# Airborne Radio Occultation (ARO) data assimilation using JEDI-MPAS for an 11-flight sequence of California ARs

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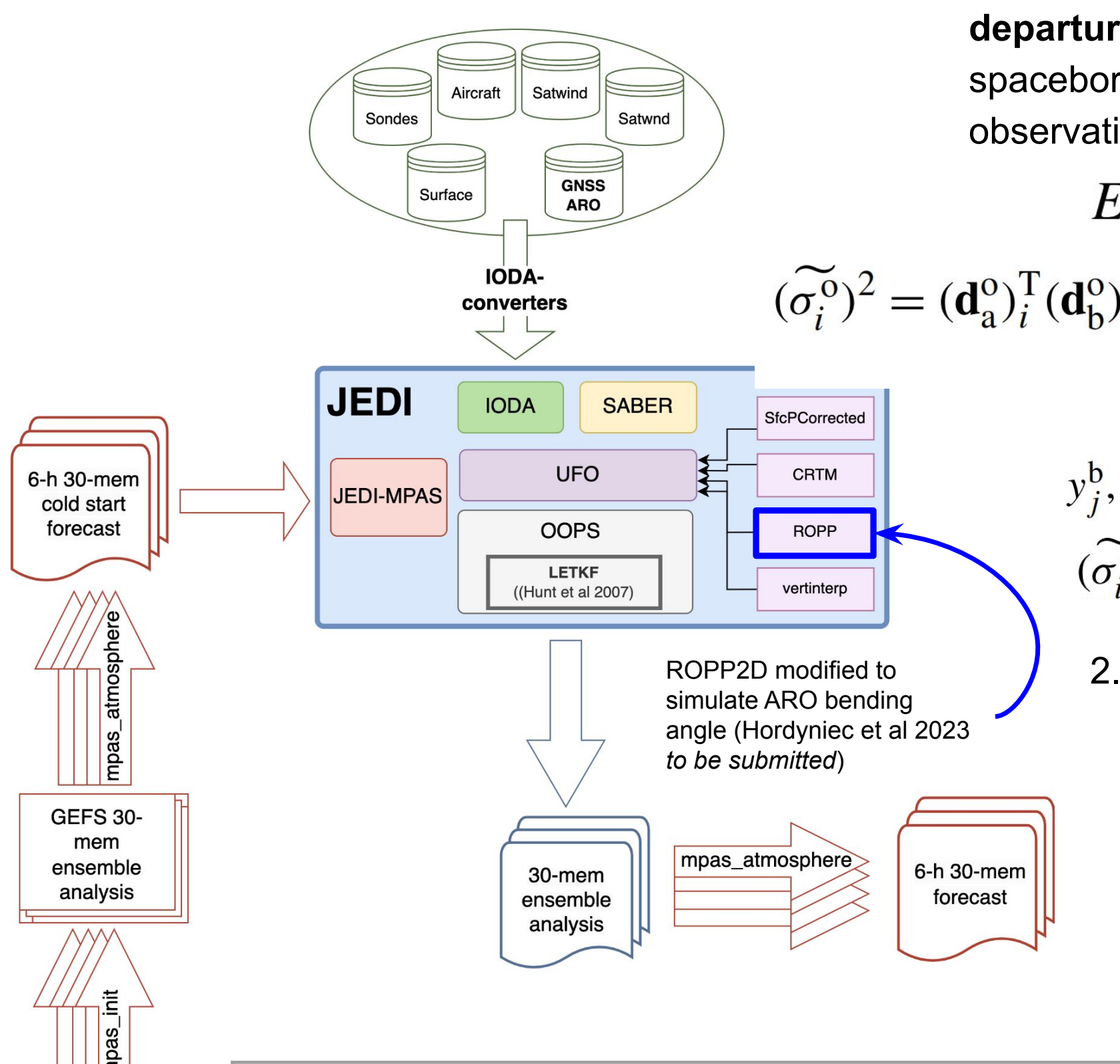
## Overview

During the **2022-2023 AR Recon campaign**, an unprecedented sequence of ARO data collection was possible between 6 to 17 January 2023. The assimilation of retrieved ARO observations presents an opportunity to investigate impact for these events. Assimilation of ARO refractivity profiles has been investigated in past studies, but **the assimilation of ARO bending angle profiles is yet to be explored**.

The goal of this study is to **investigate the potential impacts of assimilating ARO bending observations** on the analysis and prediction of ARs using the LETKF method in JEDI-MPAS. The **2D** bending angle observation operator of the EUMETSAT ROMSAF **ROPP**, available using the Unified Forward Operator (**UFO**) of the Joint Effort for Data assimilation Integration (**JEDI**), is used to simulate ARO bending angle.

## JEDI-MPAS

**Flowchart of the JEDI components and dependencies for the first DA cycle using LETKF:**



ROPP2D modified to simulate ARO bending angle (Hordyniec et al 2023 *to be submitted*)

| LETFK | |
|---|---|
| Gaspari-Cohn R-localization | horizontal loc = 1200km<br>vertical loc = 600km |
| Relaxation To Prior Perturbations (Zhang et al., 2004) | relaxation coefficient = 0.8 |

**ARO observation error:**

1. Computed observation error variances (and RMSs) using **Desroziers et. al (2005) diagnostics using observations and analysis departures** from a one month-long experiment for spaceborne GNSSRO (i.e., subset *i* with *pi* observations)

$$E[\mathbf{d}_a^o(\mathbf{d}_b^o)^T] = \mathbf{R},$$

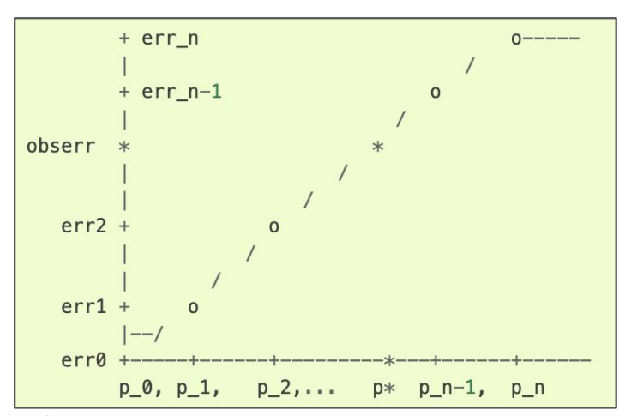
$$(\widetilde{\sigma}_i^o)^2 = (\mathbf{d}_a^o)_i^T(\mathbf{d}_b^o)_i/p_i = \sum_{j=1}(y_j^o - y_j^a)(y_j^o - y_j^b)/p_i$$

$y_j^o$ → value of observation *j*

$y_j^b$, $y_j^a$ → background and analysis counterparts

$(\widetilde{\sigma}_i^o)^2$ → diagnosed values of background and observation errors

2. Parameterized the ARO observation errors using **a piece-wise linear function of UFO (ObsErrorModelStepwiseLinear)**, varying by geometric height and latitude bands (Guerrette et. al 2023)



*Source:* JEDI documentation

## Experiments

**MPAS-Atmosphere model (Skamarock et al 2012)**

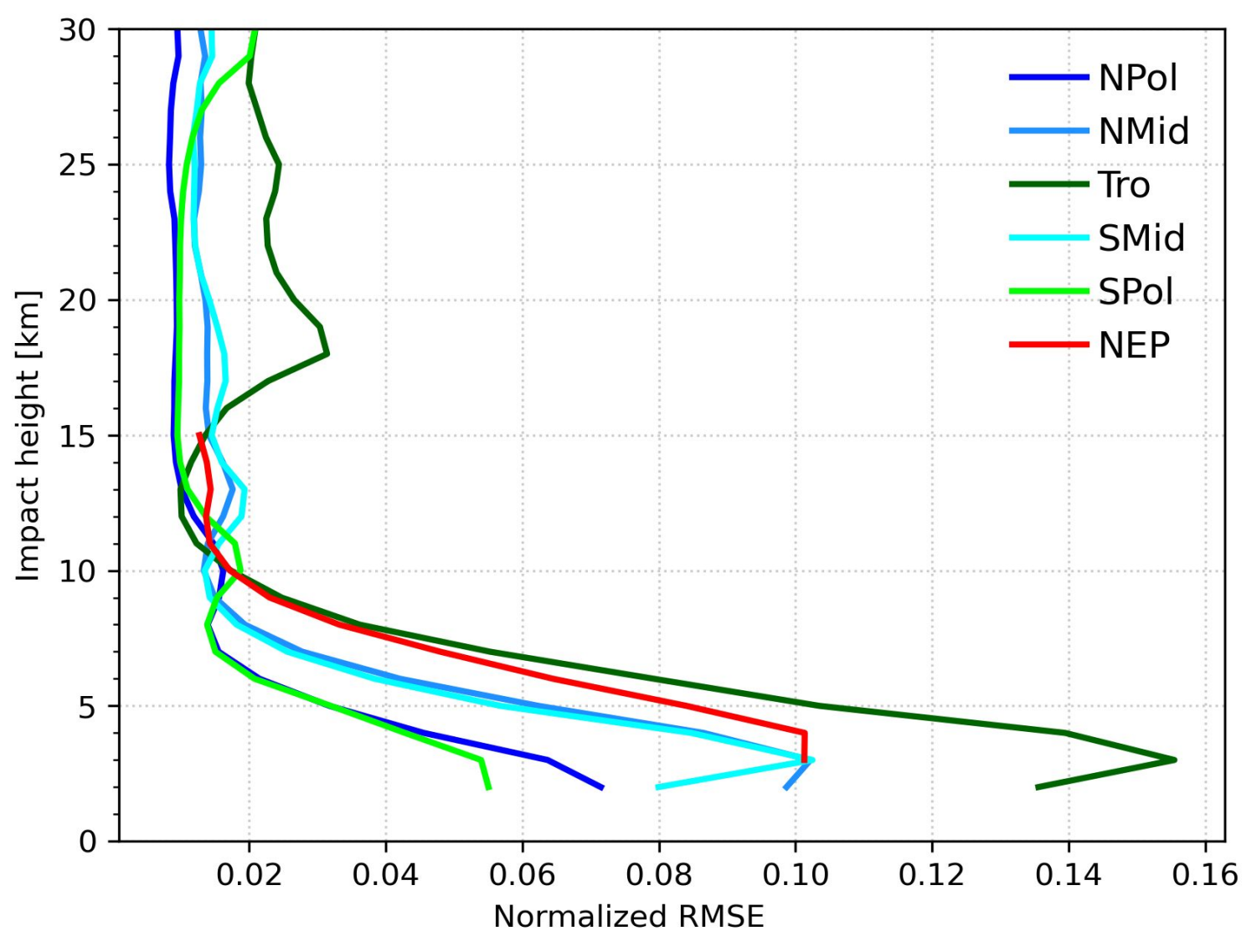
- Non-hydrostatic, unstructured mesh
- height-based terrain-following vertical coordinate
- global 60 km mesh, 55 levels, 30km top
- Mesoscale reference physical parameterizations (Table 2 in Liu et al. (2022))

**MPAS-JEDI (Liu et al 2022)**

- 6-hourly cycling
- LETKF, 30-members
- Period: 18Z 6 Jan. - 00Z 17 Jan. 2023
- Cold start at first forecast, warm start afterwards

| Experiments | Assimilated observations | |
|---|---|---|
| **ctrl** | sondes (radiosondes and dropsondes), aircraft, atmospheric motion vectors from geostationary and LEO satellites | |
| **aroba2d** | **ctrl** observations | GNSS ARO 2D bending angle (ROPP 2D modified operator)<br>- ARO observations organized by assimilation time window of 6h [-3h; +3h) |

**ARO observation error used:**

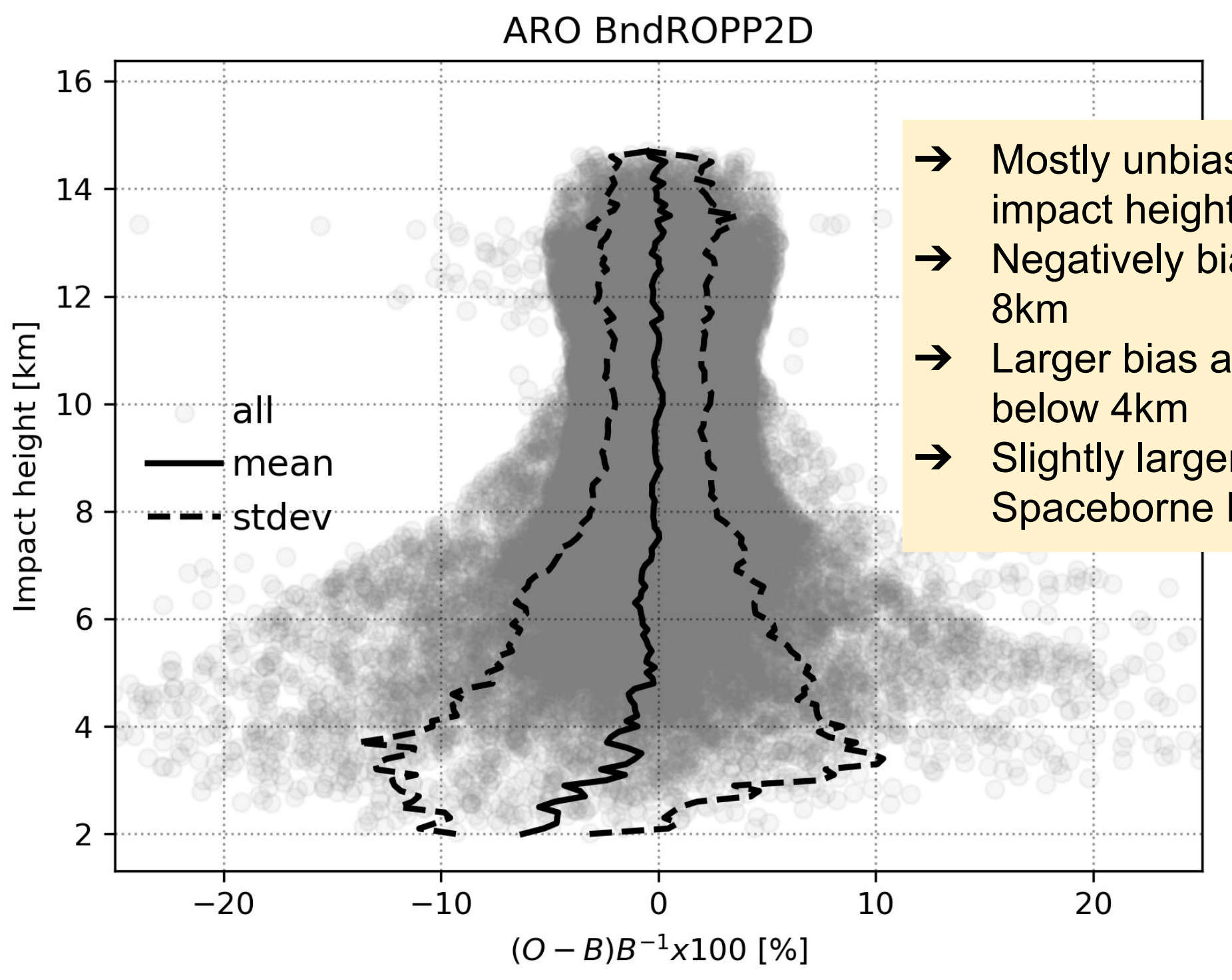


Error parameterized by latitude bands:
**NPol = 60. - 90. N**
**NMid = 30. - 60. N**
**Tro = 30. S - 30. N**
**SMid = 60. - 30. S**
**SPol = 90. - 60. S**

Corresponding Effective observation error used for the North Eastern Pacific (NEP) bands:
lon = 110. - 180. W
lat = 15. - 60. N

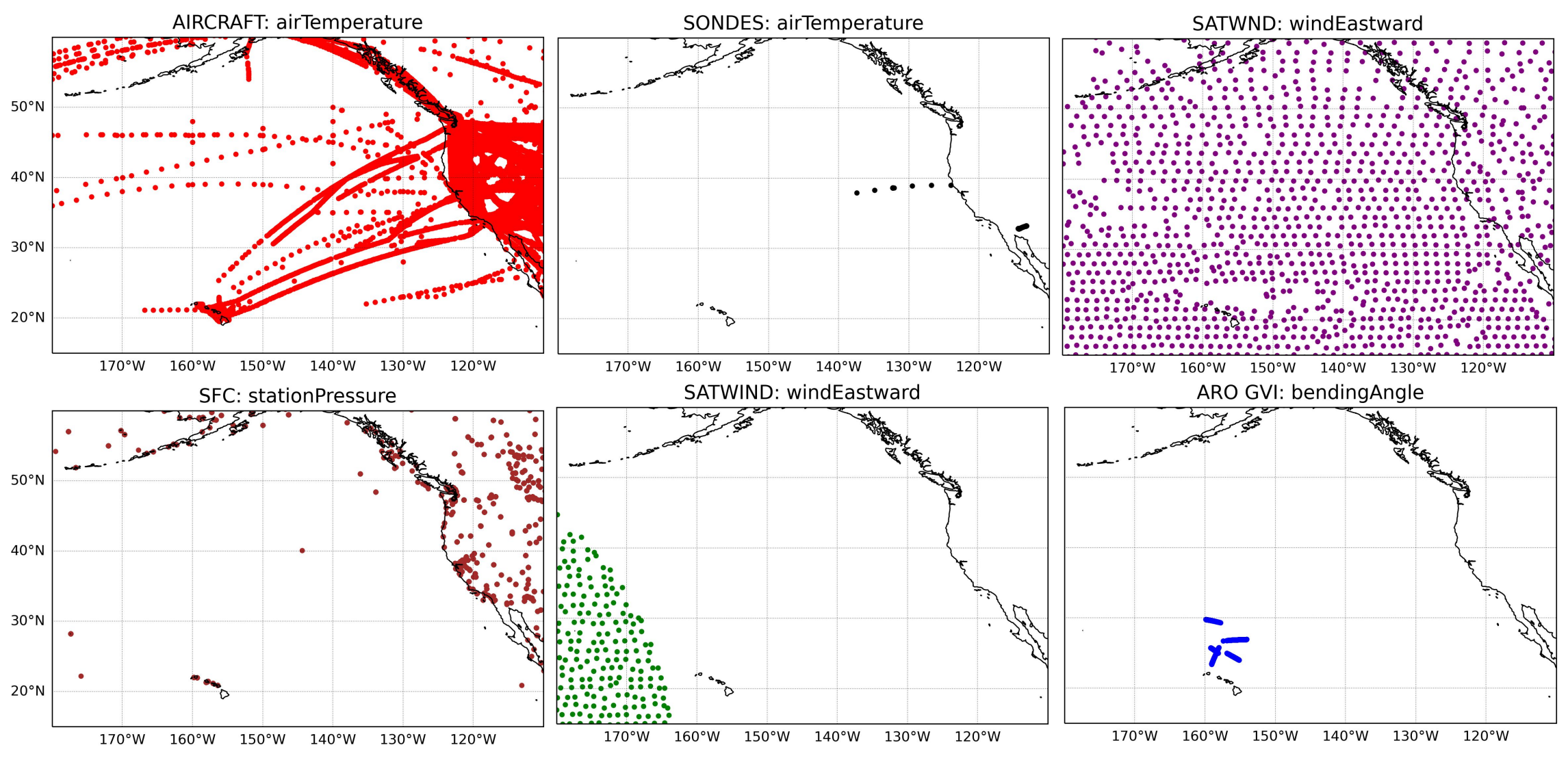
## Preliminary results

### Normalized OmB vertical profile, aggregated over the whole period and area



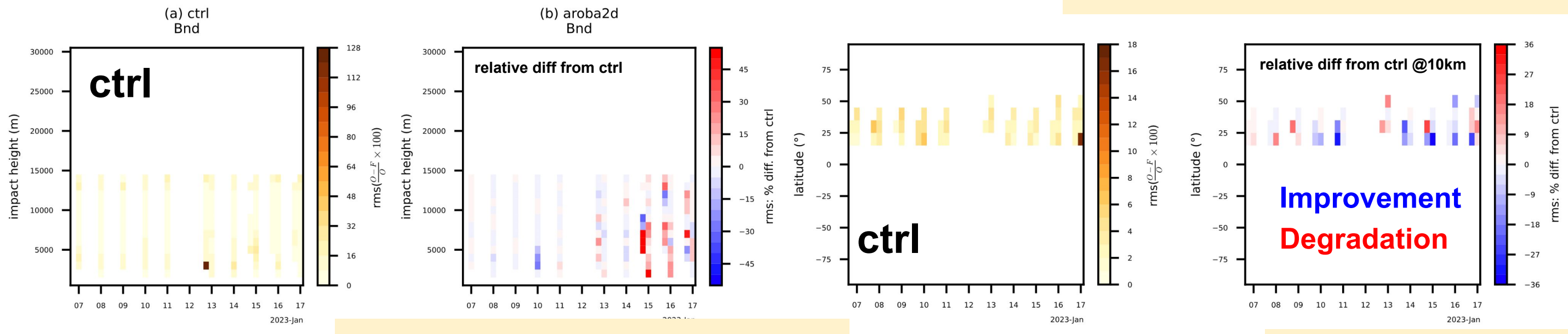
- Mostly unbiased 8-14km impact height
- Negatively biased below 8km
- Larger bias and stddev below 4km
- Slightly larger than Spaceborne RO above 8km

### Spatial distribution of assimilated observations in aroba2d at first cycle (2023010618)



### OmB differences (vs ARO obs)

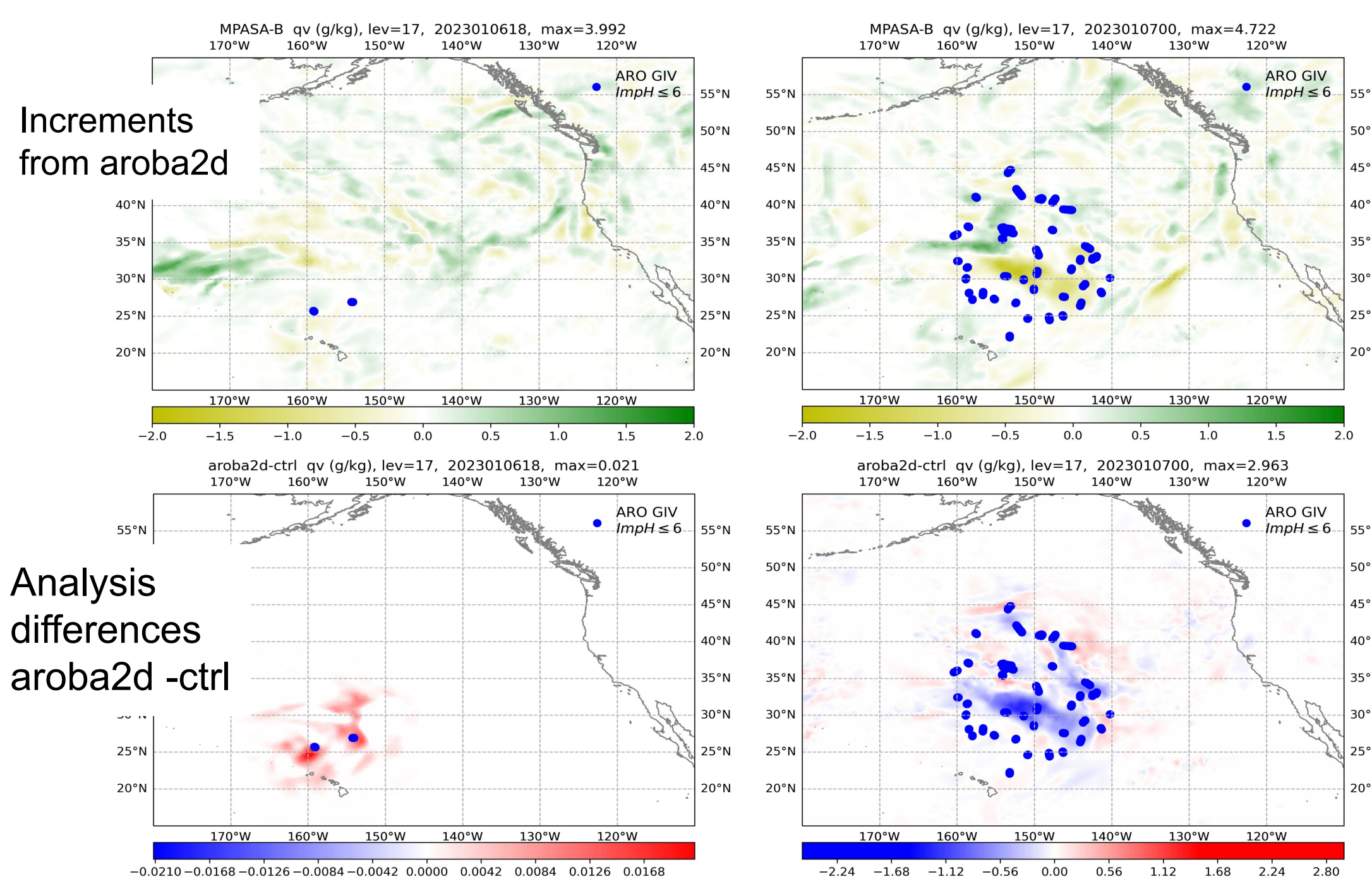
**Background > observations**



**Improvement on 1/10 day of extreme precipitation at landfall**

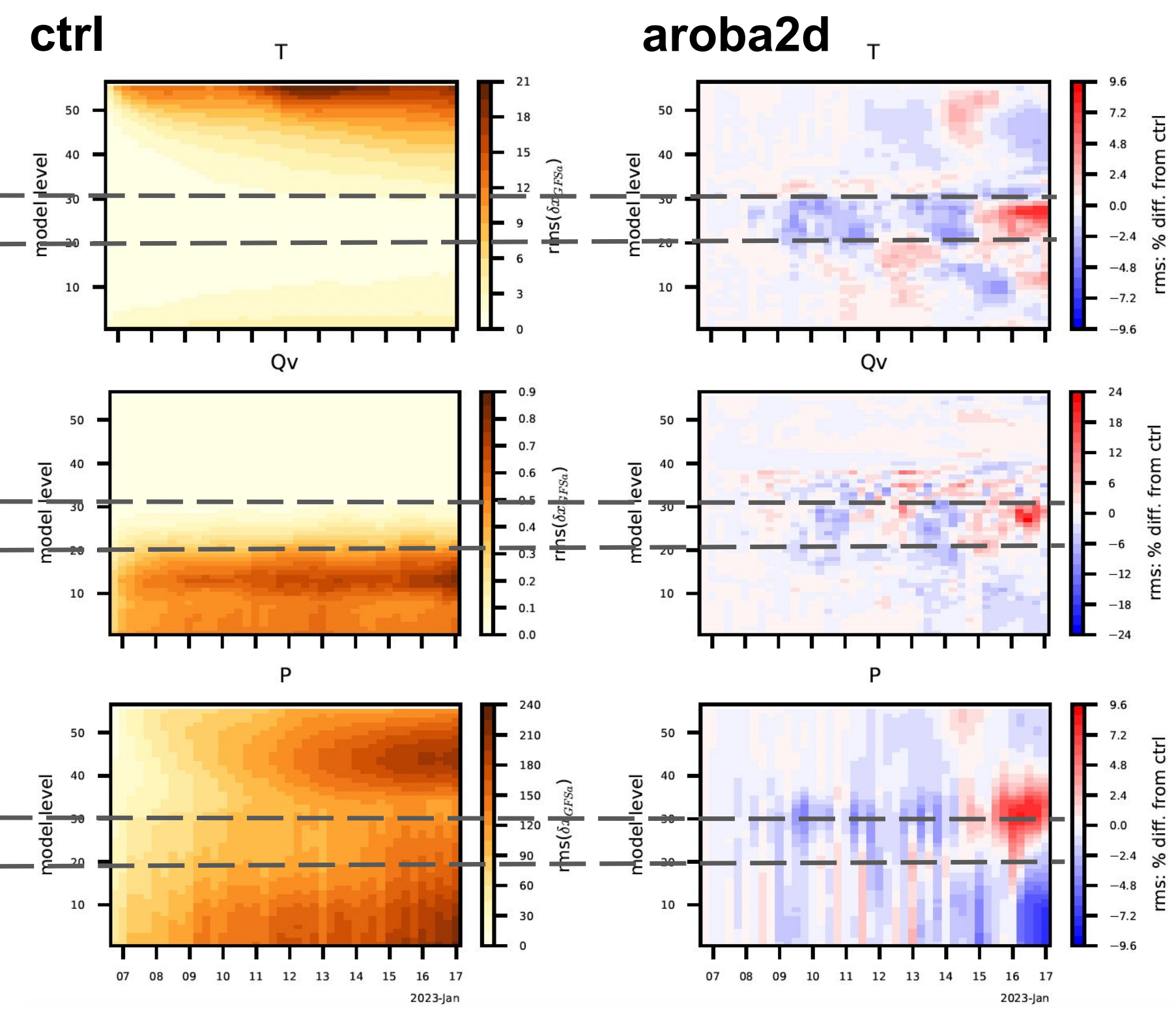
**Consistent improvement at 10 km**

### Analysis increments and differences for 2023010618 and 2023010700 @~2.8km



Qv increments due to ARO observations in the surrounding area, bringing the analysis closer to the observations

### MPAS 6-h forecast against GFS analyses



- Assimilating ARO positively impacts the MPAS 6-h forecast, especially around model level 30
- Some degradation is found the last 2 days (needs further analysis)

## Takeaways

- **We are able to assimilate ARO observations using the modified ROPP2D operator with LETKF in JEDI-MPAS;**
- **The OmB statistics show overall similar characteristics to space borne statistics, slightly larger std dev above 8 km;**
- **Adding ARO positively impacts the analysis and MPAS 6-h forecasts;**
- **The observation errors seem adequate for the study but a more detailed study of the errors is needed;**
- **Further analysis of the results is needed, in terms of precipitation and AR landfall;**
- **Future work will focus on increasing the horizontal resolution on the NEP domain and including ARO observation data assimilation in near-real time along with exploring variational data assimilation methods.**

## References

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## Acknowledgements

Data collection was funded by the California Department of Water Resources through the CW3E/NCEP Atmospheric Rivers Program, with aircraft facilities support from the U.S. Air Force Reserve Command 53rd Weather Reconnaissance Squadron and the NOAA Aircraft Operations Center. PH was supported in part by the Bekker Programme PPN/BEK/2020/1/00250/U/00001. AF Contract FA8730-21-9-0007 provided support for personnel training in JEDI/MPAS. Additional funding for ARO development at Scripps was provided by NSF GRANT AGS-1642650, NASA GRANT NNX15AU19G, and the US Army Corps of Engineers. Computational resources were provided by the CW3E COMET and NSF Cheyenne HPCMP facilities.