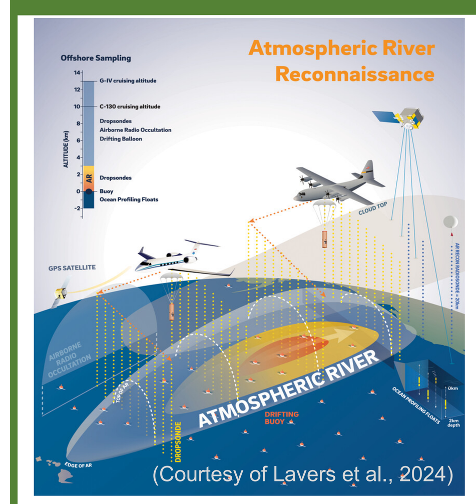
Examining the Impact of Airborne Radio Occultation Observations on Short Term Precipitation Forecasts of an Atmospheric River Using MPAS-JEDI

Nghi Do (1), Jennifer S. Haase (1), Ivette Hernandez Banos(2), Pawel Hordyniec (3), Bing Cao (1)

(1) Scripps Institution of Oceanography, University of California San Diego, USA
(2) National Center for Atmospheric Research, Boulder, USA
(3) Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, Wroclaw, Poland

n9do@ucsd.edu

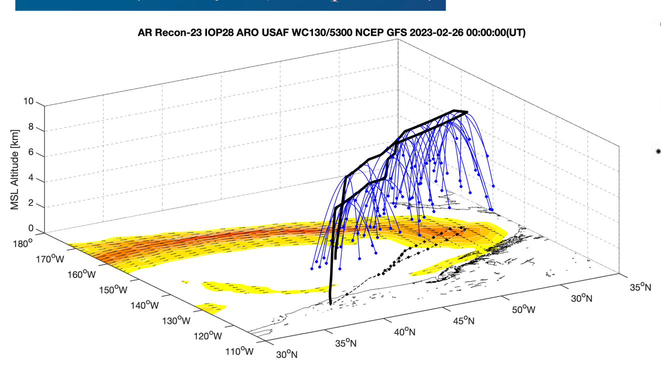
Objective

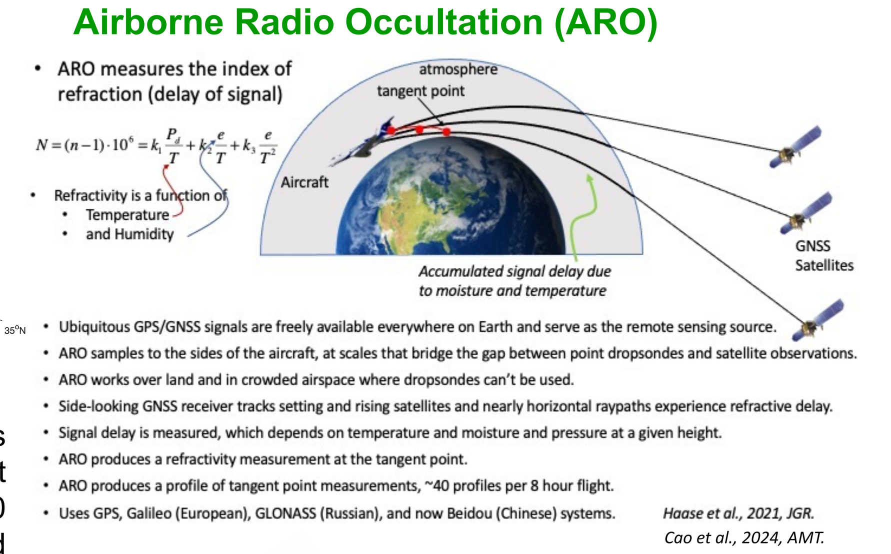


ARs & AR Recon

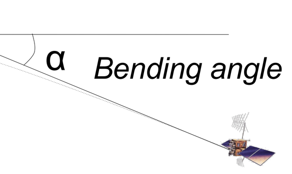
- Atmosphere Rivers (ARs) are long filaments of water vapor transport in the lowest 3-4 km altitude, accounting for > 90% of meridional water vapor transport from low to mid-latitudes (Zhu and Newell, 1998).
- Landfalling ARs over the western US are responsible for ~30–50% of annual precipitation (Zheng et al., 2021) → accurate forecasts are important for aiding water management decisions & reducing flood risks.
- AR Recon: Targeted airborne and buoy observations over the Northeast Pacific are deployed to improve forecasts of the landfall and impacts of ARs on the US west coast at lead times of 1-5 days.

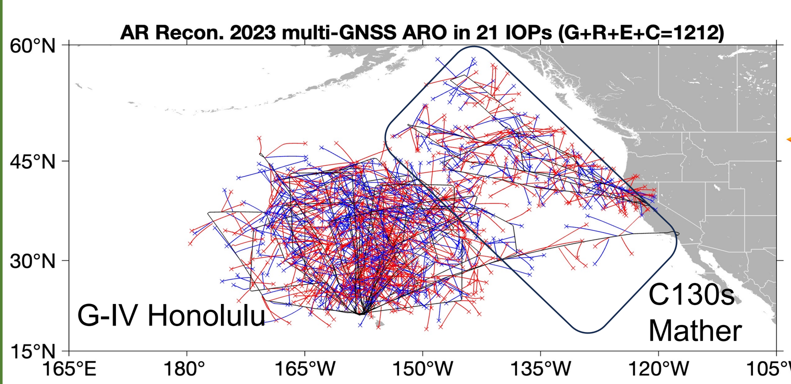
Airborne Radio Occultation (ARO)





280 ARO profiles were retrieved in 3 flights (IOP28, IOP29, and IOP34) in the first deployment by the US Air Force C-130 aircraft #5300, equipped with an upgraded multi-GNSS antenna.

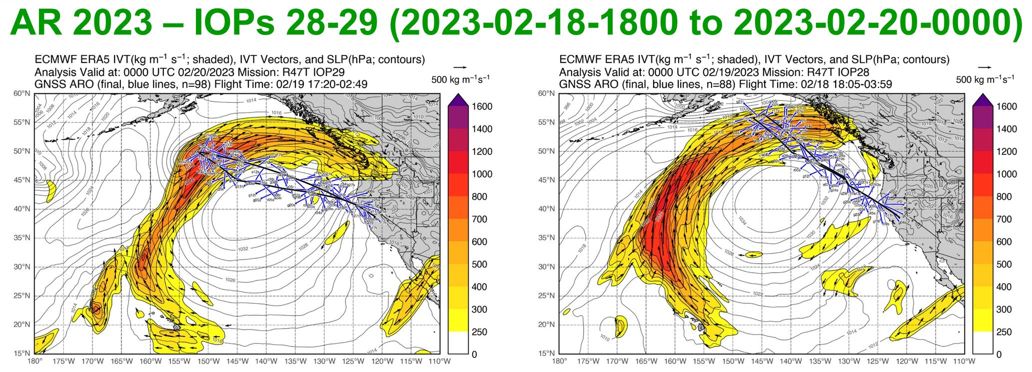




This is the first study examining the potential impact of assimilating ARO bending angle observations from the C-130's on the analysis and prediction of ARs and precipitation using MPAS-JEDI.

Experimental design

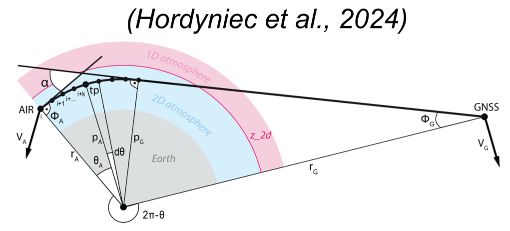
AR 2023 – IOPs 28-29 (2023-02-18-1800 to 2023-02-20-0000)



Landfalling IVT forecast to produce intense precipitation for Pacific Northwest

ROPP 2D

(Hordyniec et al., 2024)

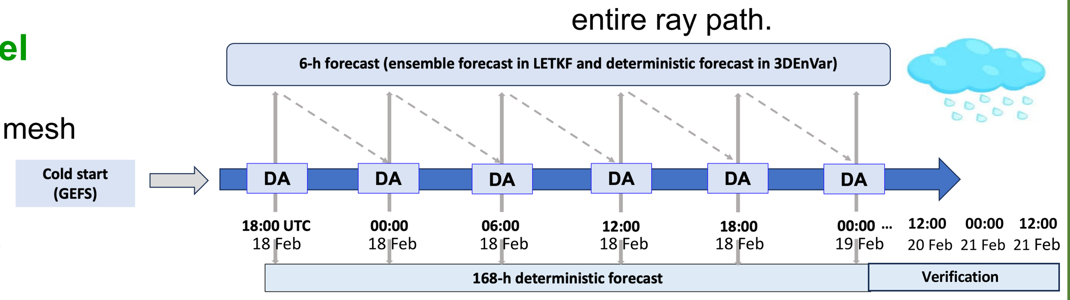


Instead of considering only the vertical profile at the tangent point, it accounts for horizontal variation in atmospheric structure along the entire ray path.

MPAS-Atmosphere model

(Skamarock et al., 2012)

- Non-hydrostatic, unstructured mesh
- Height-based terrain-following vertical coordinate
- Global 60 km mesh, 55 levels, 30km top
- Mesoscale reference physical parameterizations



Parameterization	Scheme
Convection	New Tiedtke (Tiedtke, 1989; Zhang and Wang, 2017)
Microphysics	WSM6 (Hong and Lim, 2006)
Land surface	Noah (Chen and Dudhia, 2001)
Boundary layer	YSU (Hong et al., 2006)
Surface layer	Monin–Obukhov (Jiménez et al., 2012)
Radiation, longwave/shortwave	RRTMG (Iacono et al., 2008)
Cloud fraction for radiation	Xu–Randall (Xu and Randall, 1996)
Gravity wave drag by orography	YSU (Choi and Hong, 2015)

MPAS-JEDI Workflow

(Liu et al., 2022)

- 6-hourly cycling
- 2 experiments for each method: LETKF (30-members), 3DEnVar
- NCEP GFS initial conditions cold start at 1st cycle, warm start afterwards
- DA time: IOPs 28-29 (1800 UTC 18 Feb to 0000 UTC 20 Feb 2023)
- C-130 data available: 2023-02-18 1800, 2023-02-19 0000, 2023-02-19 0600, 2023-02-19 1800, 2023-02-20 0000

ARO observation error

Similar error parameters to GNSS RO, varies by height and latitude (Guerrette et al., 2023). Pre-calculated utilizing the diagnostics proposed by Desroziers et al., (2005), leveraging observations & analysis departures from a month-long experiment designed for spaceborne GNSS RO data.

Experiments	Assimilated observations					Assimilation methods	
	Surface pressure	Sondes	Aircraft	Atmospheric motion vectors	GNSS ARO (C130)	3DEnVar	LETKF
3denvar_ctrl	x	x	x	x		x	
3denvar_aro	x	x	x	x	x	x	
letkf_ctrl	x	x	x	x			x
letkf_aro	x	x	x	x	x		x

Results

Results of analysis

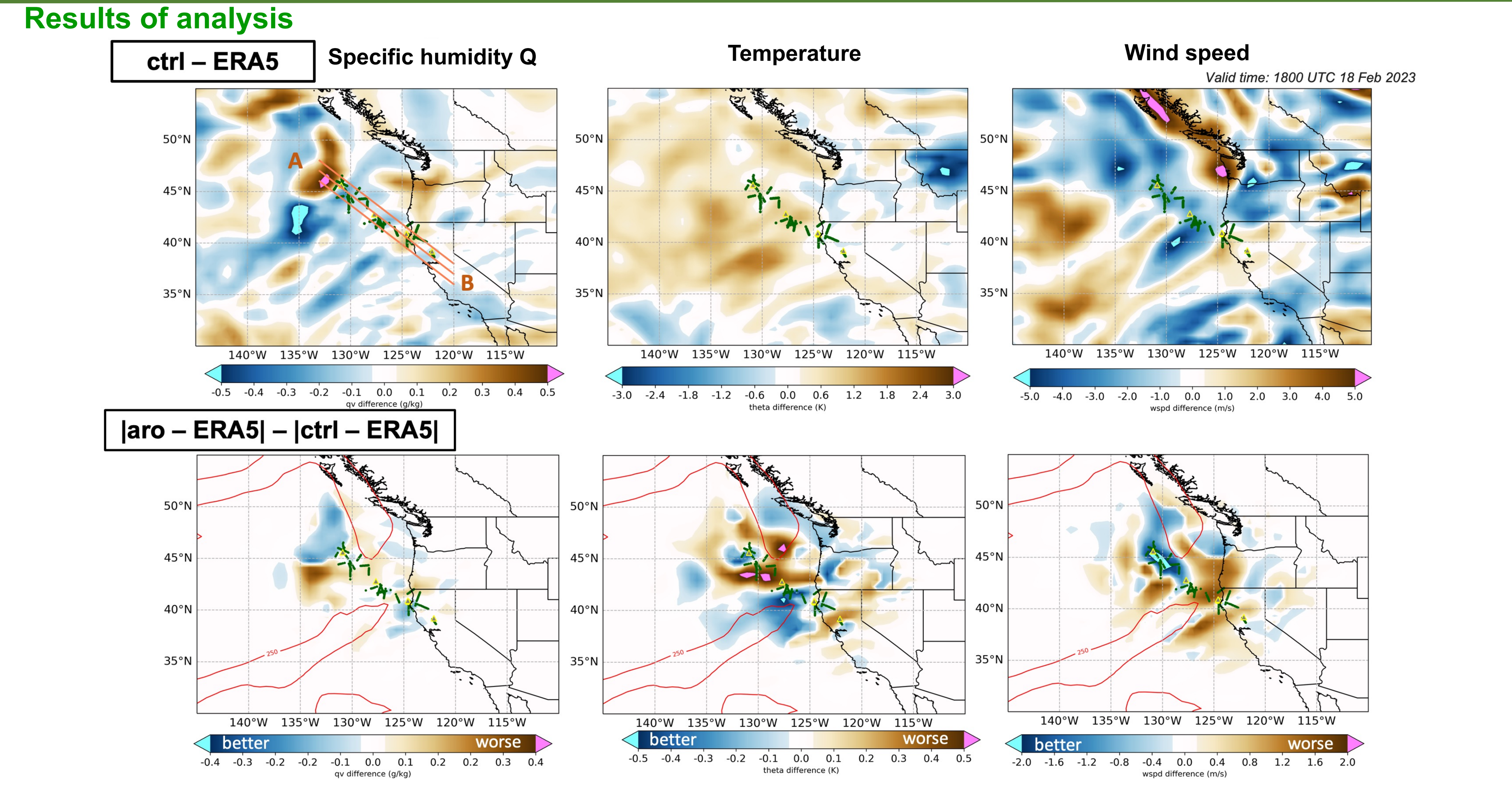


Fig 1. Data impact at the first assimilation cycle (1800 UTC 18 Feb 2023) at 6 km for 3DEnVar experiments.

- **Q**: ARO reduced moist error btw 45-50N, -130 to -135E, south of the head of the AR, and along the WA, OR, and Northern CA coasts.
- **T**: ARO mitigated warm bias south of the head of the AR, and offshore Northern CA.
- **Wind speed**: ARO strengthened the magnitude between 43-50N, south of the head of the AR, and weakened windseed near the west coast of WA and OR, reducing the error over ctrl.
- Some areas showed degradation.

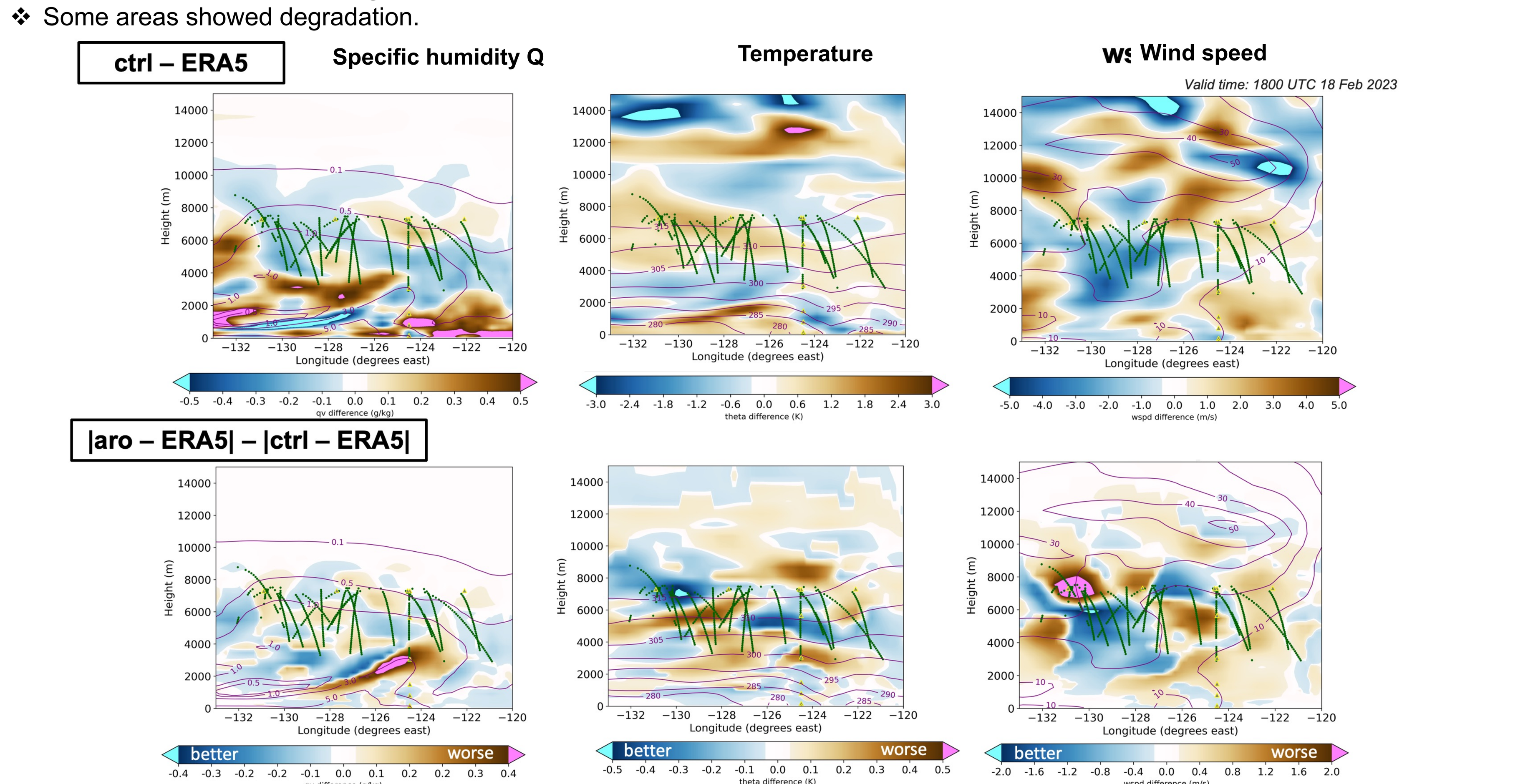


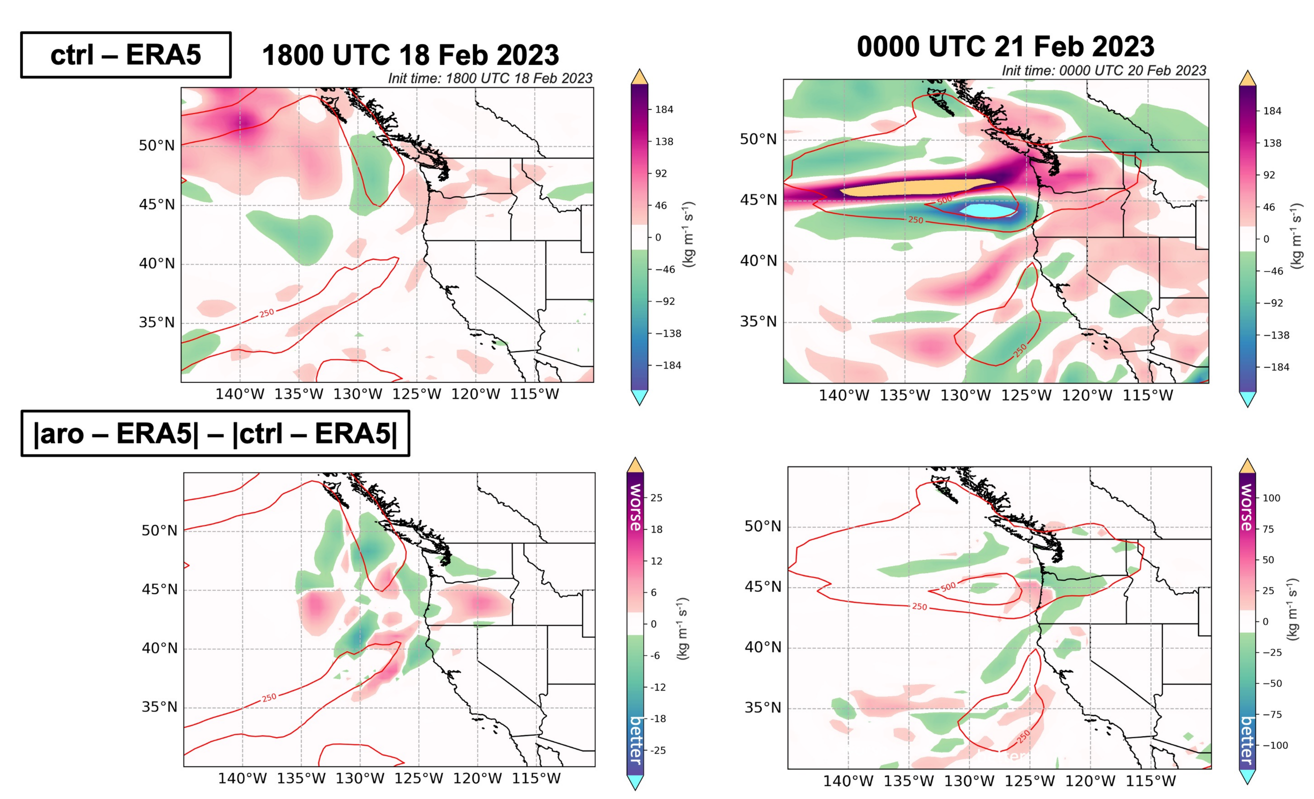
Fig 2. As in Figure 1, for the vertical cross-section along the line "A-B"

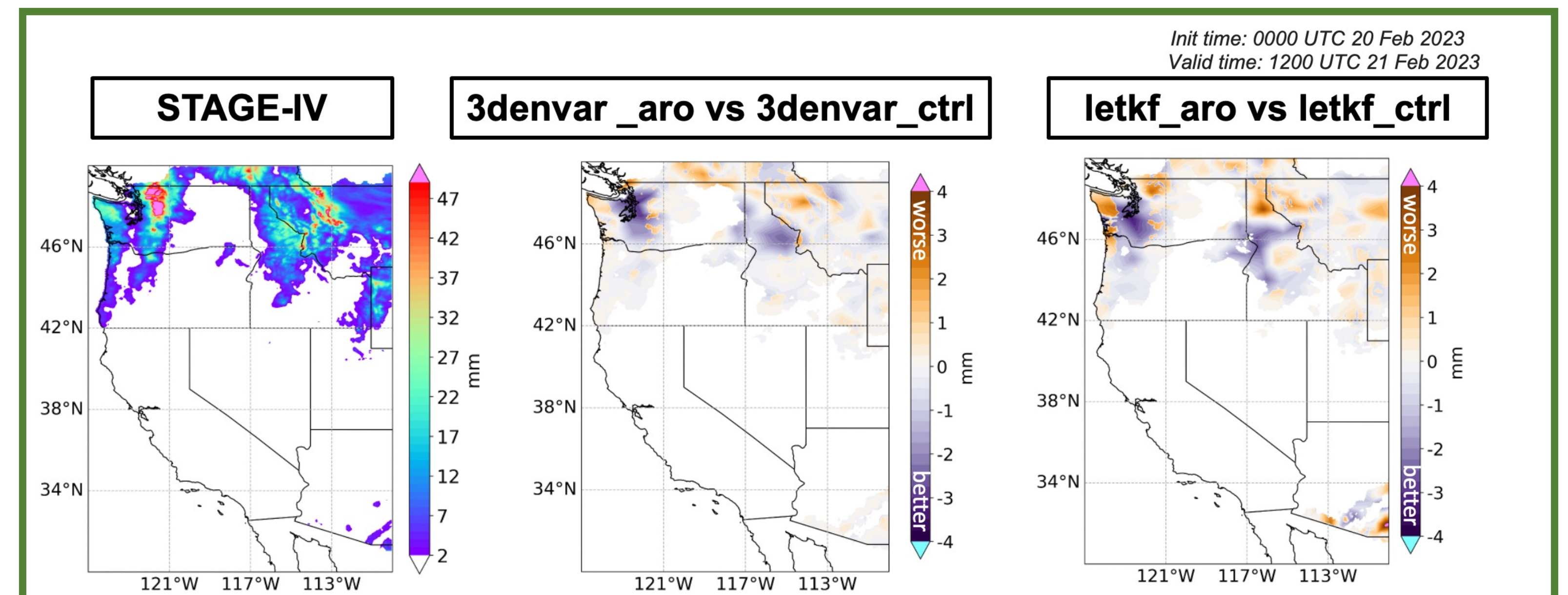
- **Q**: ARO reduced and enhanced moisture in the moist and dry error regions at 6-8 km. ARO influences moisture below profile limits.
- **T**: ARO had a positive impact on correcting the warm bias from 4-10 km by cooling most, but not all, of these regions.
- **Wind speed**: ARO improved underestimated speed below 6 km btw -127E to -132E, and in recurving jet at 8 km (not shown) at -126E.

Results of forecast

Fig 3. Impact on analysis IVT at the first cycle (1800 UTC 18 Feb 2023) and 24-h forecast IVT initialized at 0000 UTC 20 Feb 2023 for 3DEnVar experiments

- **The 1st cycle**: ARO enhanced and reduced the IVT amplitude, correcting the negative and positive errors of the ctrl.
- **24-h forecast**: ARO reduced IVT over inland WA and OR, resulting in a smaller absolute error in IVT compared with ctrl. Additionally, ARO corrected the IVT within and north of the AR core.
- However, large differences in IVT in 24-h forecast remain. ARO was not successful in completely correcting the large overall shift of the AR core.





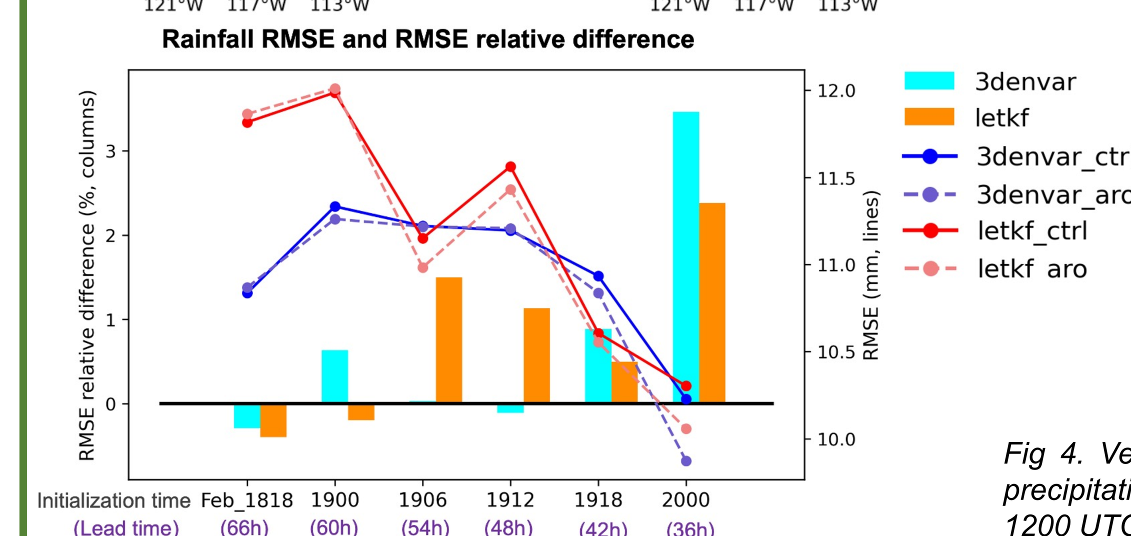


Fig 4. Verification of 24h accumulated precipitation from 1200 UTC 20 Feb to 1200 UTC 21 Feb 2023.

- Assimilation of ARO reduced the precipitation overprediction error in WA, OR, and ID by up to 4 mm, which is linked to the reduction of IVT overestimation in these areas.
- Assimilating ARO using both 3DEnVar and LETKF reduced the RMSE and improved the rainfall forecast when the forecast was initialized between 36 to 54 hours. The most notable improvement occurred when the forecast was initialized at 2000 UTC, with an improvement of 2.5-3.5%.

Conclusions

- **Assimilating the additional ARO profiles was able to correct the moisture, temperature, and wind fields, and reduce the error in forecasting integrated vapor transport at landfall. This resulted in the reduction of overestimated precipitation over the mountainous terrain in Washington and Idaho, bringing the forecasts into closer agreement with observations.**
- **Results will be useful in the future for assessing targeted observation strategies at different lead times.**

References

Cao, B., Haase, J. S., Murphy Jr, M. J., & Wilson, A. M. (2024). Observing atmospheric rivers using multi-GNSS airborne radio occultation: system description and data evaluation. *Atmospheric Measurement Techniques Discussions*, *2024*, 1-44.

Desroziers, G., Berre, L., Chapnik, B. and Poli, P. (2005): Diagnosis of observation, background and analysis-error statistics in observation space. Q.J.R. Meteorol. Soc., 131: 3385-3396.

Guerrette, J. J., Liu, Z., Ban, J., Jung, B.-J., Snyder, C., Schwartz, C. (2023): En-3DEnVar and GNSSRO Observation Error tuning with JEDI-MPAS. 19th JCSDA Science Workshop and Tech Review, Boulder CO.

Hordyniec, P., J. S Haase, M. J. Murphy, et al. Forward modeling of bending angles with a two-dimensional operator for GNSS airborne radio occultations in atmospheric rivers. ESS Open Archive . April 16, 2024.
DOI: 10.22541/essoar.171322619.96683080/v1

Lavers DA, Wilson AM, Ralph FM, Tallapragada V, Pappenberger F, Reynolds C, et al. Advancing Atmospheric River science and inspiring future development of the Atmospheric River reconnaissance program. Bulletin of the American Meteorological Society. 2024;105:E75-E83. DOI: 10.1175/BAMS-D-23-0278.1

Liu, Z., Snyder, C., Guerrette, J. J., Jung, B.-J., Ban, J., Vahl, S., Wu, Y., Trémolet, Y., Auligné, T., Ménétrier, B., Shlyaeva, A., Herbener, S., Liu, E., Holdaway, D., and Johnson, B. T. (2022): Data assimilation for the Model for Prediction Across Scales – Atmosphere with the Joint Effort for Data assimilation Integration (JEDI-MPAS 1.0.0): EnVar implementation and evaluation, Geosci. Model Dev., 15, 7859–7878.

Skamarock, W. C., J. B. Klemp, L. D. Fowler, M. G. Duda, S.-H. Park, and T. D. Ringler (2012): A multiscale nonhydrostatic atmospheric model using centroidal Voronoi tesselations and C-grid staggering. Mon. Wea. Rev., 140, 3090–3105.

Zheng, M., Delle Monache, L., Cornuelle, B. D., Ralph, F. M., Tallapragada, V. S., Subramanian, A., et al. (2021). Improved forecast skill through the assimilation of dropsonde observations from the Atmospheric River Reconnaissance program. Journal of Geophysical Research: Atmospheres, 126(21), e2021JD034967. https://doi.org/10.1029/2021JD034967

Zhu, Y., and R. E. Newell, 1998: A Proposed Algorithm for Moisture Fluxes from Atmospheric Rivers. Mon. Wea. Rev., 126, 725–735, https://doi.org/10.1175/1520-0493(1998)126<0725:APAFMF>2.0.CO;2.

Acknowledgments

AR Recon data collection and analysis supported by the Atmospheric River Research Program of the California Department of Water Resources and the Forecast-Informed Reservoir Operations Program of the US Army Corps of Engineers. Additional support provided by NASA Award 80NSSC23K1307, National Science Foundation AGS-1642650, and the Bekker Foundation. We thank the NOAA Aircraft Operation Center and the Air Force for the operation of ARO equipment and providing dropsondes. We thank F.M. Ralph, L. Delle Monache and CW3E for collaboration and support in this research, including access to the AR Recon dropsonde data, and CW3E graphics. ECMWF reanalysis-5 (ERA-5) products provided by the European Center for Medium-range Weather Forecasting. Global Forecasting System (GFS) products provided by National Center for Environmental Prediction (NCEP). ROPP software provided by the Radio Occultation Meteorology Satellite Application Facility (ROMSAF). We thank Jake Liu and MMM for collaboration and assistance. NSF and NCAR/UCAR supported the HPC allocation for executing the experiments.