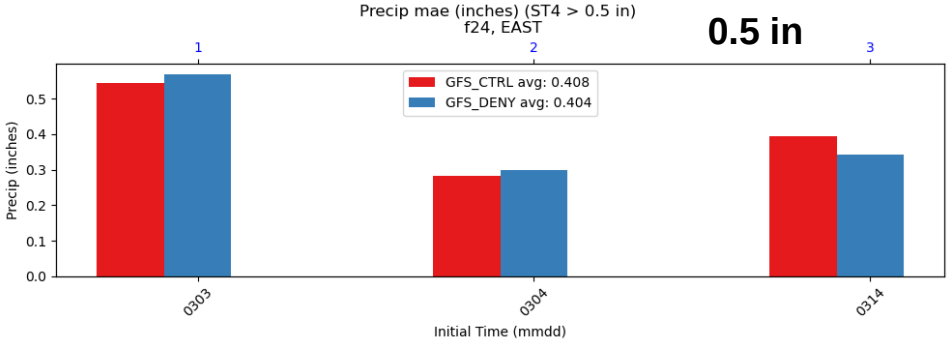


0.1 in

Smaller Mae in CTRL



0.5 in



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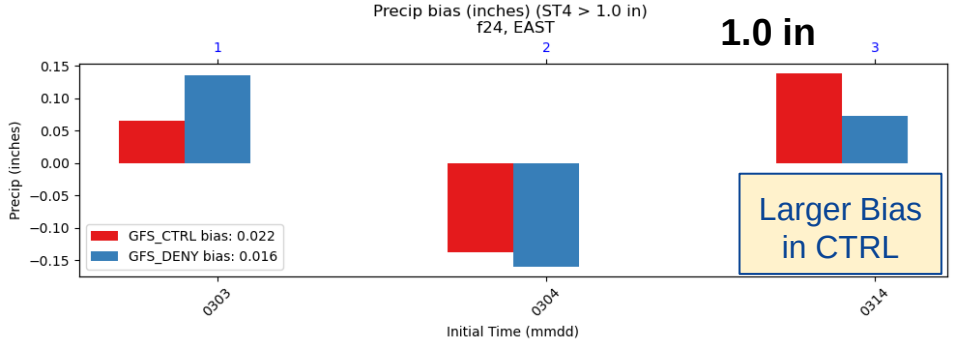
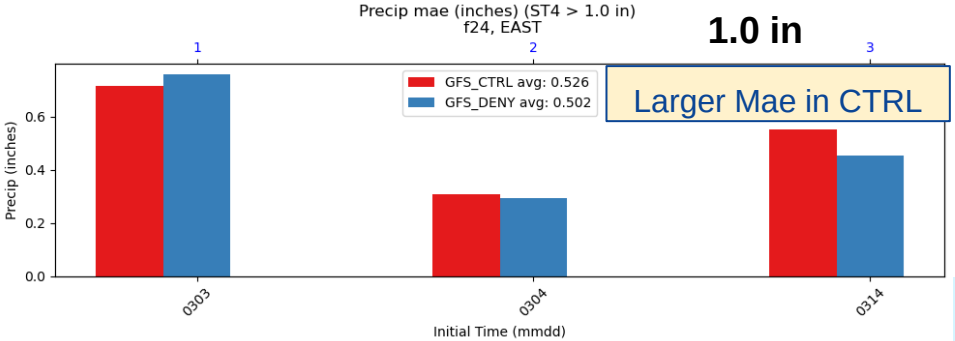


1.0 in

Larger Bias in CTRL



1.0 in

Larger Mae in CTRL

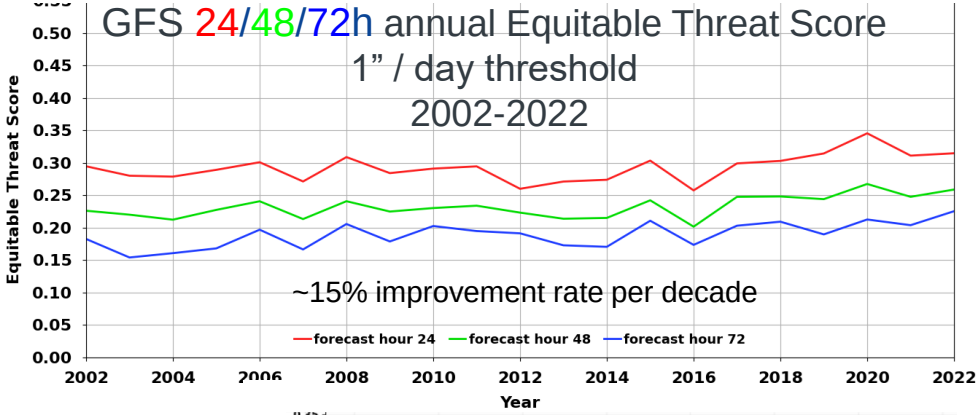
Operationalization of ARR/WSR Sensitivity Tools

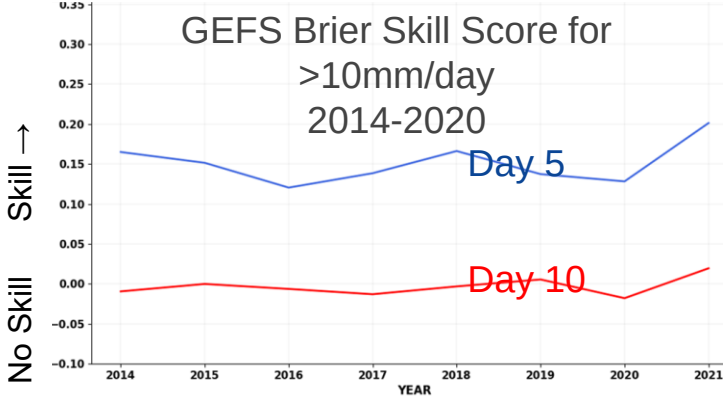
- **Ensemble Sensitivity for AR Recon**
  - ➢ https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/AR2023ens/
- **Ensemble Sensitivity for WSR Recon**
  - ➢ https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/WSR2023ens/

- ***Plan to make these tools operational, replacing existing legacy WSR tools for use by the SDMs by FY24. Will continue maintaining these tools experimentally, and will make further improvements based on emerging research on sampling strategies in collaboration with CW3E and partners.***
- ***Custom tracks should be developed interactively, based on the targeted system(s) and sensitivity tools, with an aim to sample areas of interest that can reduce the uncertainties and improve operational forecasts.***
- ***For WSR in the Atlantic and Gulf, leverage the forecasting team efforts from CW3E with shared responsibilities between CW3E, NWS WR, EMC, and potentially WPC, OPC, SPC and NWS ER could be explored.***

Precipitation Prediction Is Challenging!

Painfully slow improvement in past ....





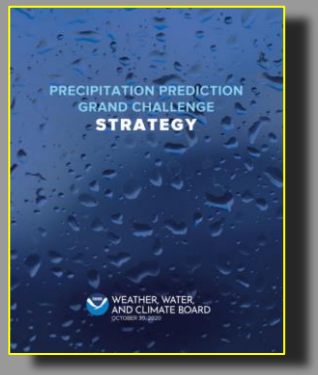
Priorities for Weather Research Report

"Unfortunately, precipitation forecast skill has not improved substantially over decades and remains one of the major technical challenges in atmospheric sciences.

Poor prediction skill for flood and drought has an inordinate impact on disadvantaged communities"

PPGC Strategic Goal:

Provide more accurate, reliable, and timely precipitation forecasts across timescales, from hours to decades, through the development and application of a seamless, fully coupled Earth System prediction model.

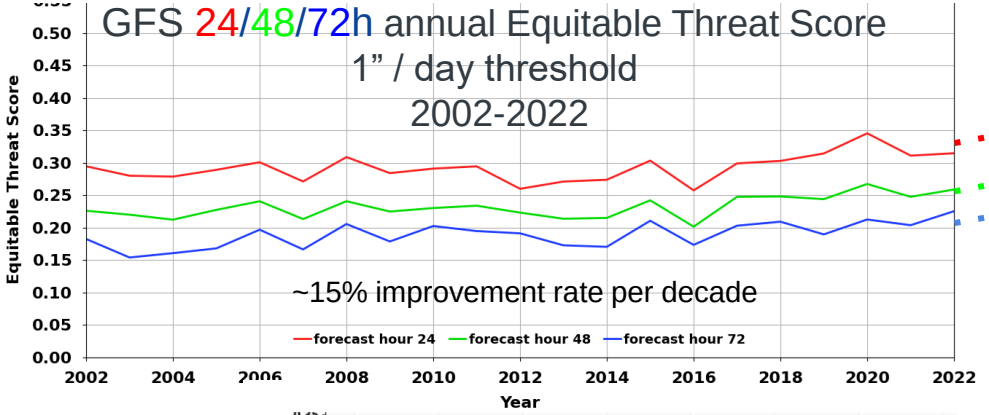


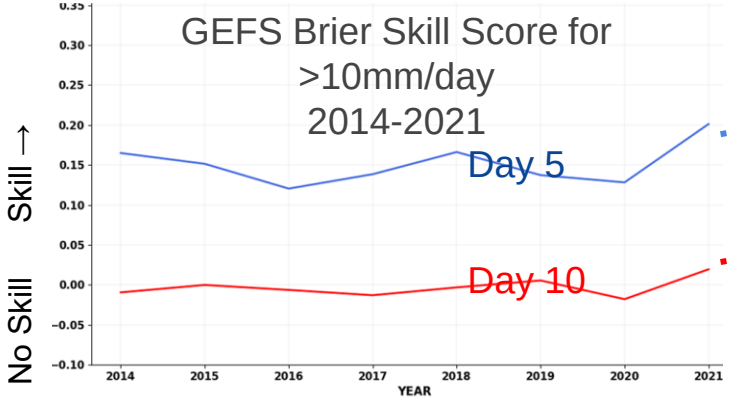
NOAA Precipitation Prediction Grand Challenge Strategy

6 Strategic Objectives:

OUTCOMES: Lead Time for Communities

Painfully slow improvement in past ....

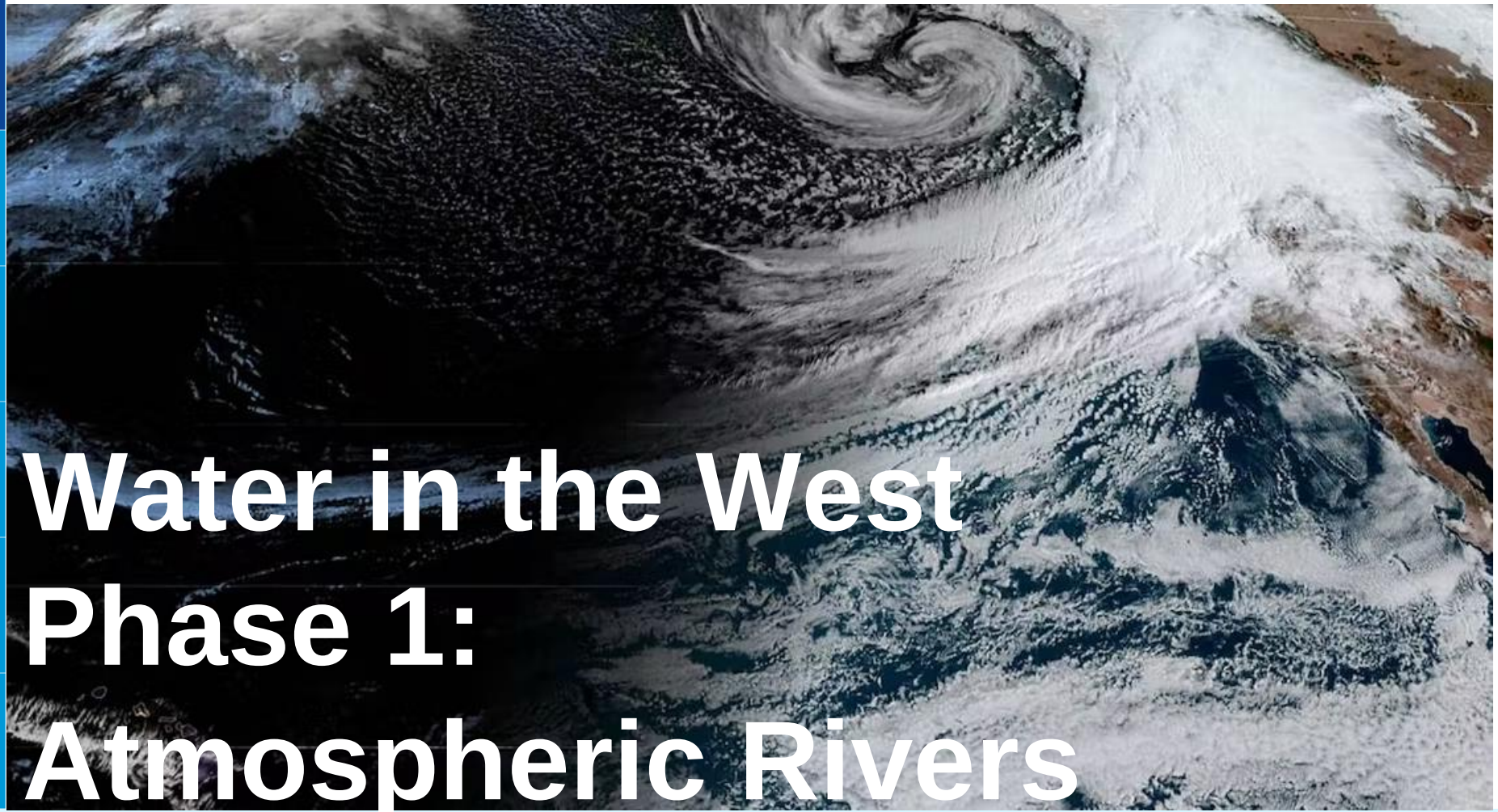




could be...

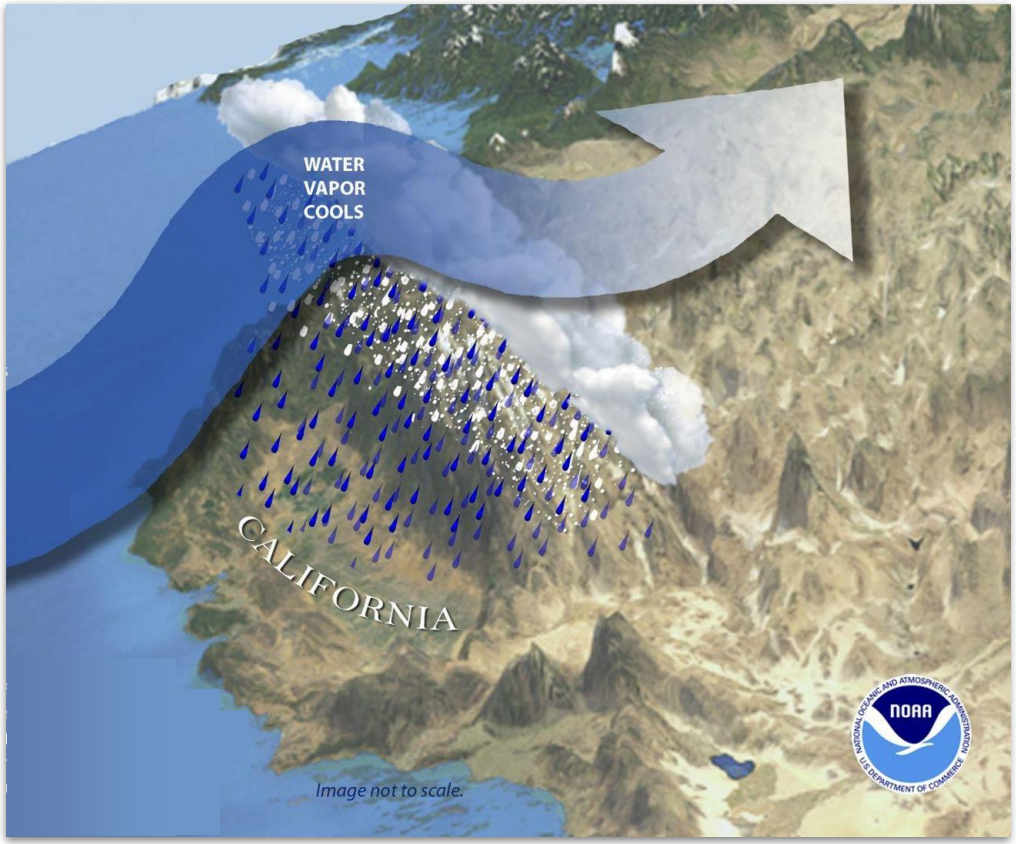
2030

★DOUBLE the historical rate of improvement, **adding 2 days of lead time for extreme precipitation events**



Water in the West Phase 1: Atmospheric Rivers

FY23 AR project objectives



- Create a prototype Atmospheric River Forecast System that improves upon current (non-operational) AR models
- Use the FY22–23 winter to test this and other AR models
- Apply social science to assess stakeholder AR forecast experiences

Project Timeline

Fall 2023

Create a baseline workflow and generate reforecasts

Spring 2024

Establish UFS-AR on AWS

Summer 2024

Testbed experiment with modelers and social scientists

Winter 2024

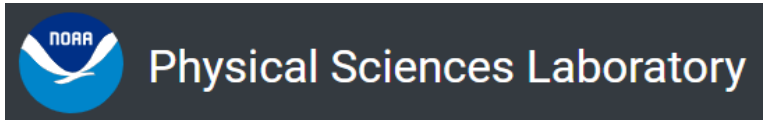
Submit model improvement recommendations

Spring 2025

Finalize UFS-AR prototype

Institutional collaboration

- Oceanic and Atmospheric Research
  - PSL: Experimental design
  - PSL/GSL: Modeling and Data Assimilation
  - WPO: Management, EPIC and SBES
  - GFDL - In-kind
- National Weather Service
  - EMC: Modeling
  - WPC: Testbed
  - OWP: CIROH grants on snow modeling in the NG-NWM
- NESDIS: NCAI (in-kind)
- Scripps CW3E: Boundary layer testing/improvement

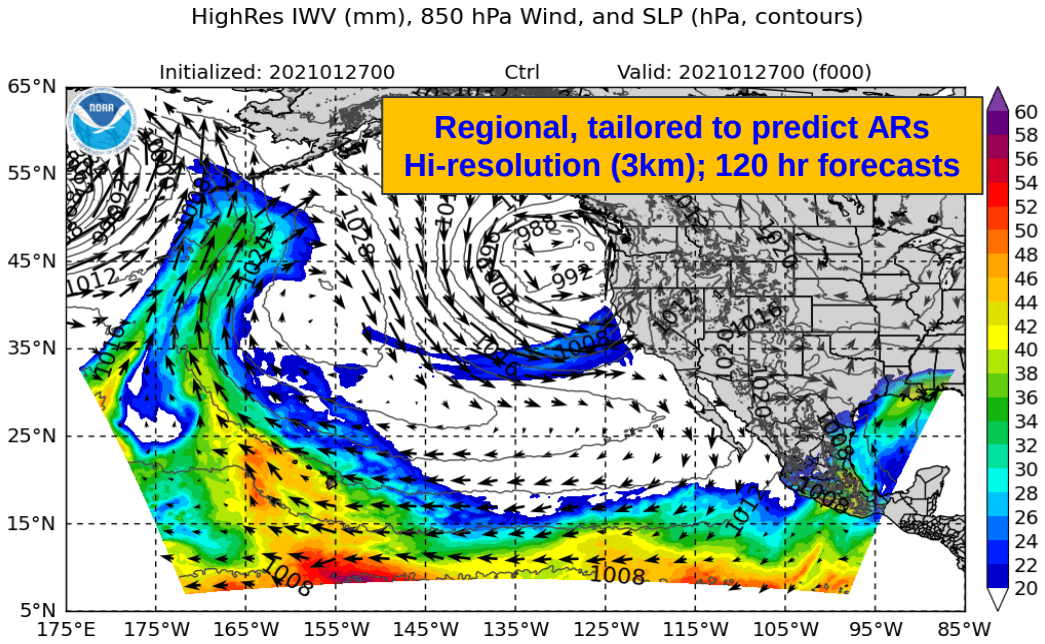


CW3E

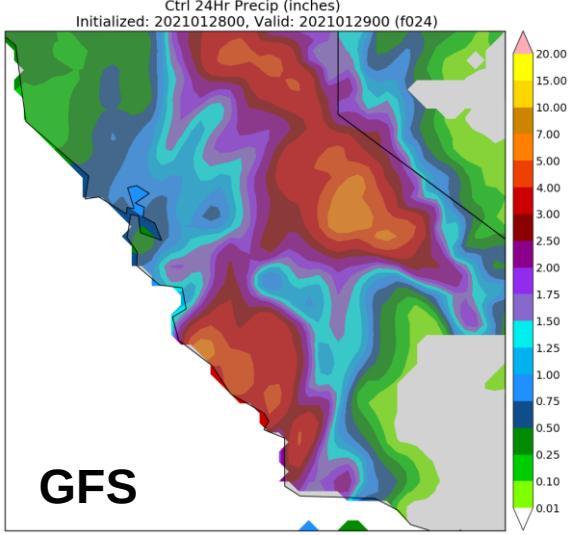
Part II

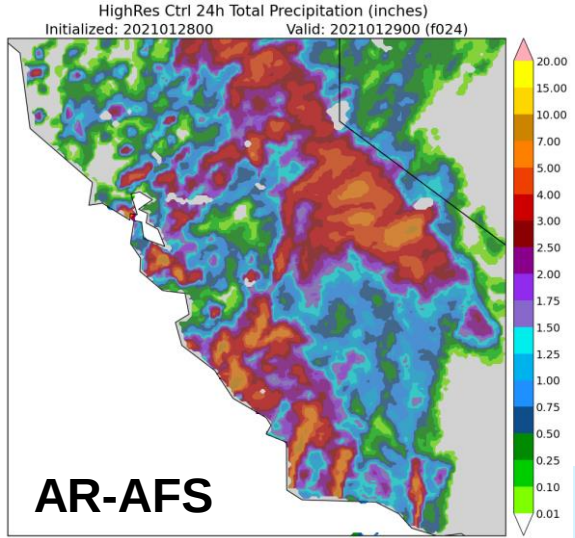
High Resolution UFS Regional Model for Atmospheric Rivers

Designed in partnership with CW3E
builds on lessons from CW3E's West-WRF model

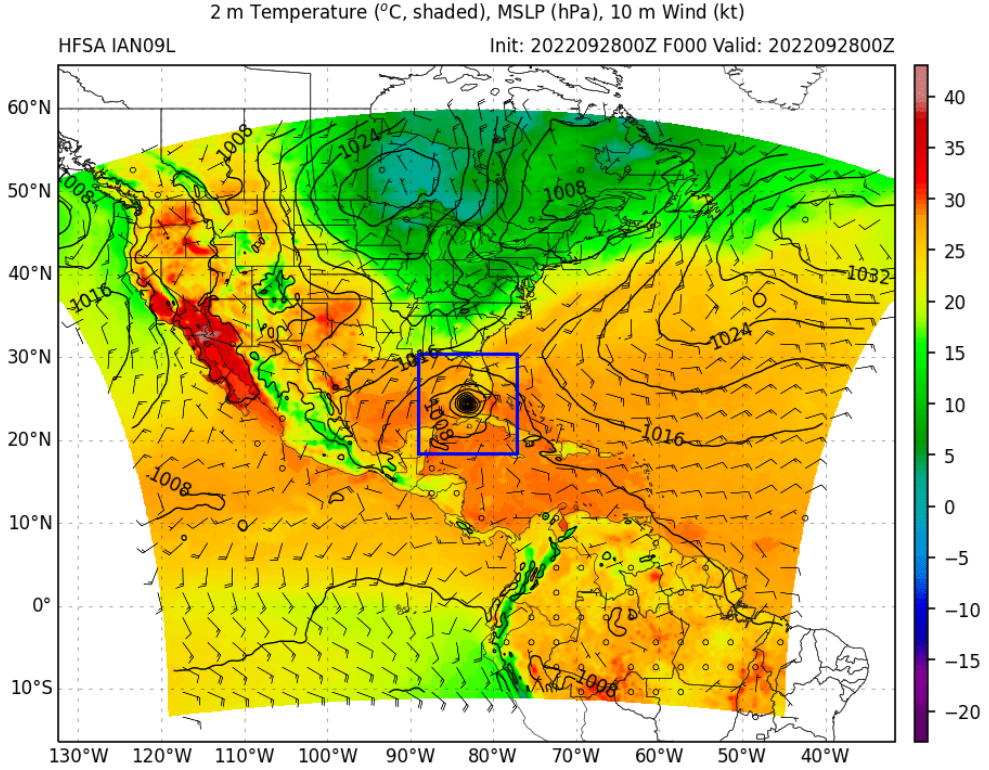


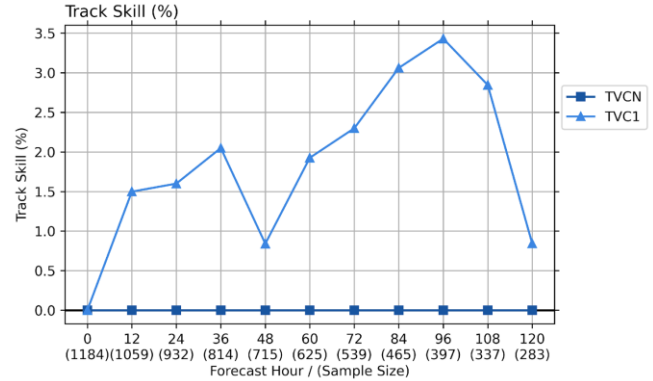
24-h precipitaion forecasts

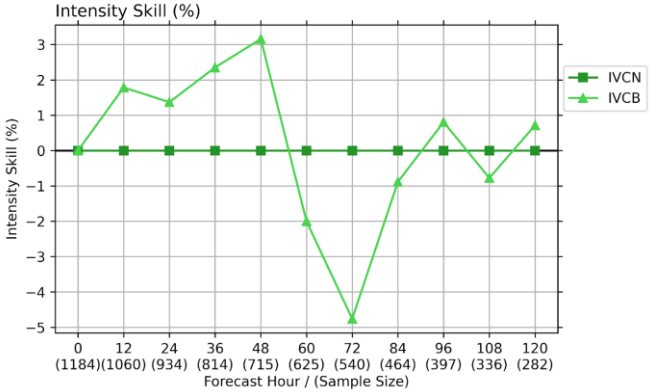




Inspired by HAFSv1 Implemented into operations on June 27, 2023







F. Martin Ralph (UCSD/SIO/CW3E) - PI
Vijay Tallapragada (NWS/NCEP) - Co-PI
Anna Wilson (UCSD/SIO/CW3E) - Coordinator

AR RECON
Research And Operations Partnership

Thanks for your Attention.

Questions?