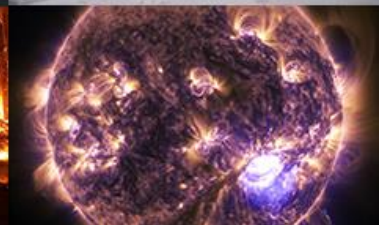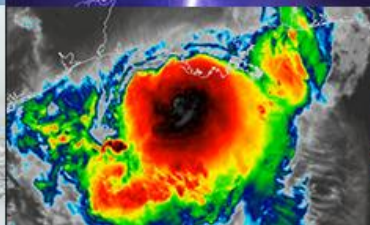# Impact of Dropsonde Data on NCEP operational GFS Forecasts from 2022-2023 Atmospheric River Reconnaissance

Xingren Wu[1], Keqin Wu[2], Vijay Tallapragada[3], and Marty Ralph[4]
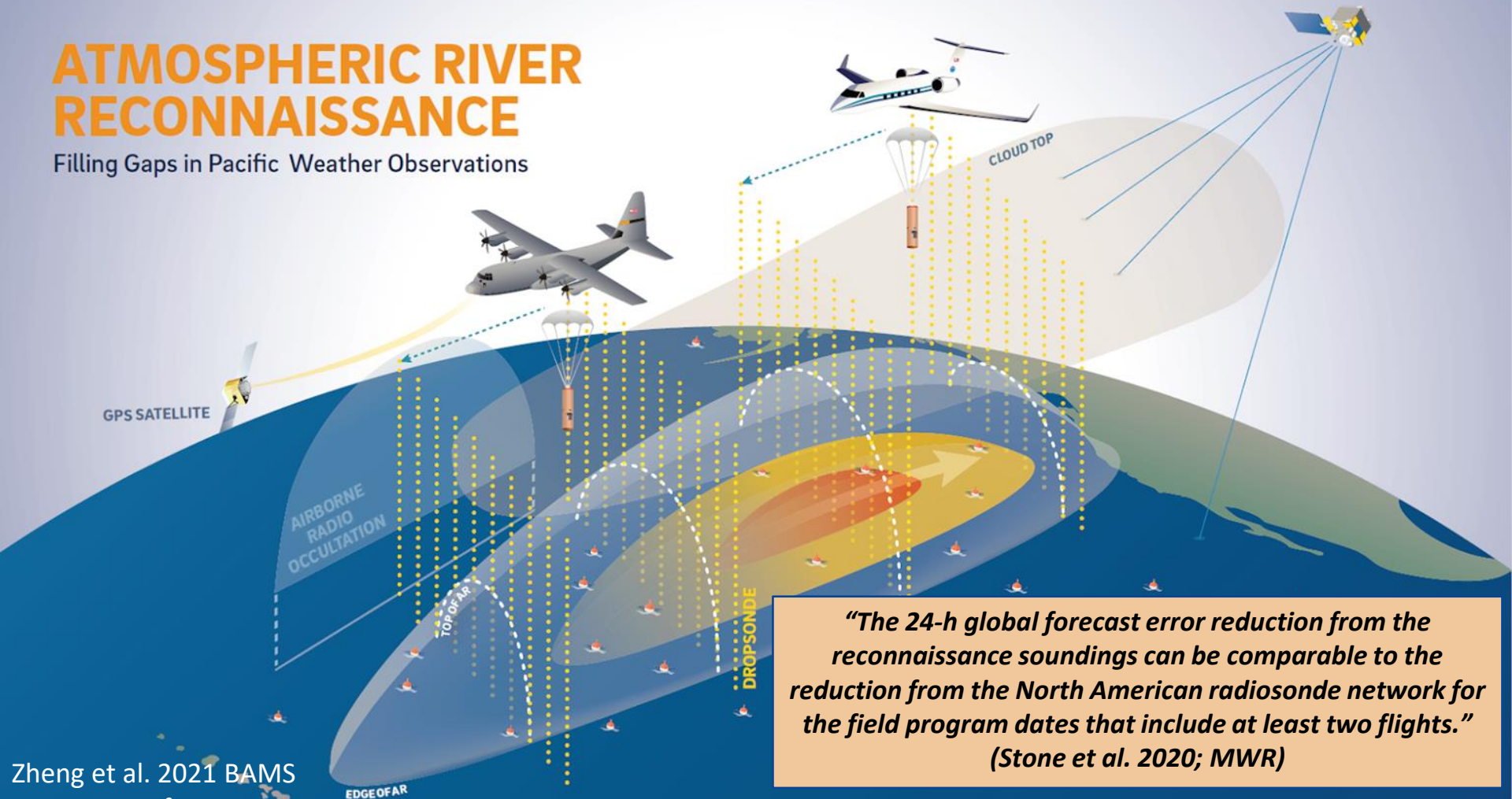
[1]Axiom@NOAA/NWS/NCEP/EMC, [2]Lynker@NOAA/NWS/NCEP/EMC, [3]NOAA/NWS/NCEP/EMC, [4]CW3E, Scripps Institution of Oceanography, UC San Diego

AR Recon Workshop 6/28/2023

NATIONAL WEATHER SERVICE

ATMOSPHERIC RIVER RECONNAISSANCE

Filling Gaps in Pacific Weather Observations

CLOUD TOP

GPS SATELLITE

AIRBORNE RADIO OCCULTATION

TOP OF AR

DROPSONDE

EDGE OF AR

"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)
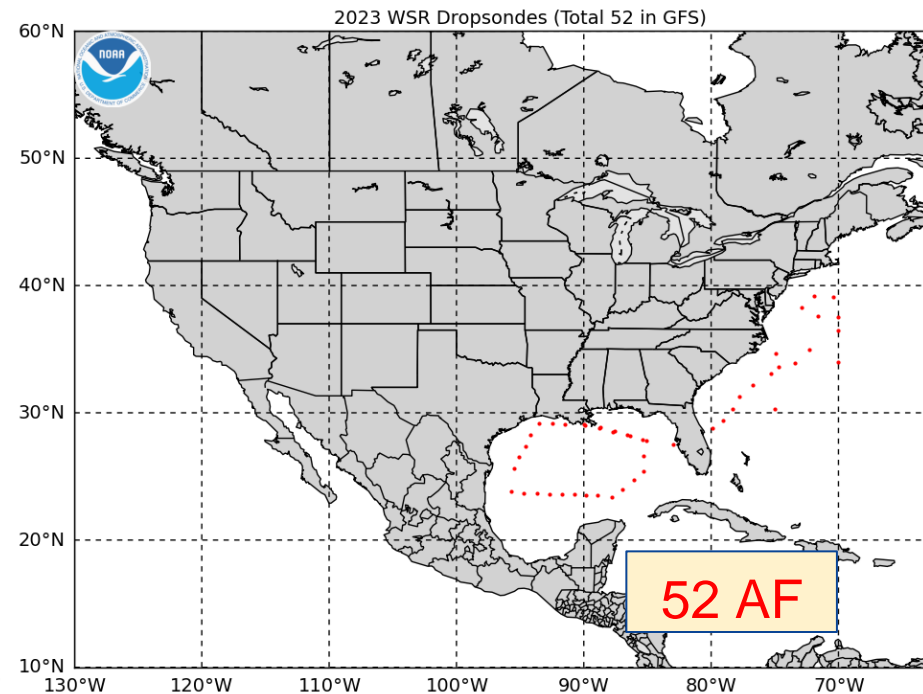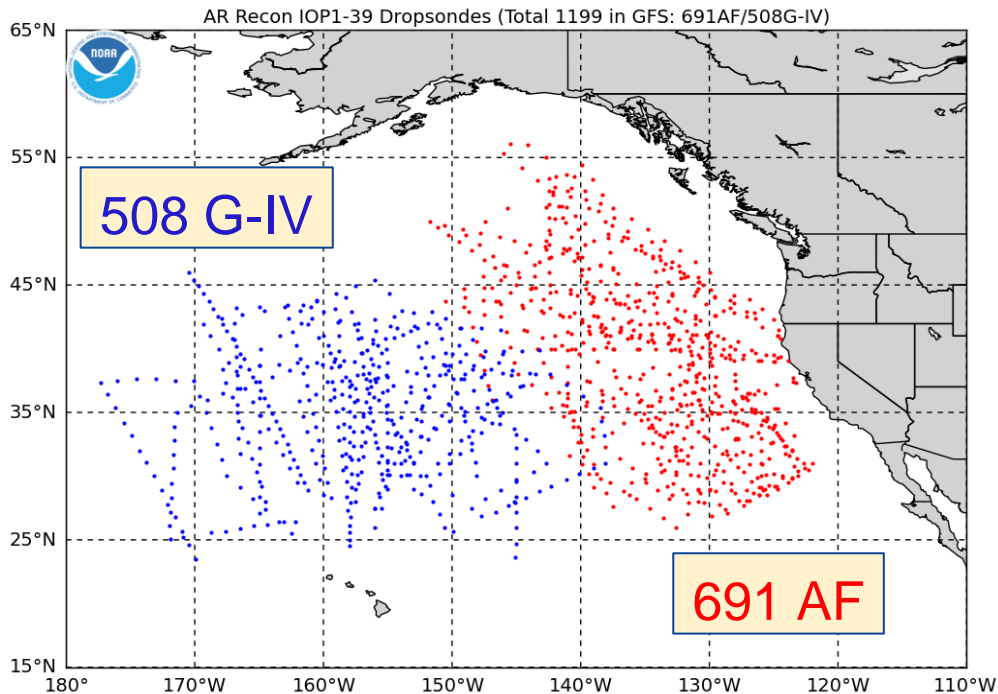
Zheng et al. 2021 BAMS
BAMS cover figure in 2021

F. M. Ralph, M. Zheng, 2021 (CW3E at UC San Diego Scripps Institution of Oceanography)

AR Recon Campaign 2022-2023
39 AR IOPs (5 Nov 2022 – 14 Mar 2023)
First (longest) AR Sequence: 13 IOPs (6-18 Jan 2023)
3 WSR IOPs (3, 4, 14 Mar 2023)

AR Recon IOP1-39 Dropsondes (Total 1199 in GFS: 691AF/508G-IV)

508 G-IV

691 AF

2023 WSR Dropsondes (Total 52 in GFS)

52 AF

Operational goals for AR Recon at NCEP

- Overarching goal: improve operational predictions of land-falling atmospheric rivers and their impacts in the western U.S.

- 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

Near Real-Time Data Deny Experiments with GFSv16.3.5

- ARR 2022-2023 season: Starting from Nov 5, 2022
- ARR near real-time data denial: Starting from Jan 6, 2023
  - CTRL – GFS operation, assimilate dropsonde and HDOBs data
  - DENY – the same setting as GFS operation, but deny dropsonde and HDOBs data

GFSv16: Forecast Model & Data Assimilation
(Mar 22 2021)

Model resolution:

127 vertical layers with model top of 80 km

Physics updates:

PBL/turbulence: sa-TKE-EDMF (Revised background diffusivity as a stability dependent function)

Radiation: Updated calculation of solar radiation absorption by water clouds; Updated cloud overlap assumptions.

Microphysics: Updated GFDL microphysics scheme for computing ice cloud effective radius

GDAS

- Local Ensemble Kalman Filter (LETKF): with model space localization and linearized observation operator to replace the Ensemble Square Root Filter (EnSRF)

- 4-Dimensional Incremental Analysis Update (4D-IAU)

- New variational QC

- Assimilate AMSU-A channel 14 and ATMS channel 15 w/o bias correction

- HDOBs: Assimilate high-density flight-level wind, temperature, and moisture observations (HDOBs) in tropical storm environment (first time in operations for GFS)

# GFSv16.3.5: Forecast Model & Data Assimilation
(Most recent update: Jan 4, 2023)

- GFS Post Processing system upgrades
- **FV3 model physics upgrade** in the Noah Land Surface Model
- **Grid-point Statistics Interpolation (GSI) Analysis** - Enhance the use of observations, add new data, improve the near sea surface temperature (NSST) analysis, and bug fixes.
- **Data assimilation upgrade related to GOES-18 and VIIRS**
- ➢ Continued use of atmospheric motion vectors from the GOES-West satellite as GOES-18 replaces GOES-17 and to include the assimilation of VIIRS (Visible Infrared Imaging Radiometer Suite) radiances from S-NPP (Suomi National Polar-orbiting Partnership) and NOAA-20

AR Recon Dropsonde Obs Counts

AR 2021
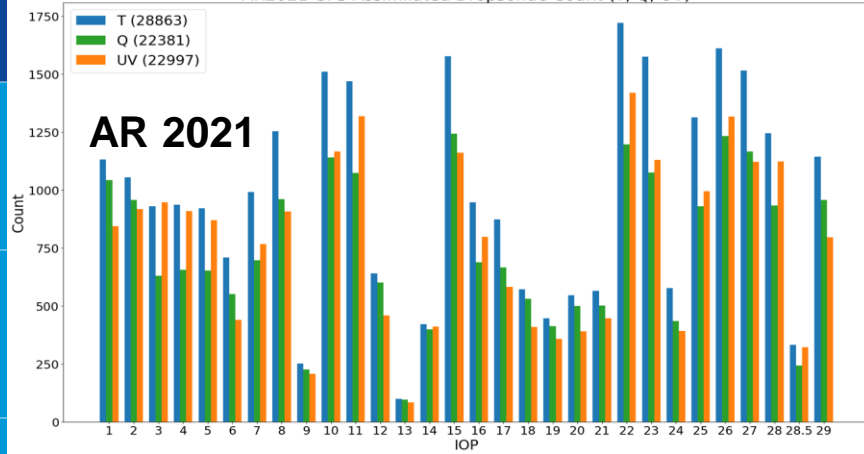
AR 2022

AR & WSR 2023
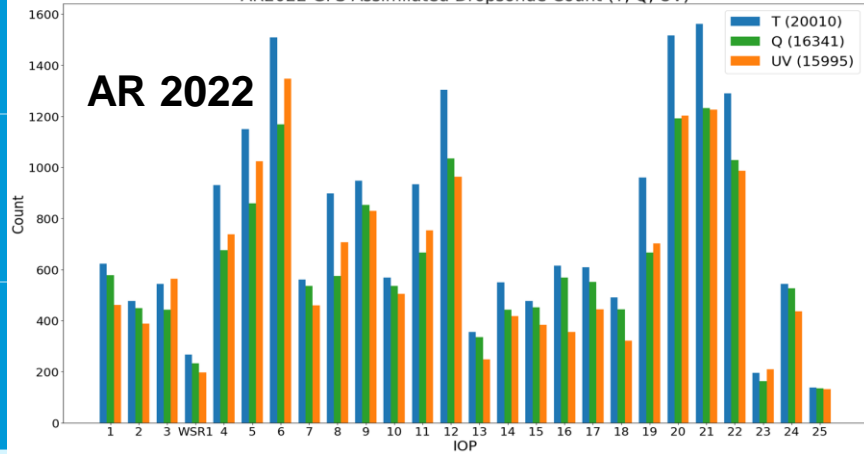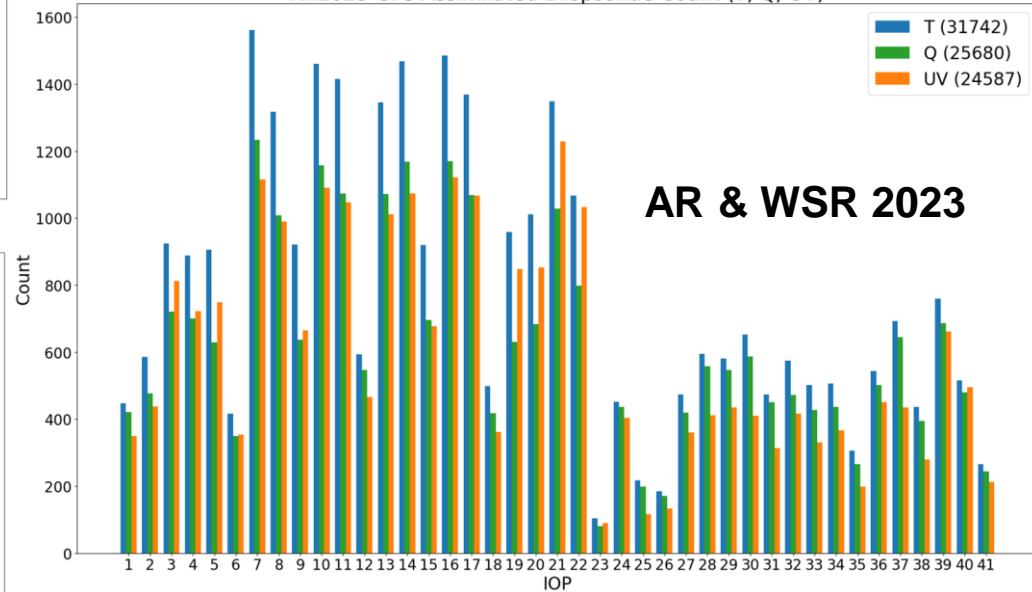
GFS DA with Dropsondes data
Mean of (A-O) and (B-O) for T, Q and UV during Jan 6 and Mar 14 from GFS
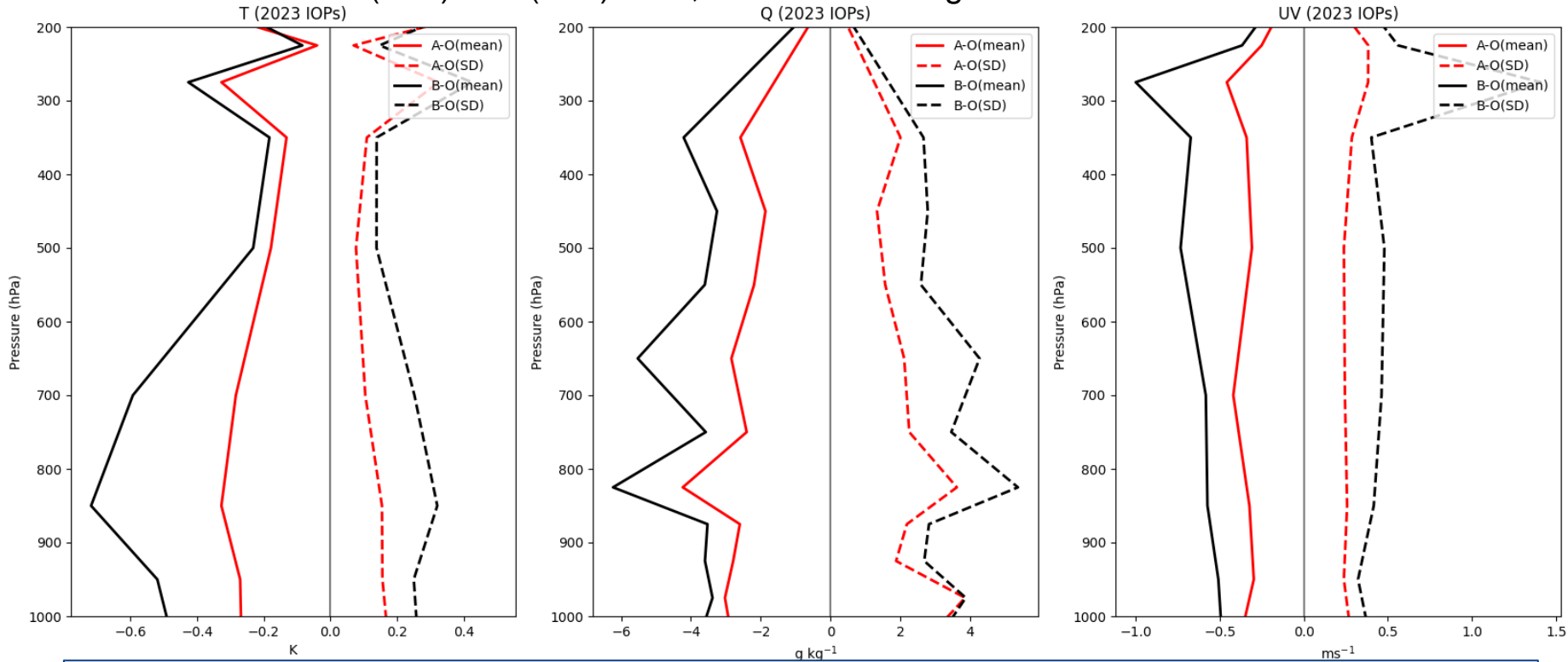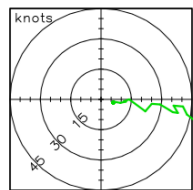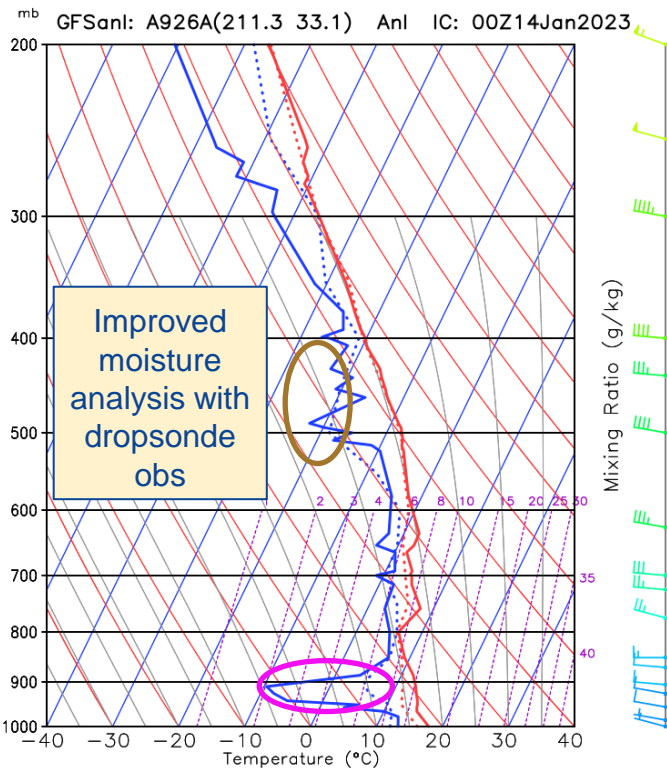

Improved analysis in T/Q/UV with dropsonde obs

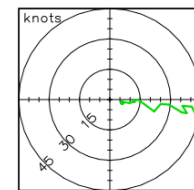# Ctrl: GFS Anl with dropsonde 00Z 14 Jan (211.3E 33.1N)

Deny: GFS Anl without dropsonde 00Z 14 Jan (211.3E 33.1N)

Improved moisture analysis with dropsonde obs
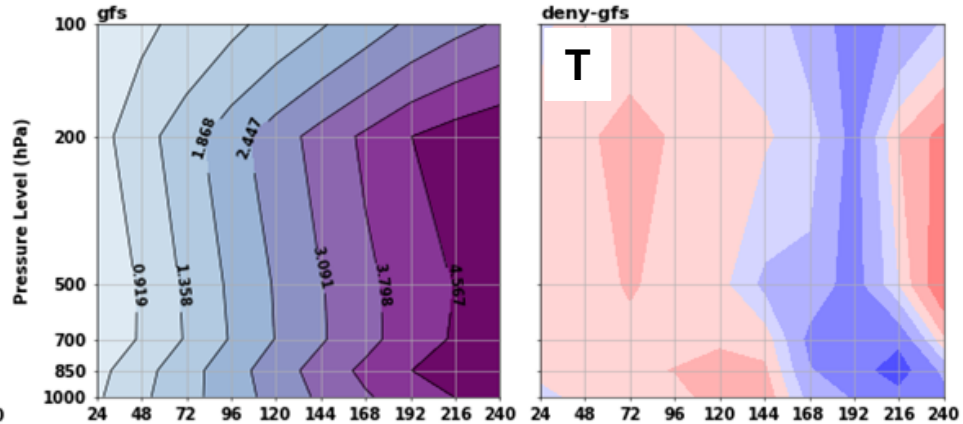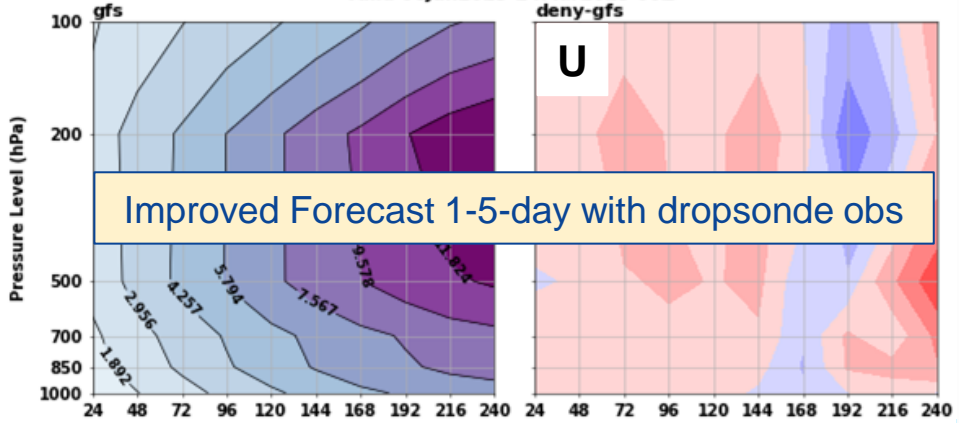
Model forecast issue

Root Mean Square Error
Geopotential Height (gpm), Pacific North America
valid 06Jan2023-24Mar2023 00Z
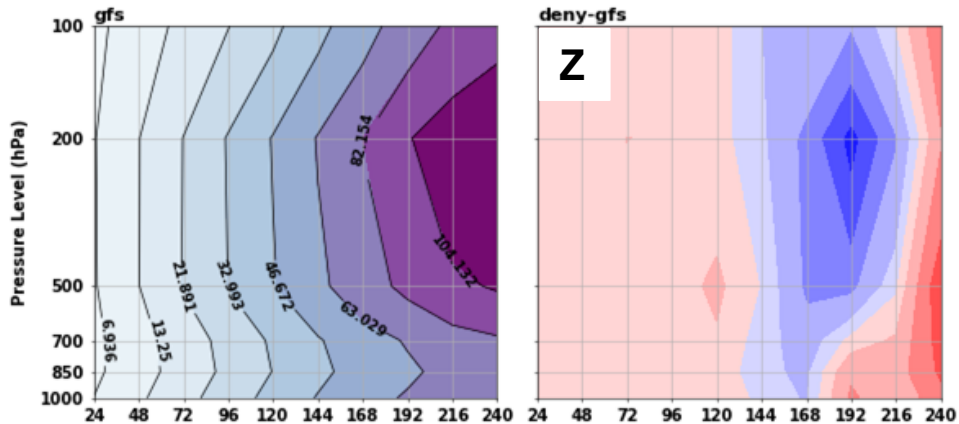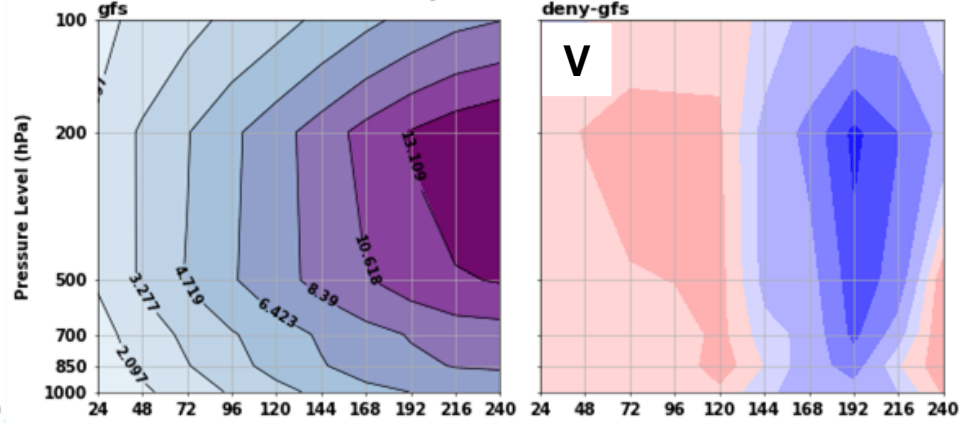
Root Mean Square Error
Temperature (K), Pacific North America
valid 06Jan2023-24Mar2023 00Z

Root Mean Square Error
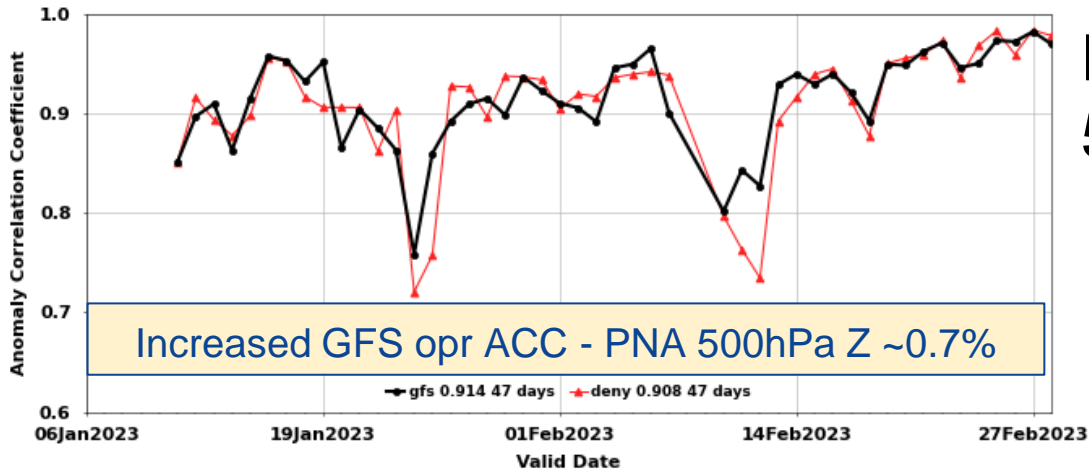Zonal Wind (m s^{-1}), Pacific North America
valid 06Jan2023-24Mar2023 00Z

Root Mean Square Error
Meridional Wind (m s^{-1}), Pacific North America
valid 06Jan2023-24Mar2023 00Z
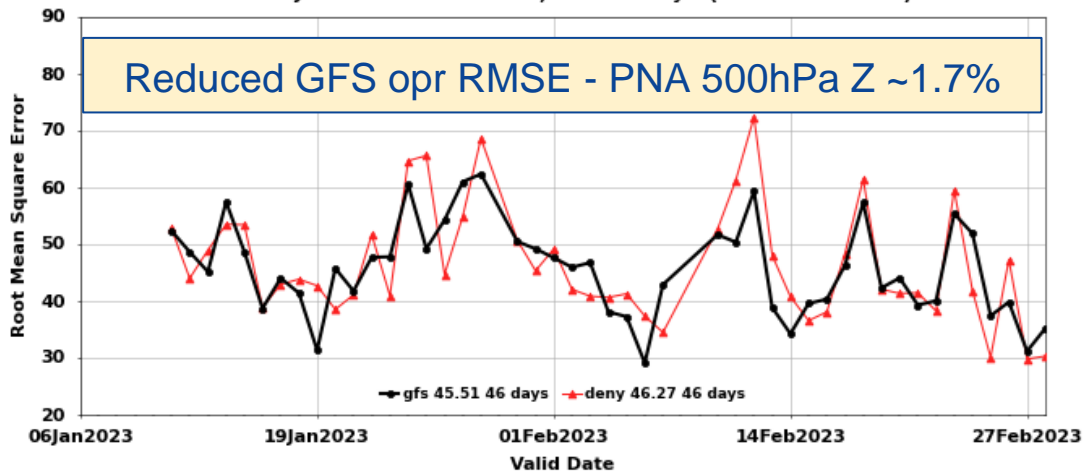
Improved Forecast 1-5-day with dropsonde obs

PNA 120-h ACC
500 hPa Z (0.914/0.908)

PNA 120-h RMSE
500 hPa Z (45.51/46.27)

PNA RMSE Temp
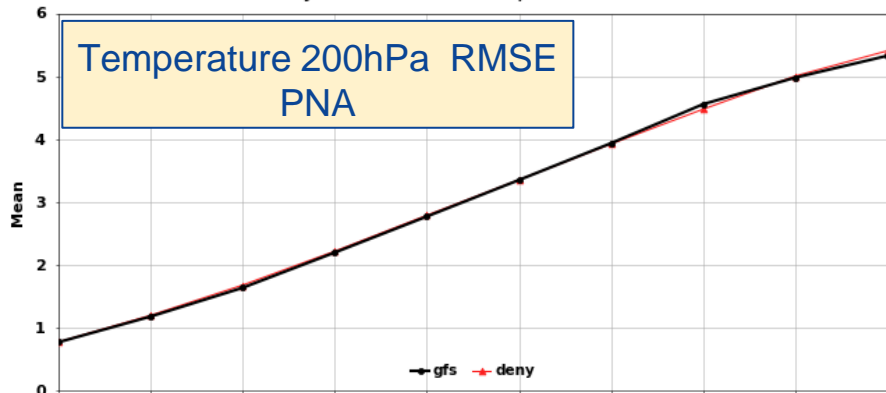
PNA RMSE Wind

Root Mean Square Error
200 hPa Temperature (K), Pacific North America
valid 06Jan2023-24Mar2023 00Z, forecast hour means

Temperature 200hPa RMSE
PNA

Improved Forecast 1-5-day
with dropsonde obs

Root Mean Square Error
200 hPa Vector Wind (m s^{-1}), Pacific North America
valid 06Jan2023-24Mar2023 00Z, forecast hour means

Wind 200hPa RMSE
PNA

Improved Forecast 1-5-day
with dropsonde obs

Root Mean Square Error
200 hPa Temperature (K), Pacific North America
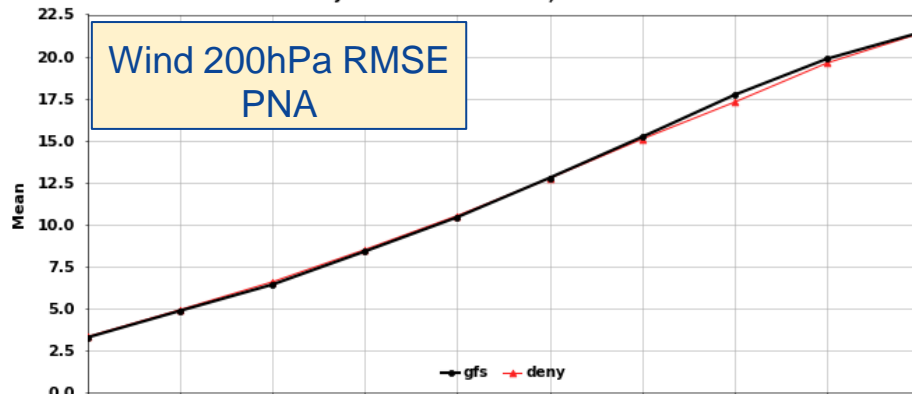valid 06Jan2023-24Mar2023 00Z, Forecast Day 3 (Forecast Hour 72)

2.5% difference

gfs 1.644 71 days   deny 1.685 71 days
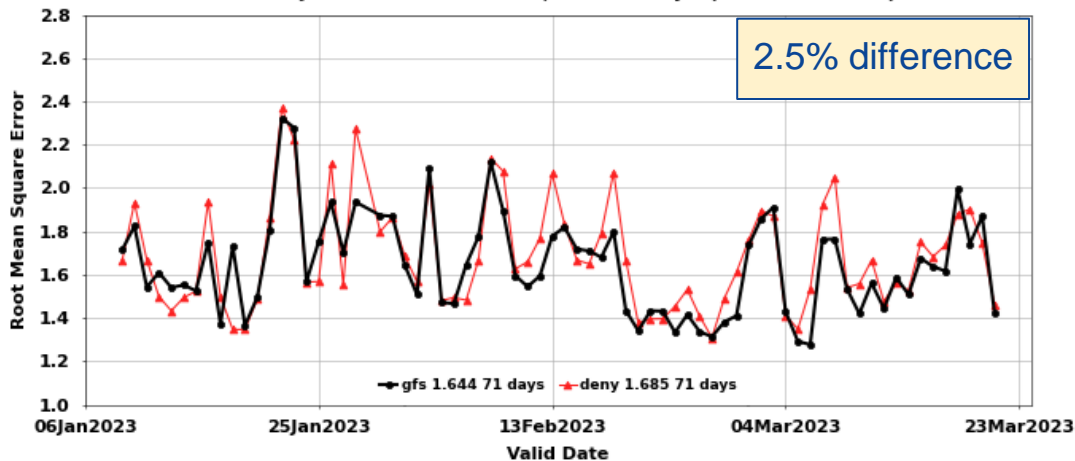
PNA 72-h RMSE
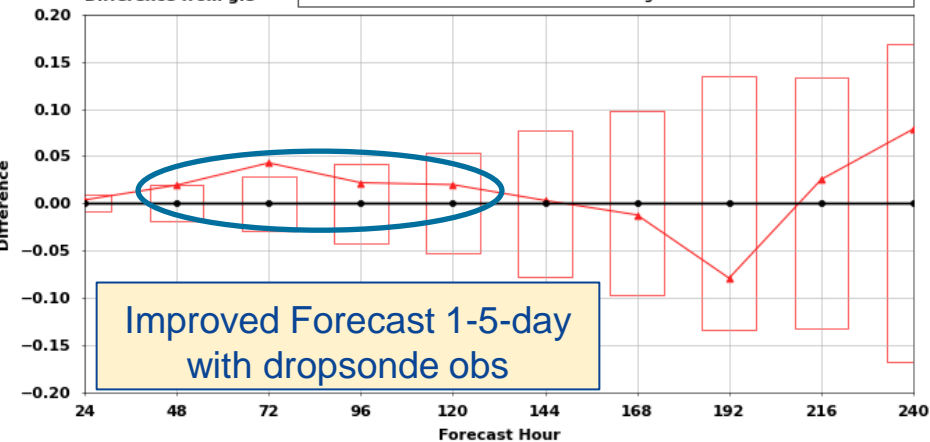Temp 200 hPa

Improved Forecast with dropsonde obs

PNA 72-h RMSE
Wind 200 hPa

Root Mean Square Error
200 hPa Vector Wind (m s^{-1}), Pacific North America
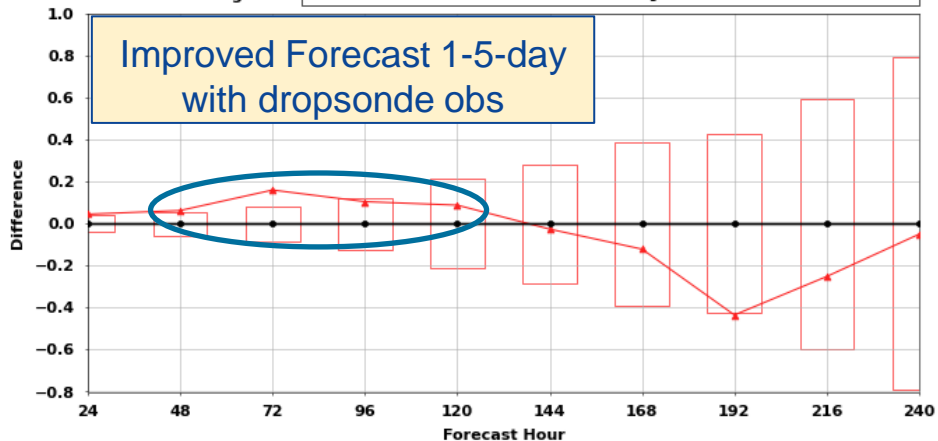valid 06Jan2023-24Mar2023 00Z, Forecast Day 3 (Forecast Hour 72)

2.6% difference

gfs 6.407 71 days   deny 6.571 71 days

NATIONAL WEATHER SERVICE
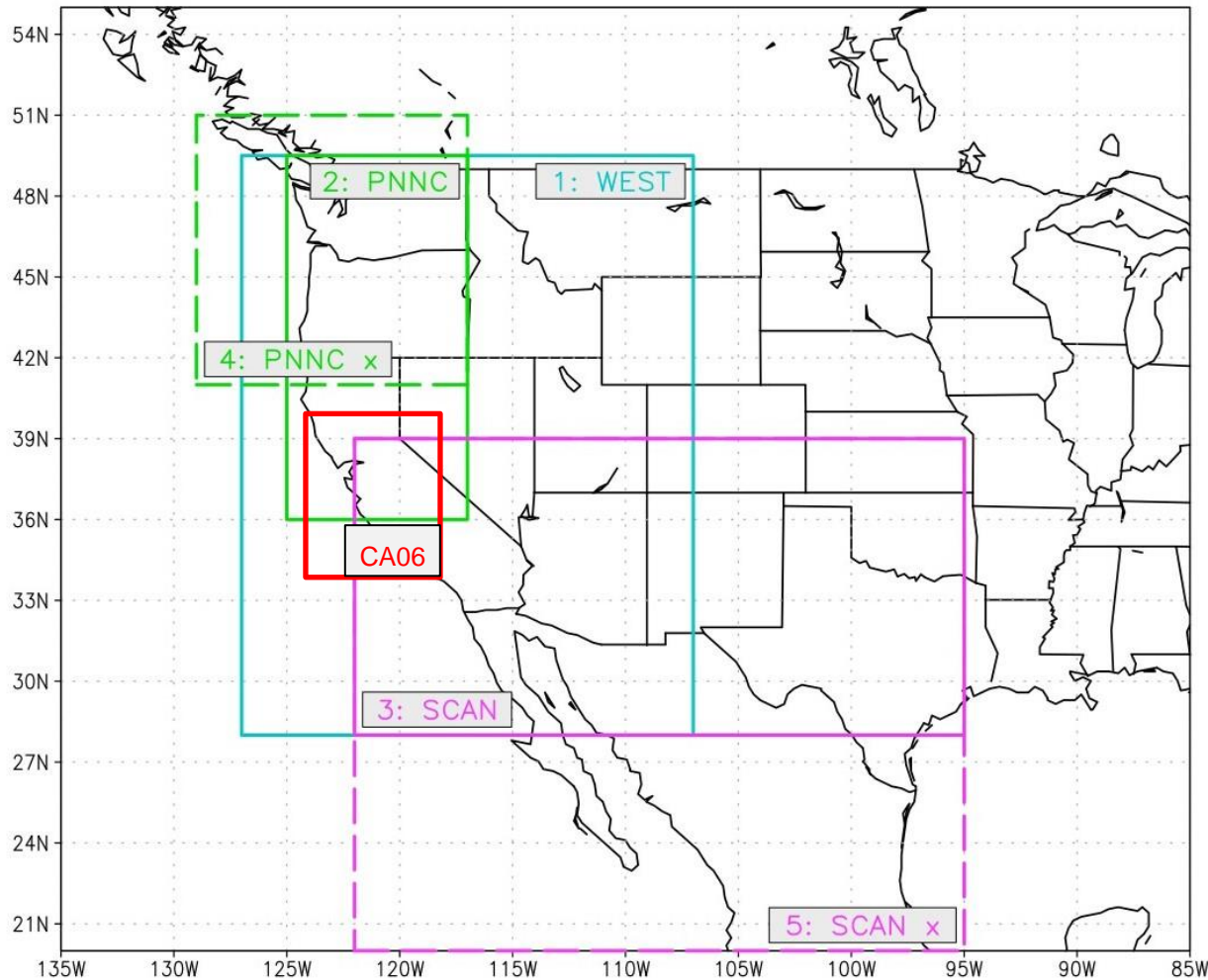
Spatial domains for precipitation verifications
(Lord et al. 2023. WAF)

West Coast
WEST: **107-127 W, 28-49.5 N**
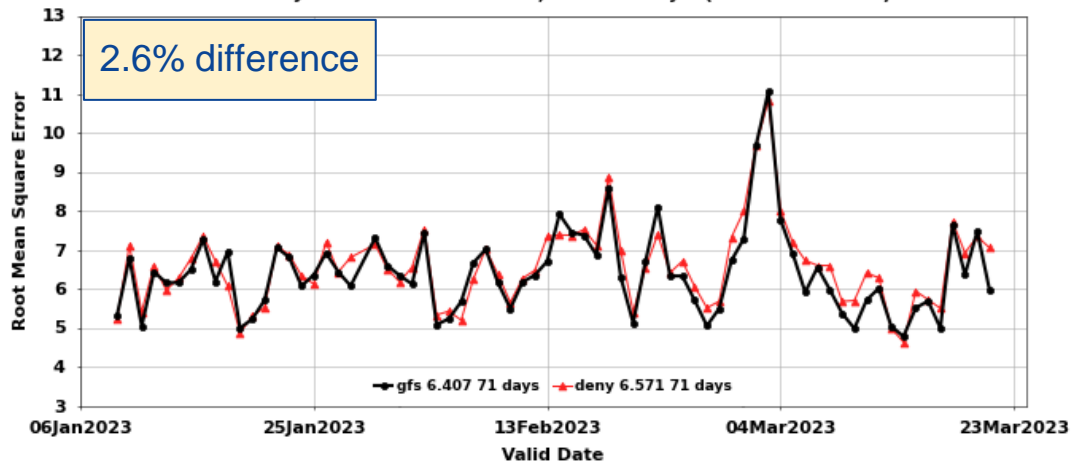
Pacific Northwest and Northern California
PNNC: **117-125 W, 36-49.5 N**

Southern California, Arizona, New Mexico
SCAN: **95-122 W, 28-39 N**

(Addition here)

CA06: **118-124 W, 36-40 N**

CONUS: The continental U.S.

WEST (>0.1 in) Mean Precipitation

GFS 24Hr Precipitation (> 0.1) MEAN WEST 2023

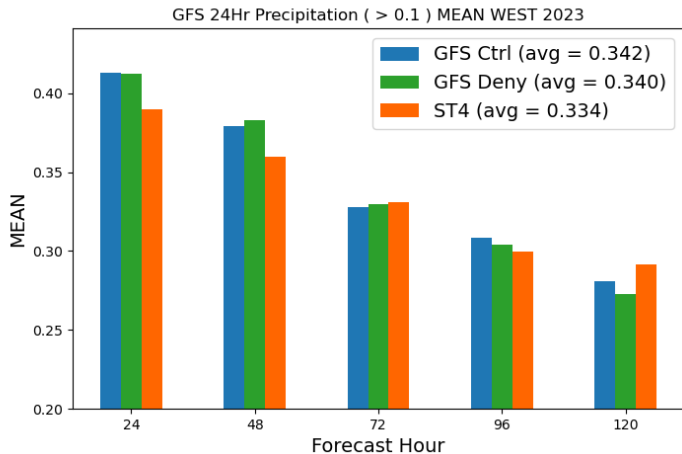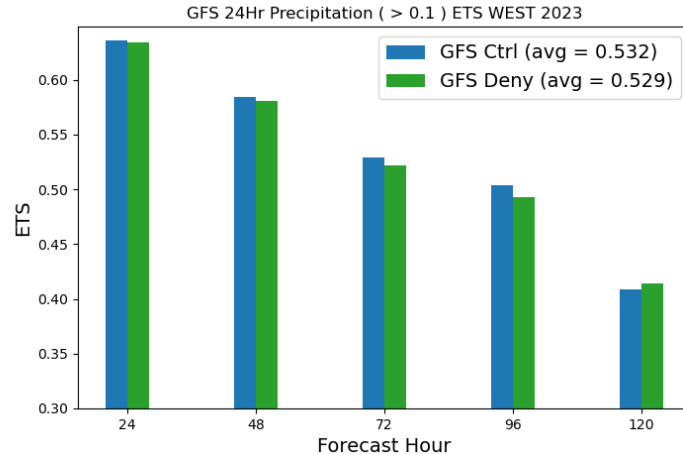- GFS Ctrl (avg = 0.342)
- GFS Deny (avg = 0.340)
- ST4 (avg = 0.334)

WEST (>0.1 in) Equitable Threat Score

GFS 24Hr Precipitation (> 0.1) ETS WEST 2023

- GFS Ctrl (avg = 0.532)
- GFS Deny (avg = 0.529)

WEST (>0.5 in) Mean Precipitation

GFS 24Hr Precipitation (> 0.5) MEAN WEST 2023

- GFS Ctrl (avg = 0.689)
- GFS Deny (avg = 0.680)
- ST4 (avg = 0.704)
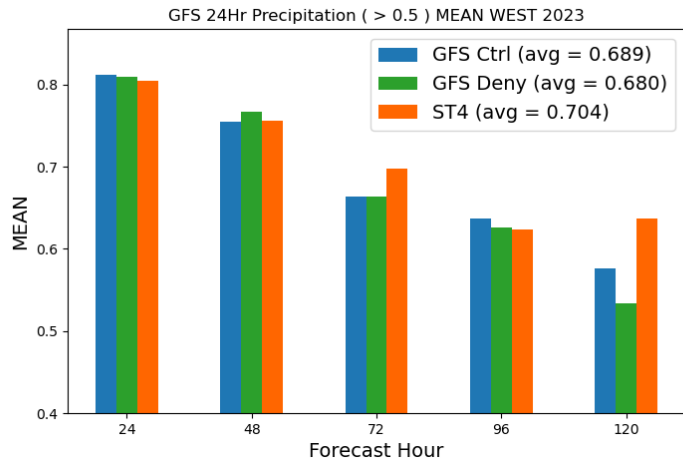
WEST (>0.5 in) Equitable Threat Score

GFS 24Hr Precipitation (> 0.5) ETS WEST 2023

- GFS Ctrl (avg = 0.368)
- GFS Deny (avg = 0.364)
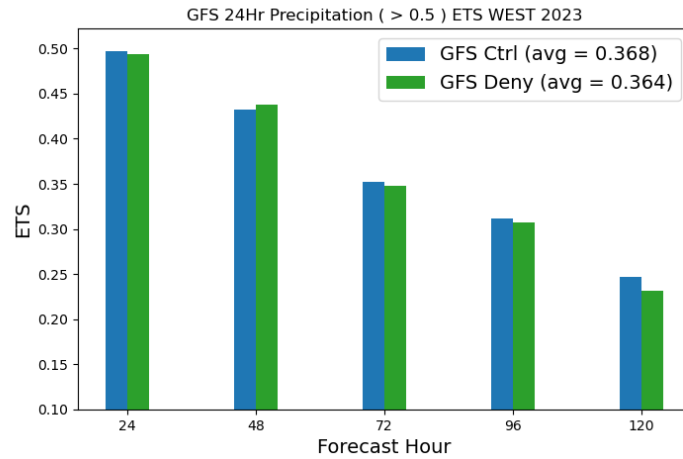
AR Recon precipitation (>0.1 in) F72 MAE

GFS 24hr Precipitation (> 0.1) F72 MAE AR Recon 2023

GFS Ctrl (avg = 0.254)
GFS Deny (avg = 0.264)

~3.9% improvement
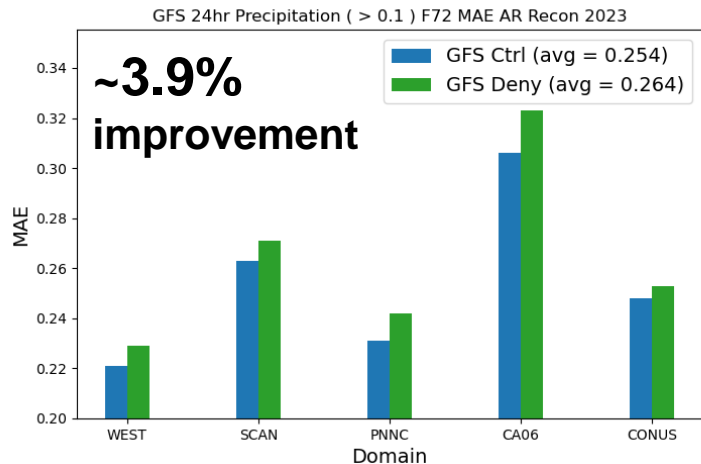
AR Recon precipitation (>0.5 in) F72 MAE

GFS 24hr Precipitation (> 0.5) F72 MAE AR Recon 2023

GFS Ctrl (avg = 0.457)
GFS Deny (avg = 0.479)

~4.6%
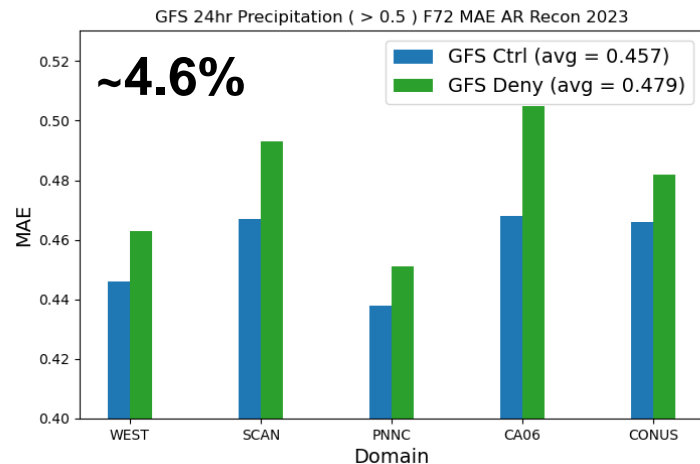
AR Recon precipitation (>1.0 in) F72 MAE

GFS 24hr Precipitation (> 1.0) F72 MAE AR Recon 2023

GFS Ctrl (avg = 0.671)
GFS Deny (avg = 0.721)

~6.9%
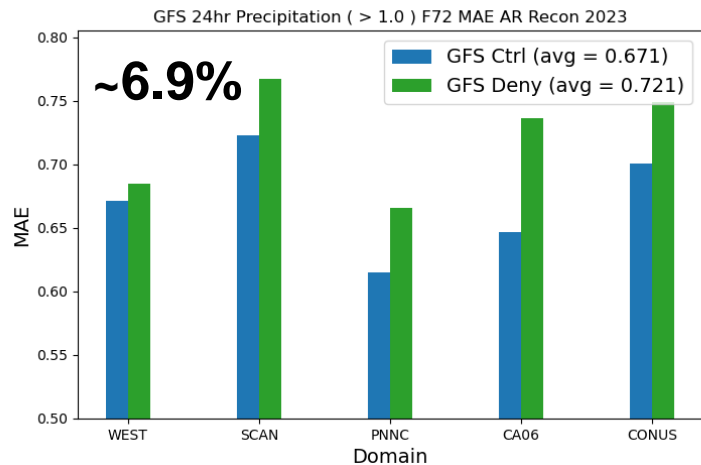
AR Recon precipitation (>2.5 in) F72 MAE

GFS 24hr Precipitation (> 2.5) F72 MAE AR Recon 2023

GFS Ctrl (avg = 1.529)
GFS Deny (avg = 1.620)

~5.6%
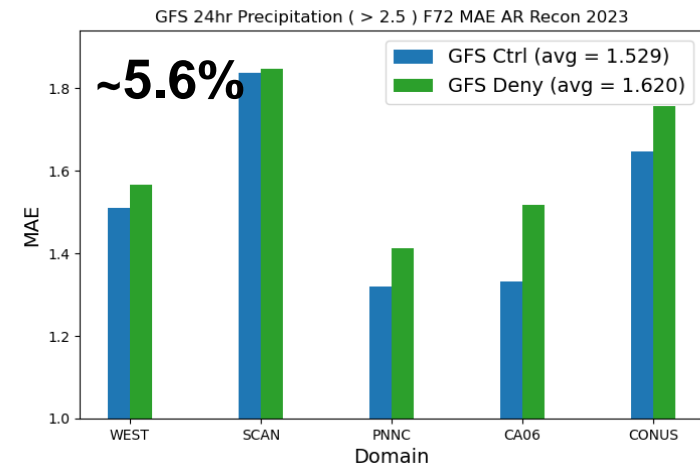
Precipitation F72 MAE
CA06

Dropsonde obs helps to reduce precipitation mae in CTRL
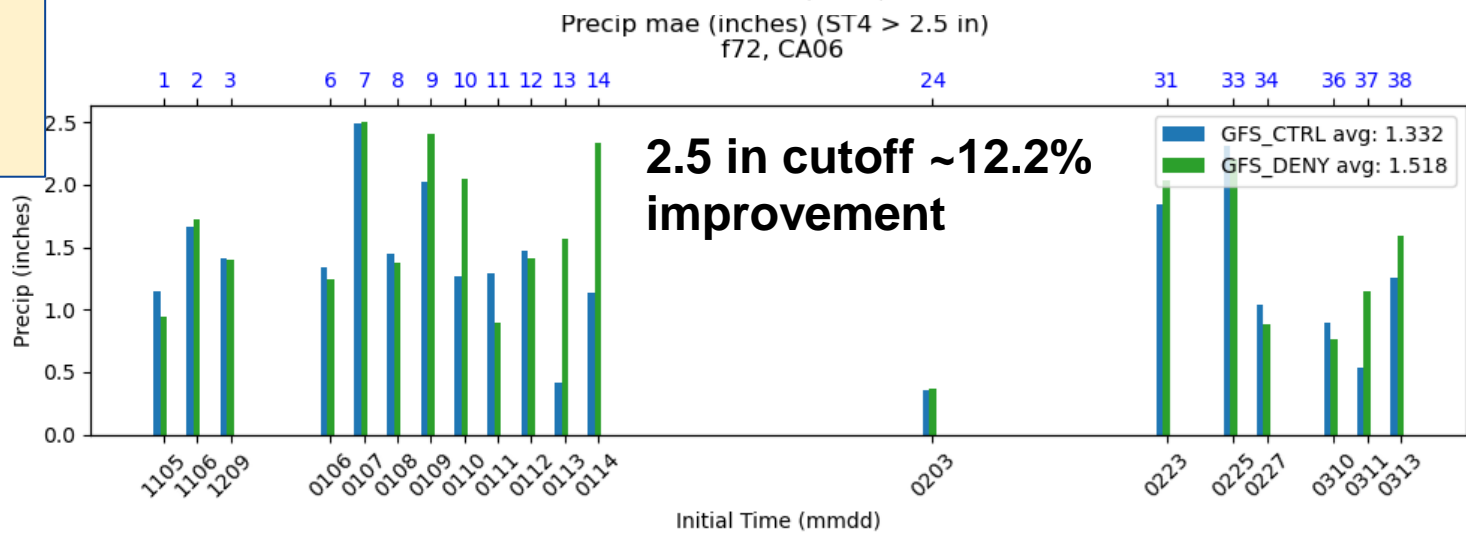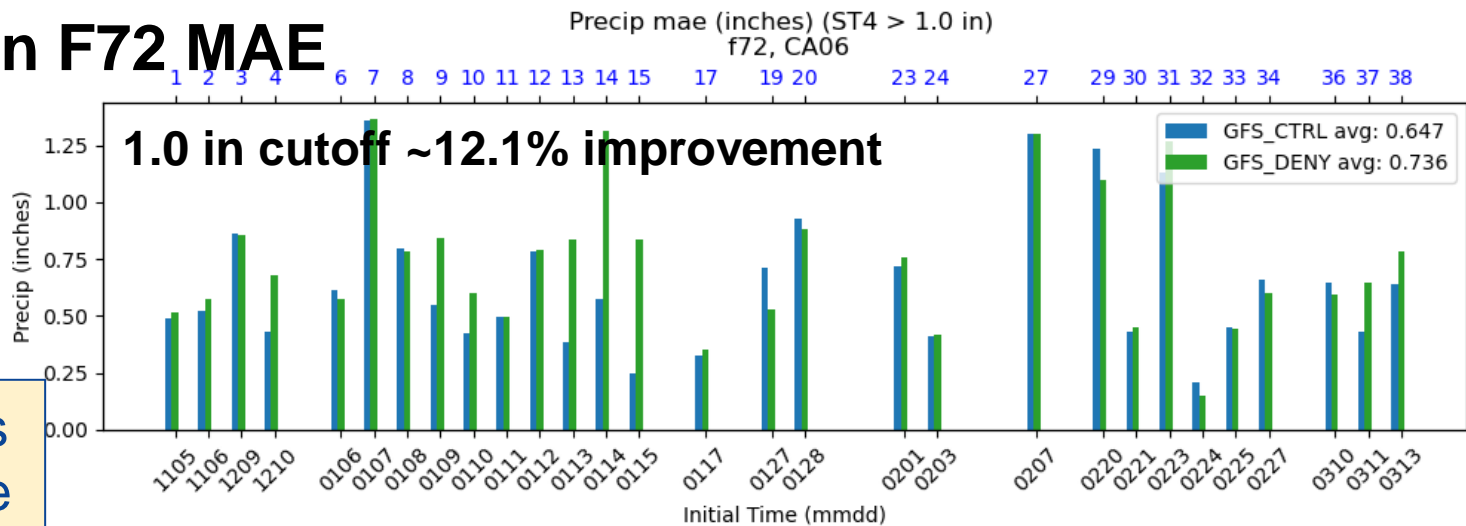
Case Study: IOP 14 (00Z Jan 14)
72-hour forecast, verify at 00Z Jan 17
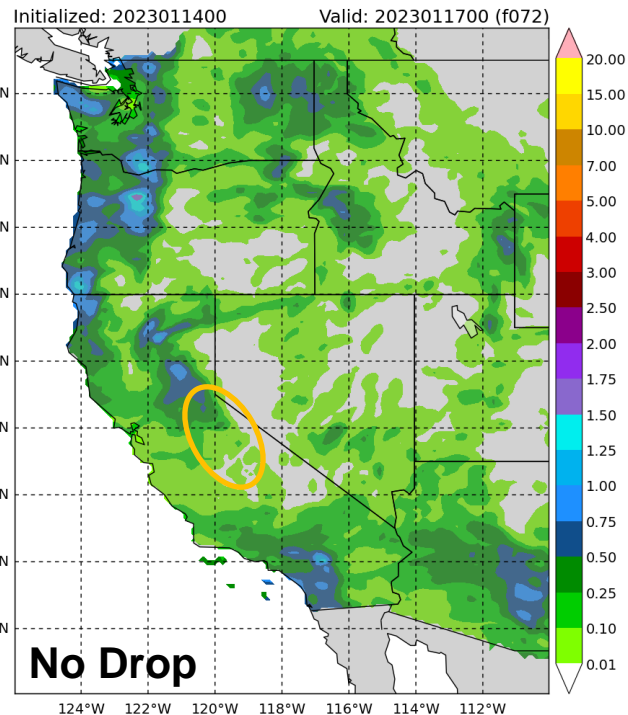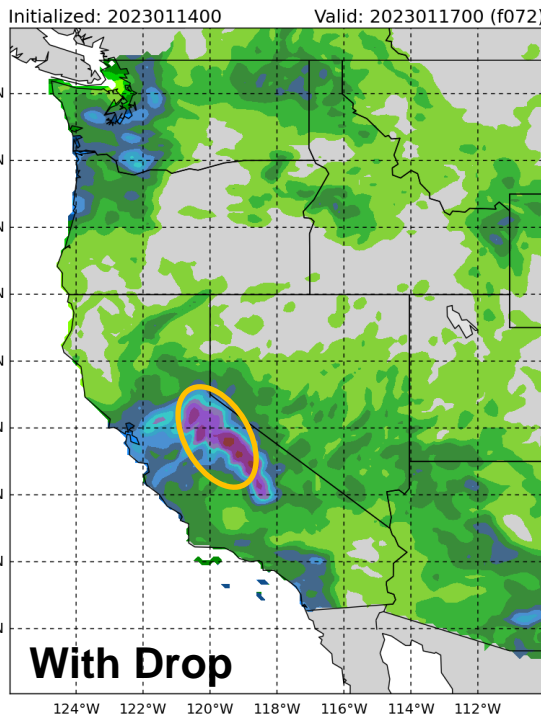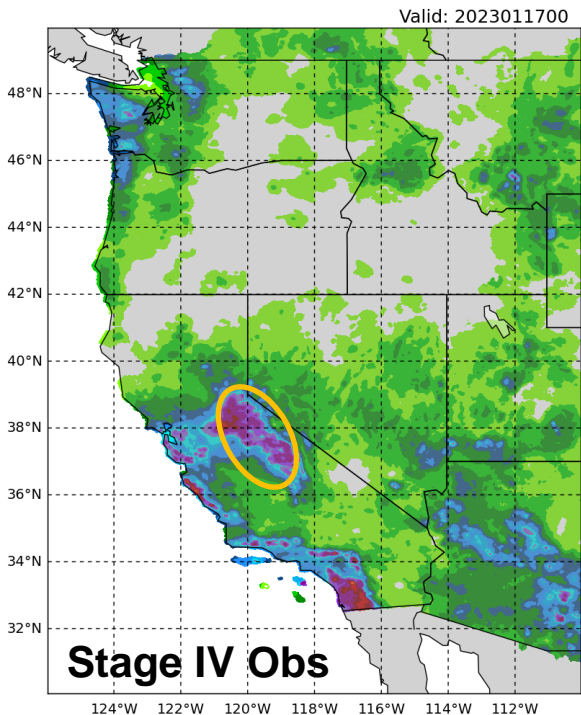
Forecast MAE Improvement: (Ctrl-Deny)/Deny*100%

F48 - 39 IOPs: **30N-45N,130W-115W**

GFSv16 IVT, IVT Vector, and SLP (hPa, contours)
Anl: 2023011000
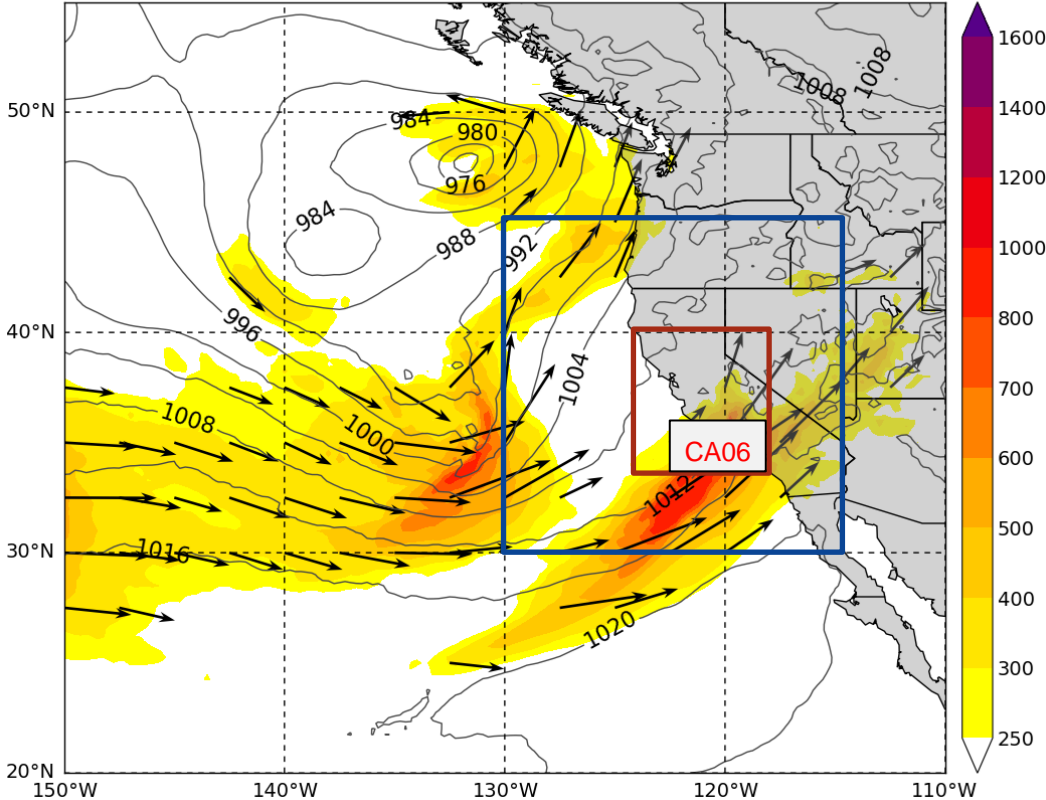
IVT	IWV	MSLP
-1.8	-3.5	-2.7

Level	925	850	700	500	400	300
SPFH	-2.5	-2.4	-4.7	-2.4	1.1	-0.0
WSPD	-0.9	-3.4	-1.9	-2.2	-3.5	-1.1
Z	-2.4	-2.1	-1.4	-0.7	0.2	-1.6
T	-2.4	-3.0	-3.5	0.8	-2.1	-0.9

Positive impacts from the assimilated dropsonde obs for IVT structures, and the field of moisture, wind, geopotential height and temperature.

IOP 6-18 F72 precipitation MAE
CA06: 34N-40N,124W-118W

F48 Forecast MAE Improvement:
(Ctrl-Deny)/Deny*100%
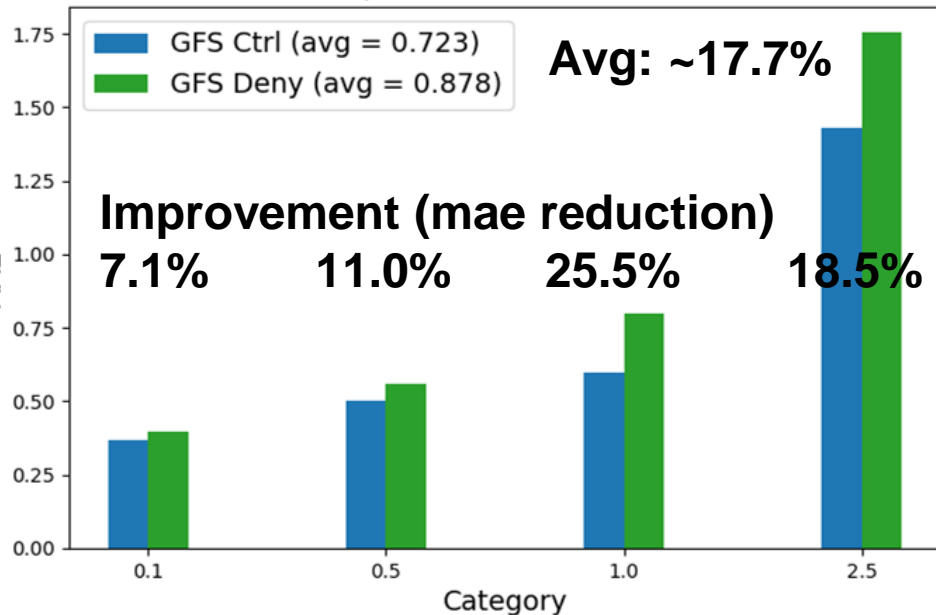### 30N-45N,130W-115W

GFS 24hr Precipitation CA06 F72 MAE AR Recon 2023

GFS Ctrl (avg = 0.723)
GFS Deny (avg = 0.878)

Avg: ~17.7%

Improvement (mae reduction)
7.1%   11.0%   25.5%   18.5%

	IVT	IWV	MSLP		
	-4.5	-6.9	-10.9		

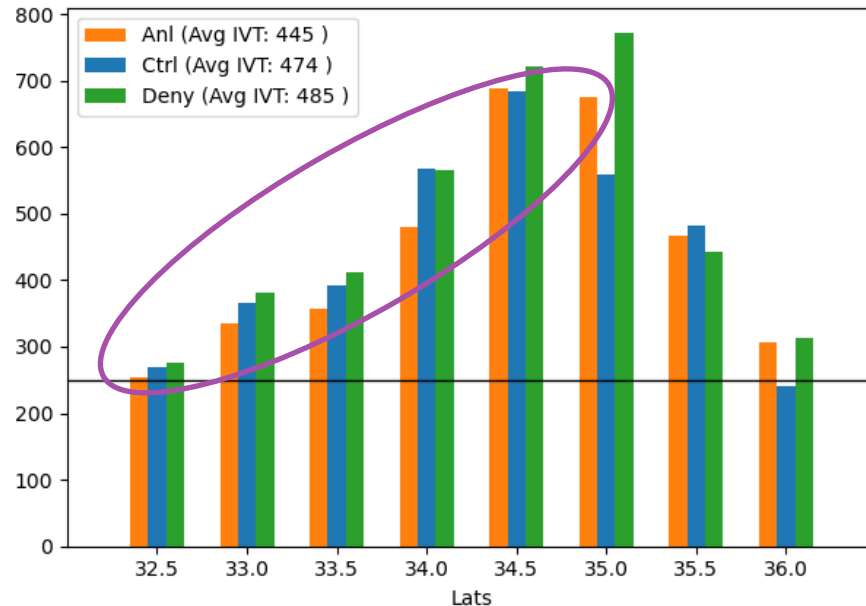| Level	925	850	700	500	400	300
SPFH	-6.5	-7.7	-8.9	-4.4	-2.0	4.3
WSPD	-7.0	-6.0	-7.2	-6.0	-8.0	-2.3
Z	-11.2	-10.9	-7.7	-4.7	-2.1	-1.6
T	-6.3	-7.7	-7.3	-0.8	-1.5	2.4

Positive impacts from the assimilated **dropsonde obs** for CA precipitation, IVT structures, and the field of moisture, wind, geopotential height and temperature.

AR 2023 Jan 10 Landfall Forecast: GFS IVT Jan 10 00Z
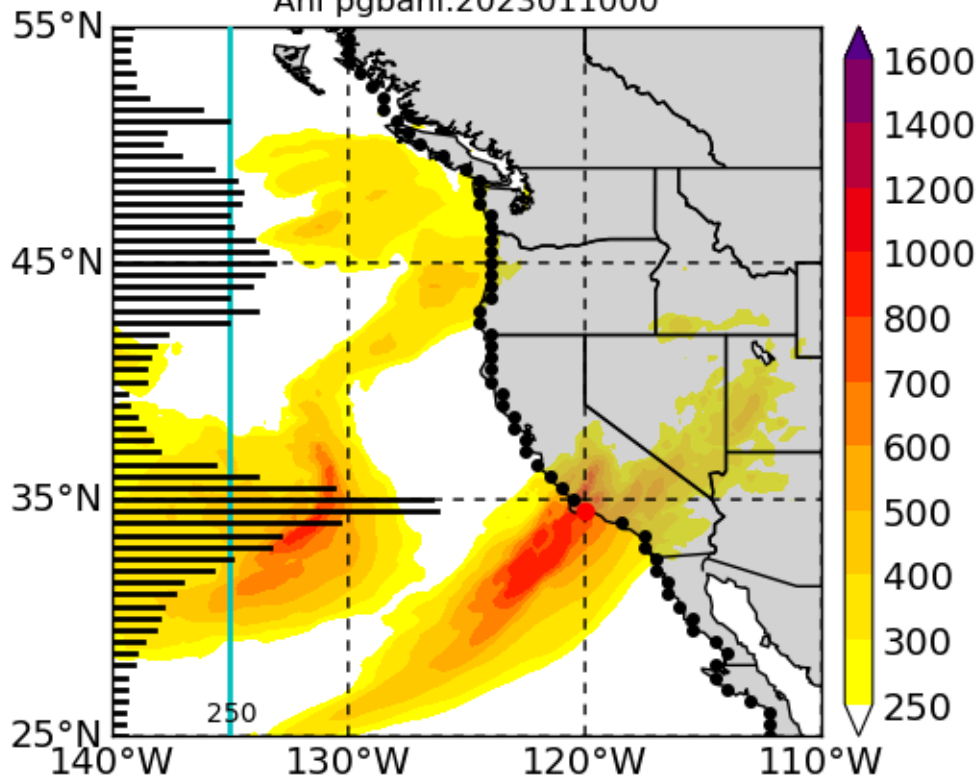
The positive impact of the dropsonde data in IVT

Summary

- AR dropsonde data help improve GFS forecast over the Pacific North American (PNA, 180-320E 20-75N) due to improvement in GFS analysis.

- There is a positive impact on the GFS forecast skill for the precip over the U.S. West, especially with 72-h lead, along with improved analysis and forecast of moisture, wind, and AR landfall.

- Data gaps associated with ARs can be addressed with targeted AR Recon field campaigns which provide vital observations for improving precipitation forecasts over the U.S. West.

Thanks for your attention

GFSv16 and data denial

Precipitation: https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/GFSv16_prec24h

Precipitation Bias: https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/GFSv16_prec24hDmC

IVT/IWV: https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/GFSv16_AR2023

IVT/IWV bias: https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/GFSv16_AR2023_FmA

IVT/IWV difference (Deny/Ctrl): https://www.emc.ncep.noaa.gov/gc_wmb/wd20xw/GFSv16_AR_DmC

Acknowledgements: AR Recon Team

Questions?