Center for Western Weather and Water Extremes
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

Improving Sampling Strategies for Atmospheric River Reconnaissance

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Chris Davis, Jake Liu (NCAR), James Doyle, Carolyn Reynolds (NRL)
Ashley Lundry, Jack Parrish, Paul Flaherty & the G-IV team (NOAA AOC)
Lt. Col. Ryan Rickert & the USAF C-130 team (USAF 53rd WRS)

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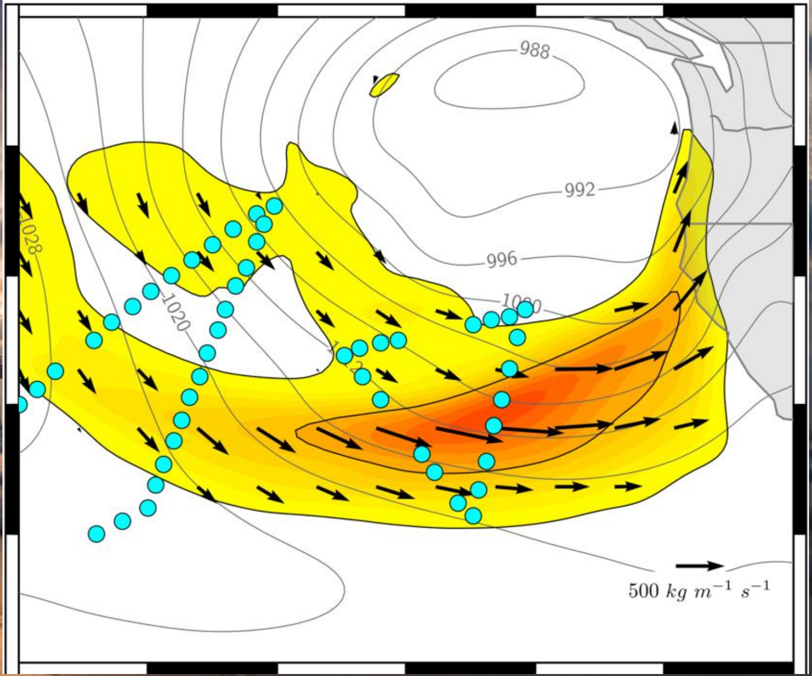

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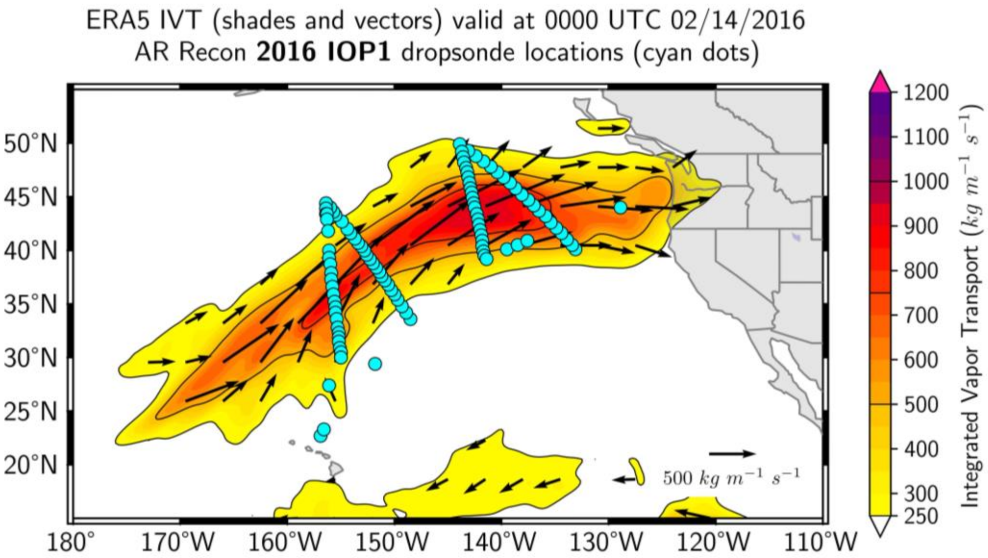
Outline

- Objectives and Research Questions
- CW3E West-WRF GSI Configuration
- Results for AR Recon 2016, 2018, and 2019
  - Highlight 1: Impact on model initial conditions
  - Highlight 2: Impact on the forecast skill of ARs and precipitation
- Results for AR Recon 2021
  - Highlight 3: Analyze AR Recon sampling strategy
    - Temporal distribution of dropsonde deployment
    - Spatial distribution of dropsonde deployment
- Results for AR Recon 2020
  - Highlight 4: Impact of dropsonde assimilation on the assimilation of satellite radiances
- Summary
- Ongoing work: AR Recon 2023

Objectives and Research Questions



Objectives

- Leveraging of AR Recon data for process-based studies
- Demonstrating the value of AR Recon data for numerical weather prediction

Research questions

I. How do dropsondes modify initial conditions in a regional model?

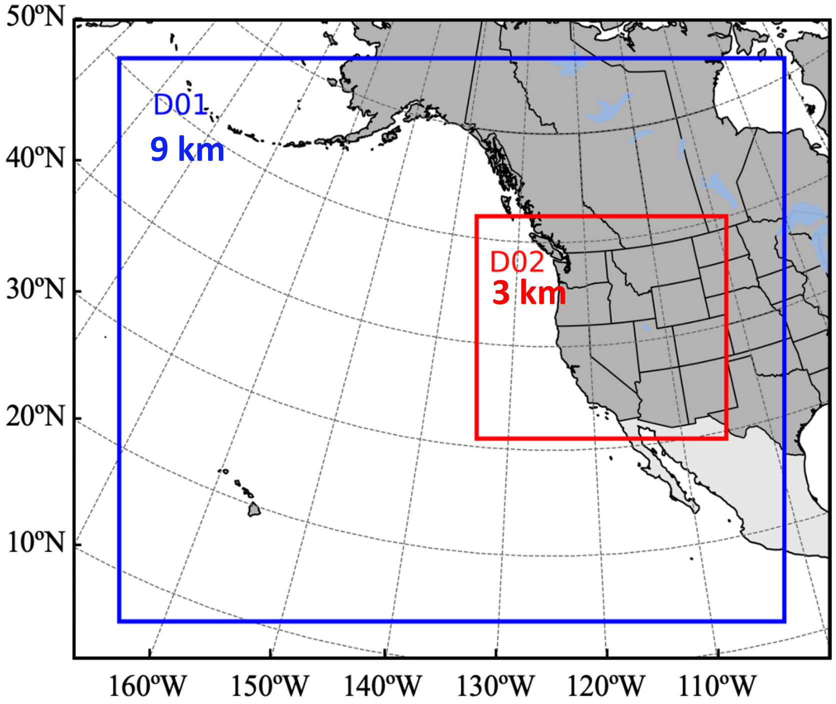
II. What is the impact of AR Recon data on the forecast skill of ARs and the precipitation?

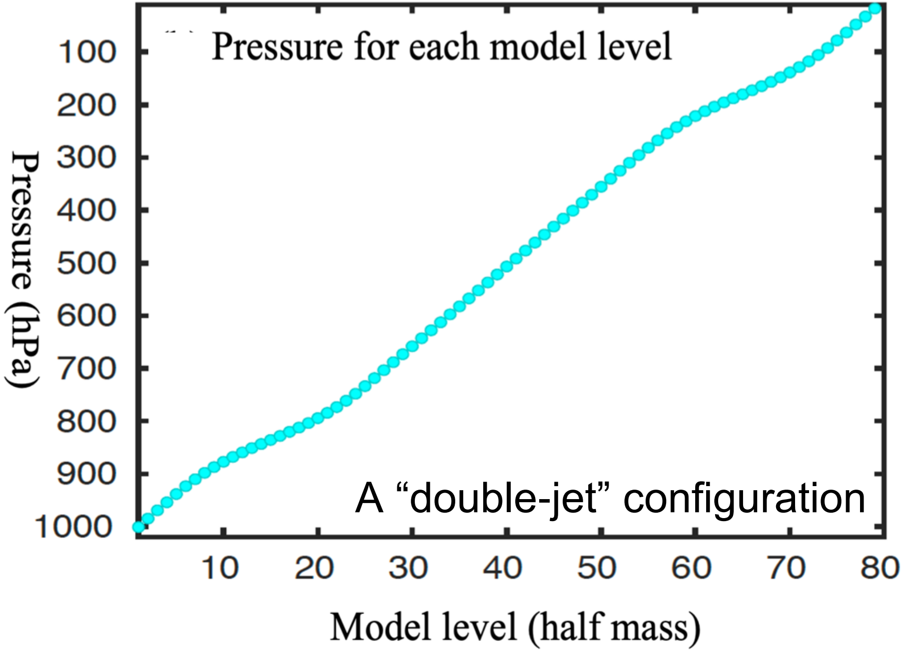
III. How does the temporal and spatial distribution of dropsondes impact the skill of landfalling ARs and the associated precipitation?

IV. What is the impact of dropsonde data on the assimilation of satellite radiances?

CW3E West-WRF/GSI Configuration

Forecasting model: West-WRF (a regional implementation of WRF-ARW)

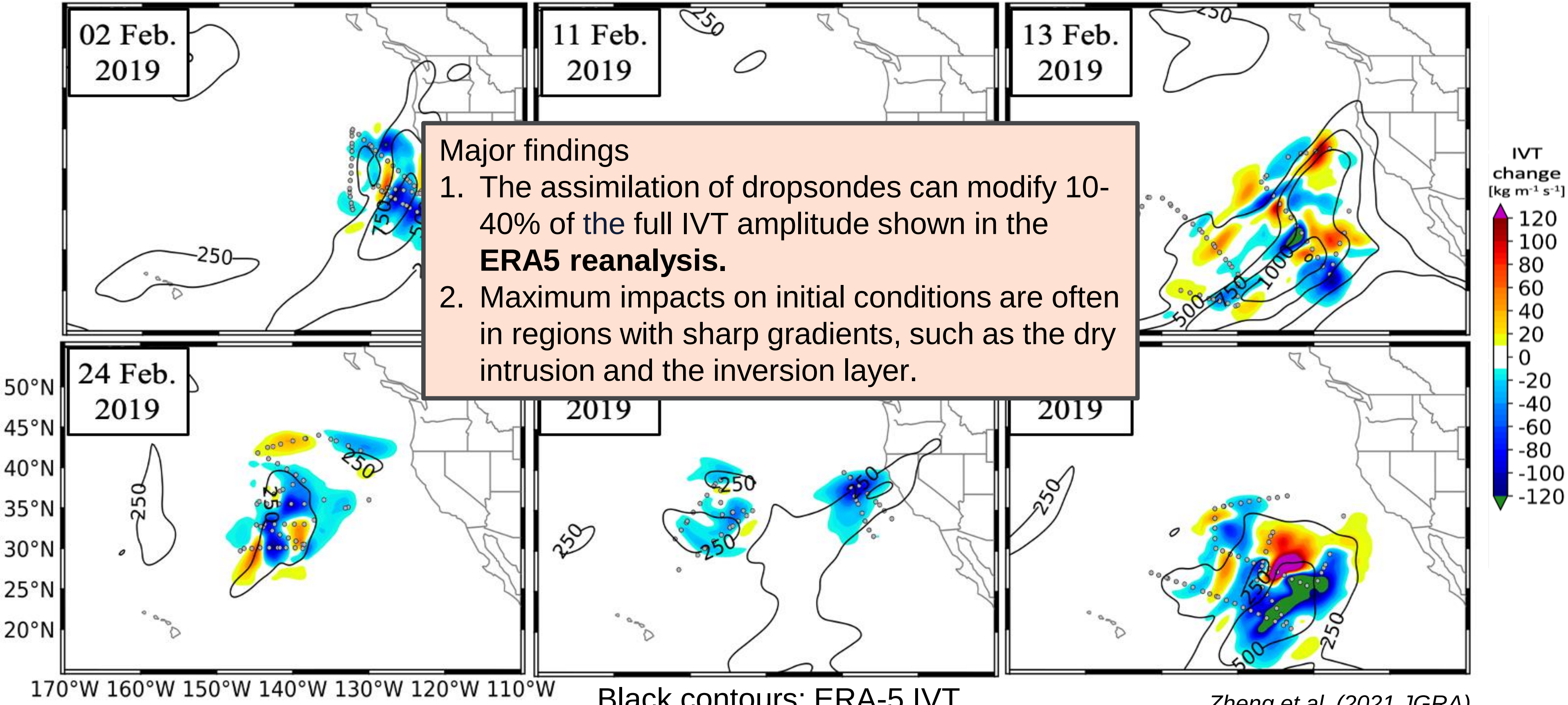




Assimilation system: GSI 4DEnVar; 6-hourly cycling; 30-mem ensemble input; observations: conventional data; GPS RO; AMVs; satellite radiances—AMSU-A, ATMS, MHS, SSMIS, AIRS, HIRS4, IASI

Highlight 1: Impact on Initial Conditions, WithDROP – NoDROP

Difference in integrated water vapor transport (IVT) at initial time



Major findings

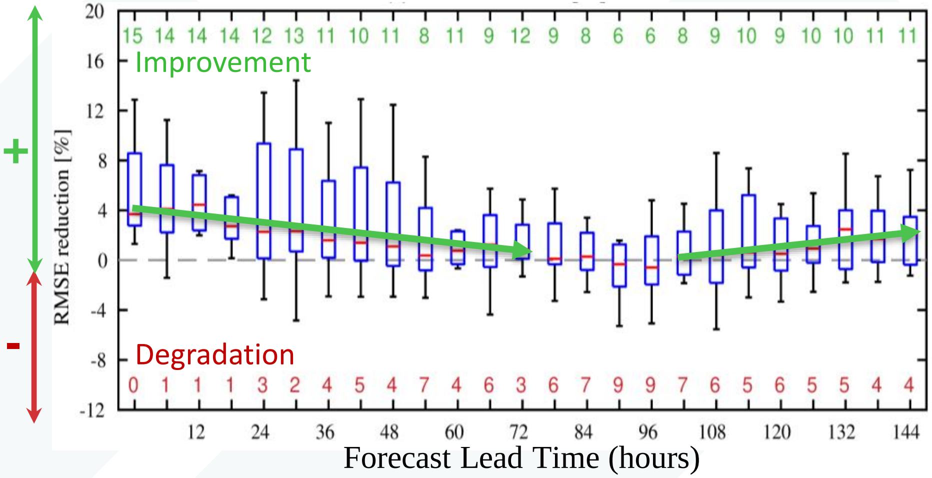
1. The assimilation of dropsondes can modify 10-40% of the full IVT amplitude shown in the **ERA5 reanalysis.**
2. Maximum impacts on initial conditions are often in regions with sharp gradients, such as the dry intrusion and the inversion layer.

Black contours: ERA-5 IVT

Zheng et al. (2021 JGRA)

Highlight 2: Impact on the Forecast Skill of ARs and Precipitation
15 IOPs in 2016, 2018-19

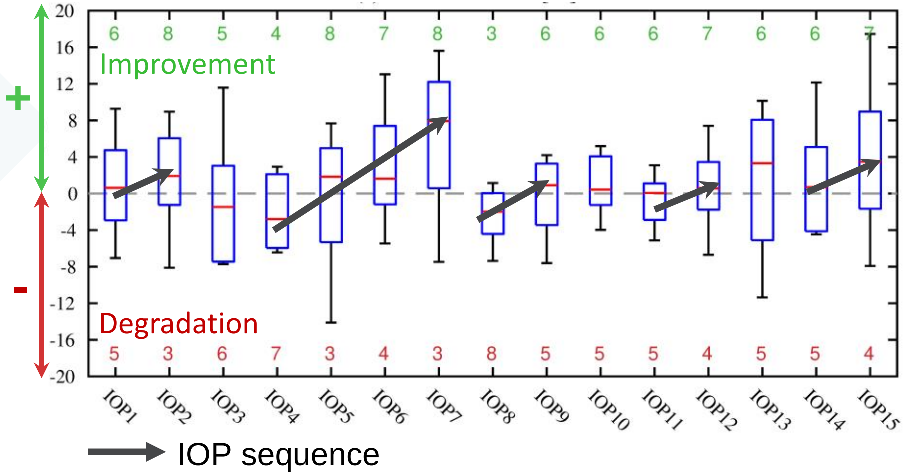
Impact on IVT



IVT verification domain: 15°N-60°N, 165°W-105°W; ground truth: ERA5

Dropsondes have reduced the forecast error of IVT over the Northeast Pacific with continuous improvement out to day 3.

Impact on Precipitation



IOP sequences (i.e., back-to-back IOPs every other day) have the most positive impact on improving the precipitation forecast skill over the US West.

Precip. verification domain: 30°N-50°N, 110°W-125°W; ground truth: Stage-IV

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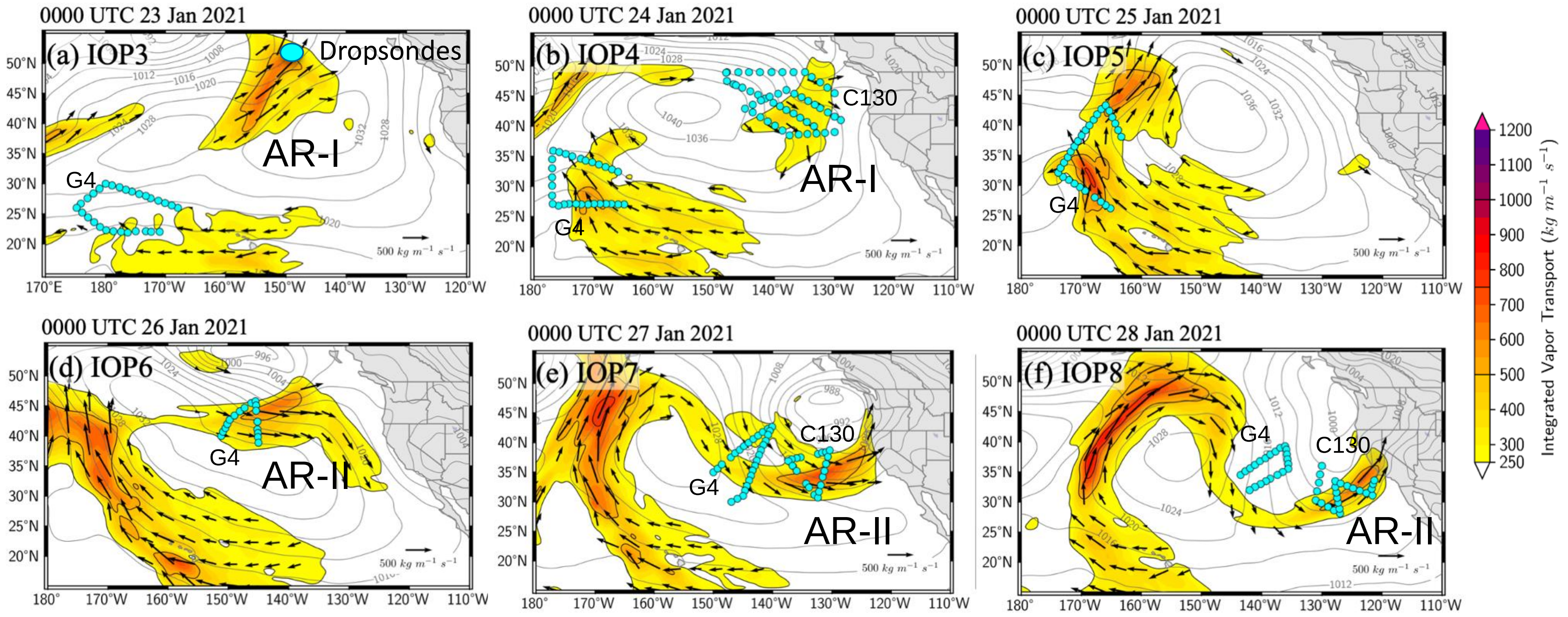
Zheng et al. (2021 JGRA)

Highlight 3: AR Recon Sequence, 23-28 January 2021



- The <u>first</u> 6-day flight sequence since the first AR Recon mission in February 2016
- A high-impact event included in the USS 2021 Billion-Dollar Weather and Climate Disasters by NOAA

Sampling Strategies – Dropsonde Temporal Distribution

- **Two baseline experiments**
  - "*Control*": assimilate AR Recon dropsonde data from all 6 IOPs at high vertical resolution (~200-300 data points per profile)
  - "*NoDrop*": as "Control" but without dropsondes
- **Temporal Sampling (TS) experiments – to explore impact of mission frequency**
  - "*TS2*": assimilate AR Recon dropsondes every other day
  - "*TS3*": assimilate AR Recon dropsondes every 3 days
  - "*TS5*": assimilate AR Recon dropsondes every 5 days (i.e., IOP7)

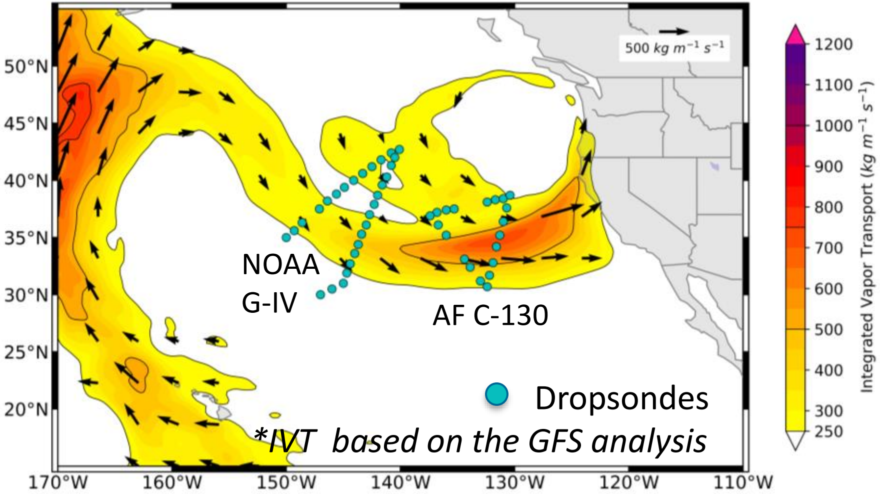
A summary of the use of dropsonde data used in baseline and TS experiments

Name & IOPs	IOP3 Jan 23	IOP4 Jan 24	IOP5 Jan 25	IOP6 Jan 26	IOP7 Jan 27	IOP8 Jan 28
Control	Y *	Y	Y	Y	Y	Y
NoDROP	N	N	N	N	N	N
TS2	Y	N	Y	N	Y	N
TS3	Y	N	N	Y	N	N
TS5	N	N	N	N	Y	N

**Y: YES (dropsonde data assimilated)*

Example: IOP 7 at 0000 UTC 27 January

Locations of dropsondes used for the "Control"



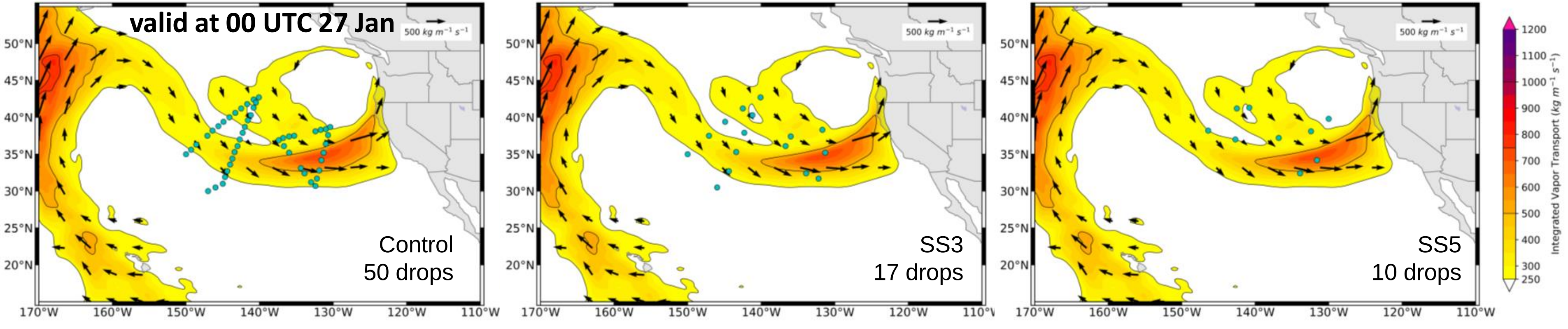
Sampling Strategies – Dropsonde Spatial Distribution

Spatial Sampling (SS) experiments – to test impact of dropsonde horizontal spacing

– "*SS3*": all IOPs, high vertical resolution, but every 3 dropsondes (e.g., 10 dropsondes out of 30)
– "*SS5*": same as Control, but every 5 dropsondes (e.g., 6 dropsondes out of 30)
– "*SS-C130*": same as Control but only from C-130 aircraft
– "*SS-G4*": same as Control but only from G-IV aircraft

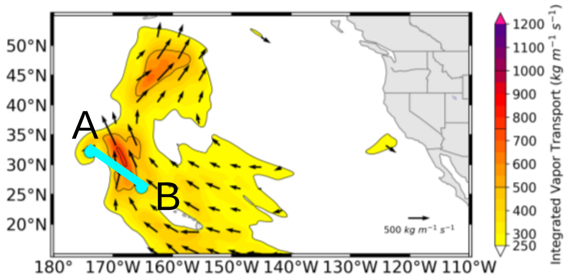
Name / IOPs	IOP3 Jan 23	IOP4 Jan 24	IOP5 Jan 25	IOP6 Jan 26	IOP7 Jan 27	IOP8 Jan 28
SS3	Y * (1/3)	Y (1/3)	Y (1/3)	Y (1/3)	Y (1/3)	Y (1/3)
SS5	Y (1/5)	Y (1/5)	Y (1/5)	Y (1/5)	Y (1/5)	Y (1/5)
SS-C130	N	Y	N	N	Y	Y
SS-G4	Y	Y	Y	Y	Y	Y

* Y(1/3, 1/5): assimilated 1/3 or 1/5 dropsondes, Y: full horizontal resolution

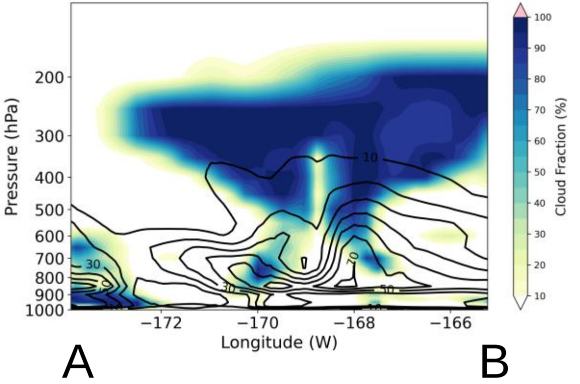


Results from TS EXPs — Cross section vapor flux (vq) difference

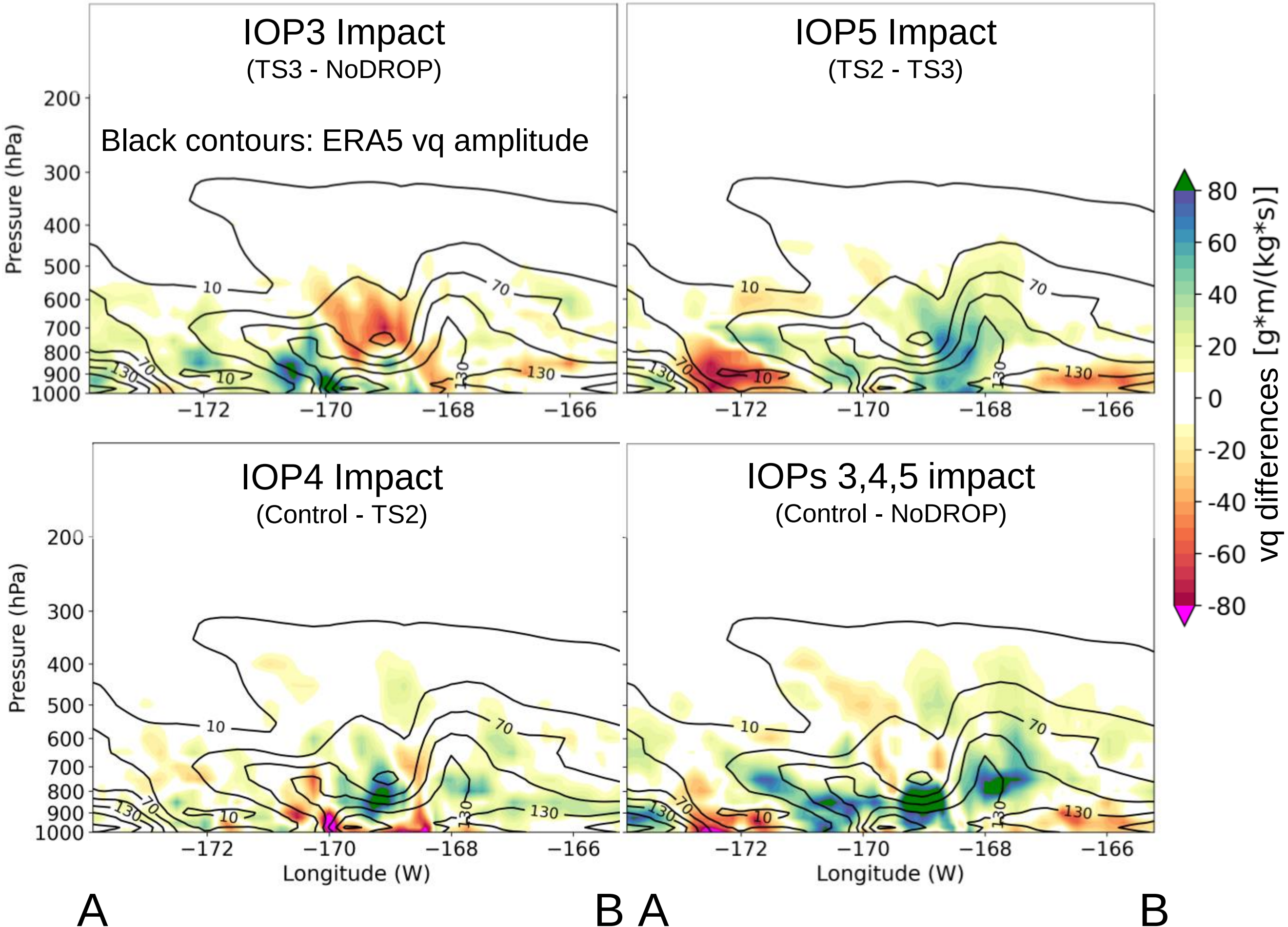
IOP5: Valid at 00 UTC 25 Jan



Black contours: ERA5 IVT



Black contours: ERA5 layered IVT



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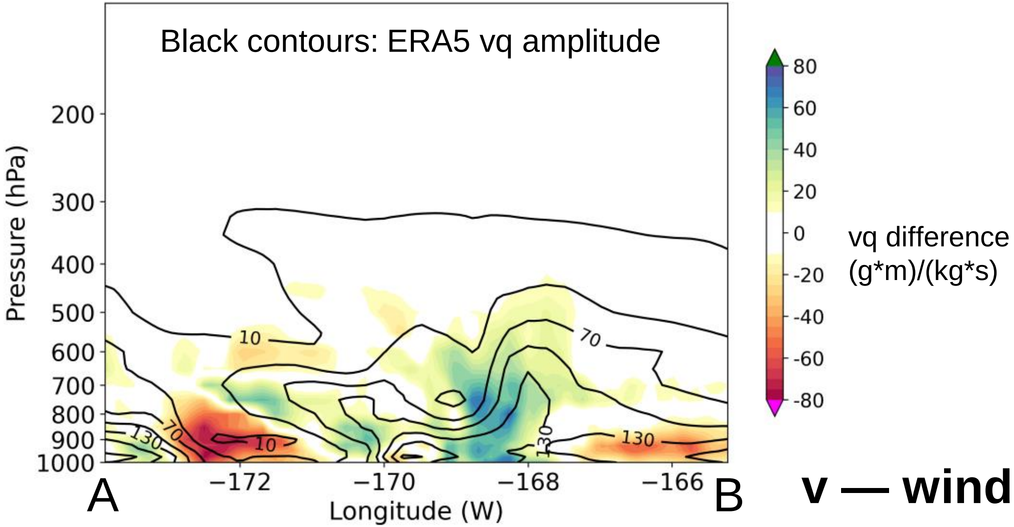
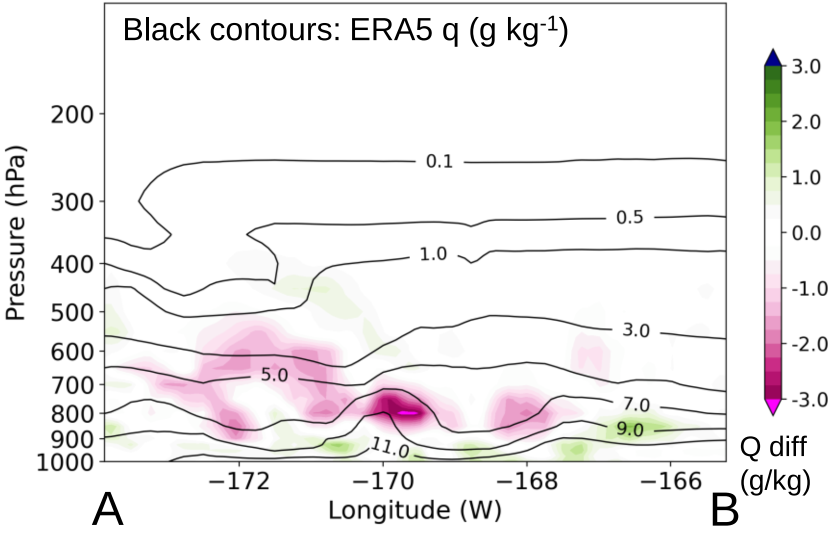
IOP5 Impact

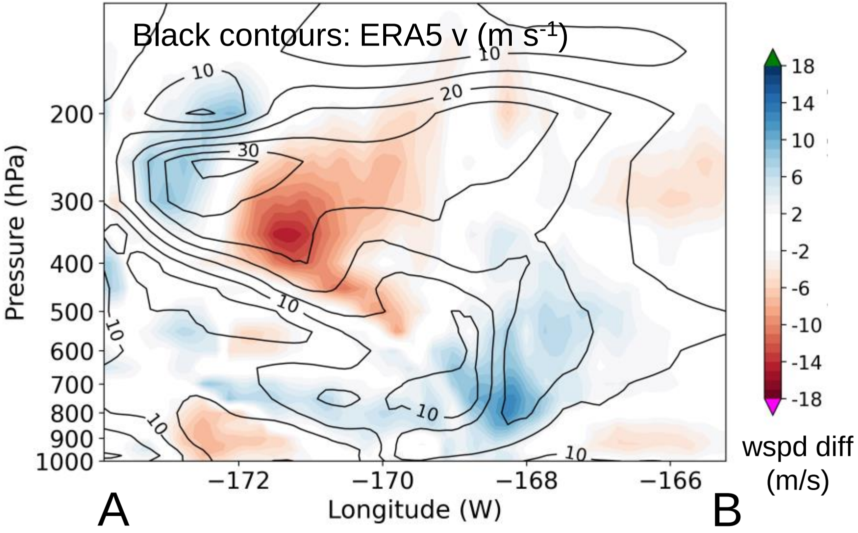
(TS2 - TS3)



q — humidity

v — wind speed

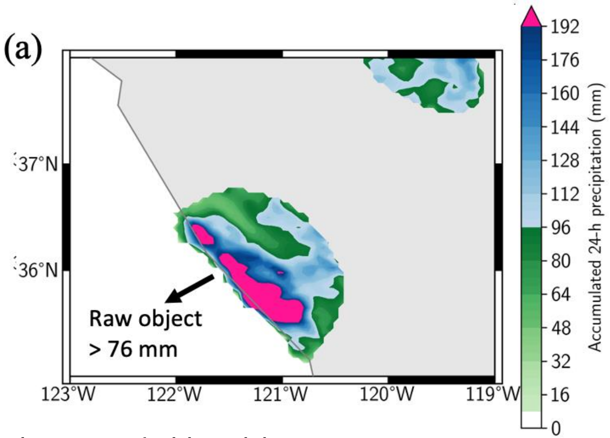


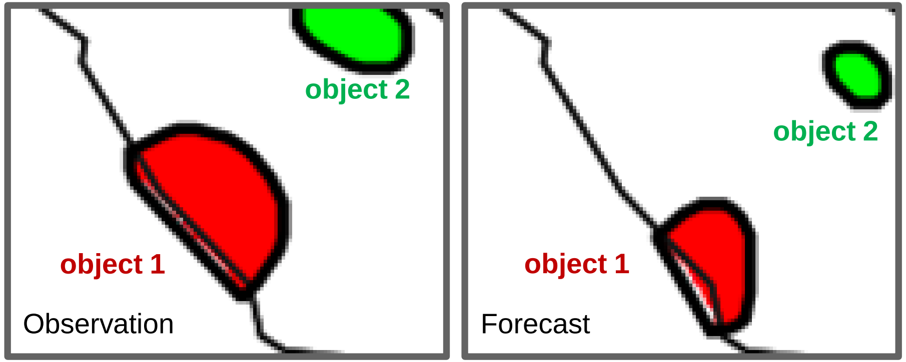


Compare baseline EXPs — precipitation forecasts

Met-MODE Validation

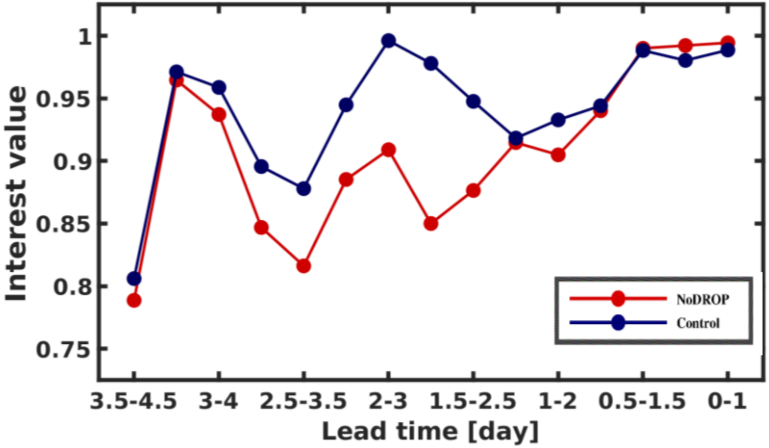
Valid: 12Z 27–28 Jan 24-h accumulated precipitation

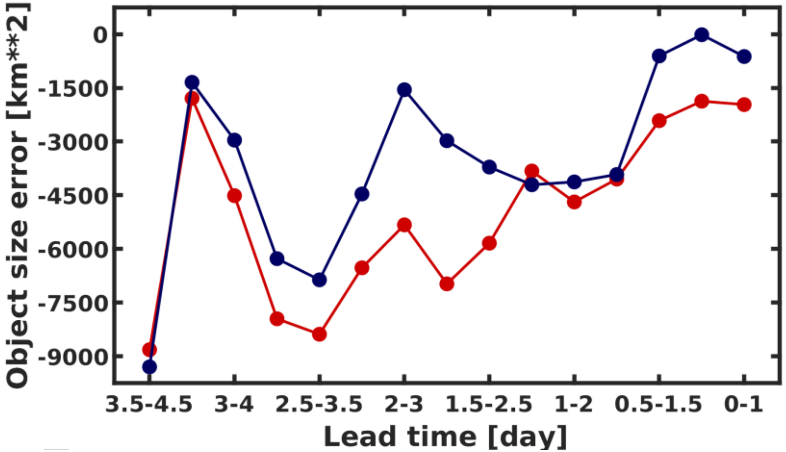




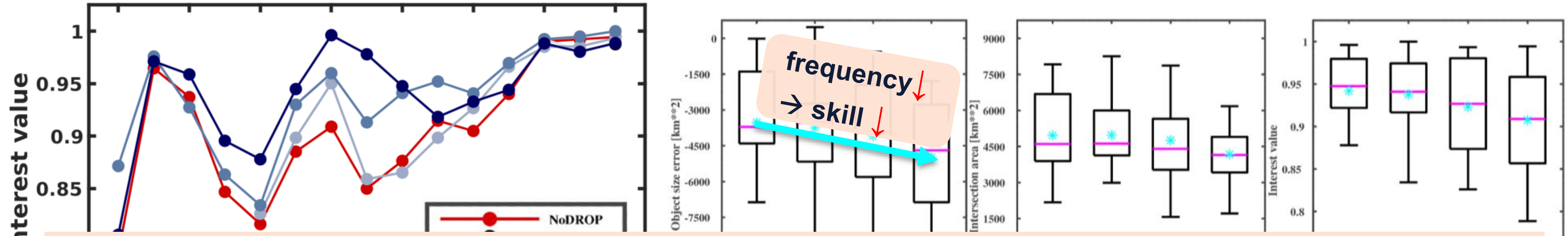
Skill for the coastal object (1)

The higher the better



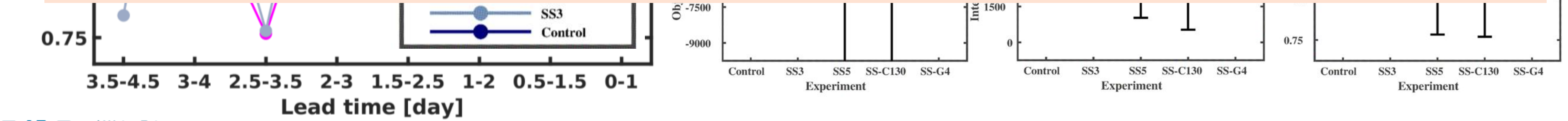


Results from TS and SS EXPs — precipitation forecasts



Major findings

1. Decreased temporal and spatial resolution in general degraded the QPF skill. The worst skill was seen in NoDROP, TS3, and SS5. Dropsondes can significantly improve the forecast skill of coverage of heavy precipitation.
2. Future operational AR Recon missions incorporate daily mission or back-to-back flights, at least maintain current dropsonde spacing, support high resolution data transfer capacity on the C-130s, and utilize G-IV aircraft in addition to C-130s.



and Water Extremes

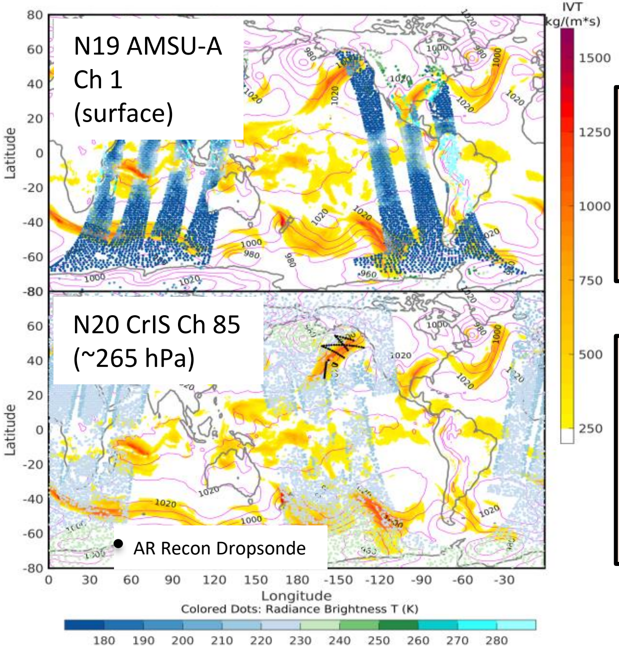
Figure source: Zheng et al. 2023 (MWR, submitted)

Highlight 4: Impact of Atmospheric River Reconnaissance Dropsonde Data on the Assimilation of Satellite Data in GFS

Purpose: Investigate impact of AR Recon data on the assimilation of radiances

Data and Models: Observational data used in the data denial experiments (i.e., Control vs. Deny) for dropsondes using GFS-GDAS at NCEP.

Two types of satellite observations for a 6-h GDAS window

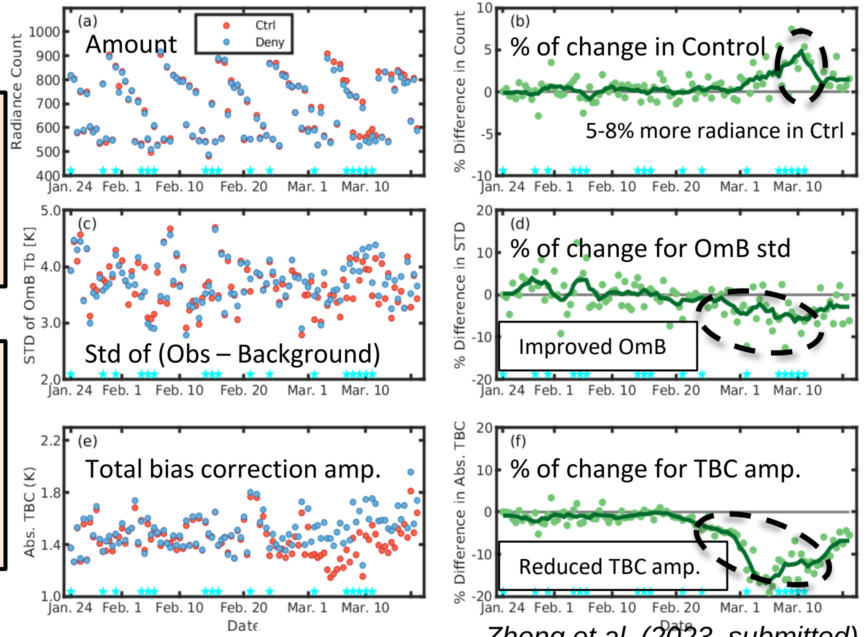


PNA region: 20°N-75°N, 40°W-180°W

Major finding 1: the assimilation of dropsondes results in an increase of 5-10% in the amount of tropospheric radiances assimilated

Major finding 2: The assimilation of dropsonde data results in reduced total bias corrections for radiance data needed by modeling systems to use radiances.

Comparison of N19 AMSU-A channel 1 radiance in Control and Deny



Zheng et al. (2023, submitted)

Summary

The assimilation of dropsondes can modify 10-40% of the IVT amplitude field in the analyses. Dropsondes improve the representation of ARs near sharp gradients, as in the presence of dry intrusion and an inversion layer.

Dropsondes reduce the forecast error of IVT over the Northeast Pacific with continuous improvement out to day 3. IOP sequences have the most positive impact on improving the precipitation forecast skill over the US West.

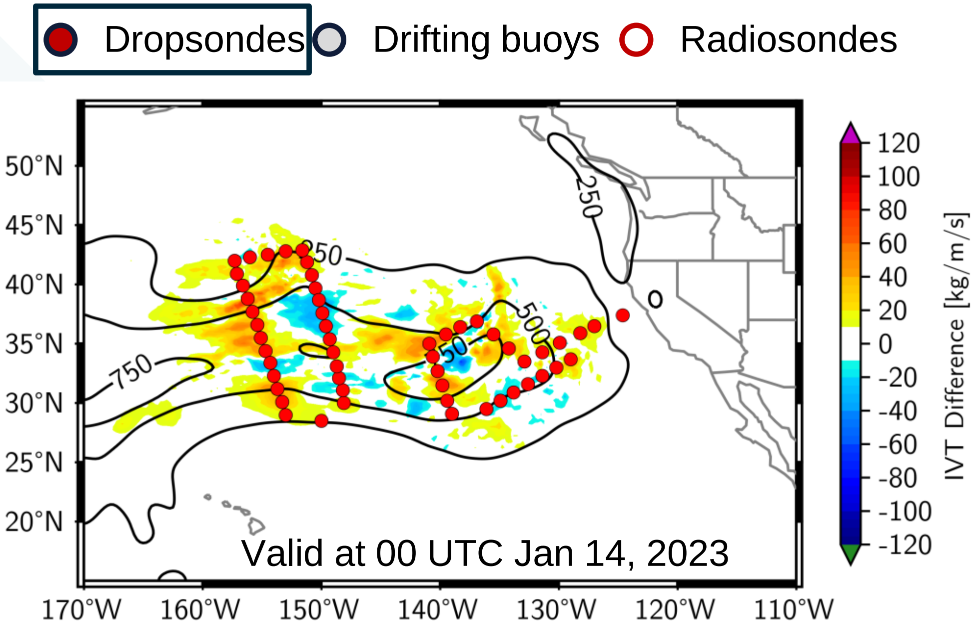
Dropsonde data can lead to an increase of 5-10% in the amount of tropospheric radiance assimilated.

Decreased temporal and spatial resolution in general degrades the QPF skill. Dropsondes can significantly improve the prediction of heavy precipitation spatial coverage.

Do these results indicate that additional samples (from more aircrafts, basins, IOPs, etc.) would further improve numerical weather predictions?

Ongoing Work

- Evaluate impact of dropsondes collected in AR Recon 2023 (data impacts under various AR seasons).
- Assess impact of other types of AR Recon data, including drifters, radiosondes (Minghua, Anna, & Xingren), and airborne radars (Jia Wang & Minghua & NOAA AOC).
- Assess data impacts in the framework of probabilistic forecasting.



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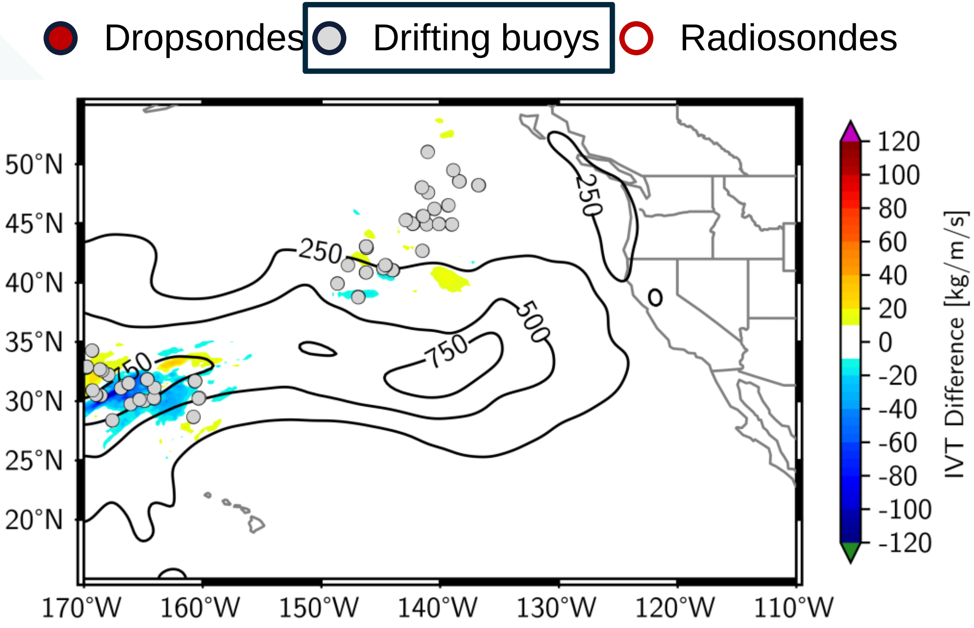

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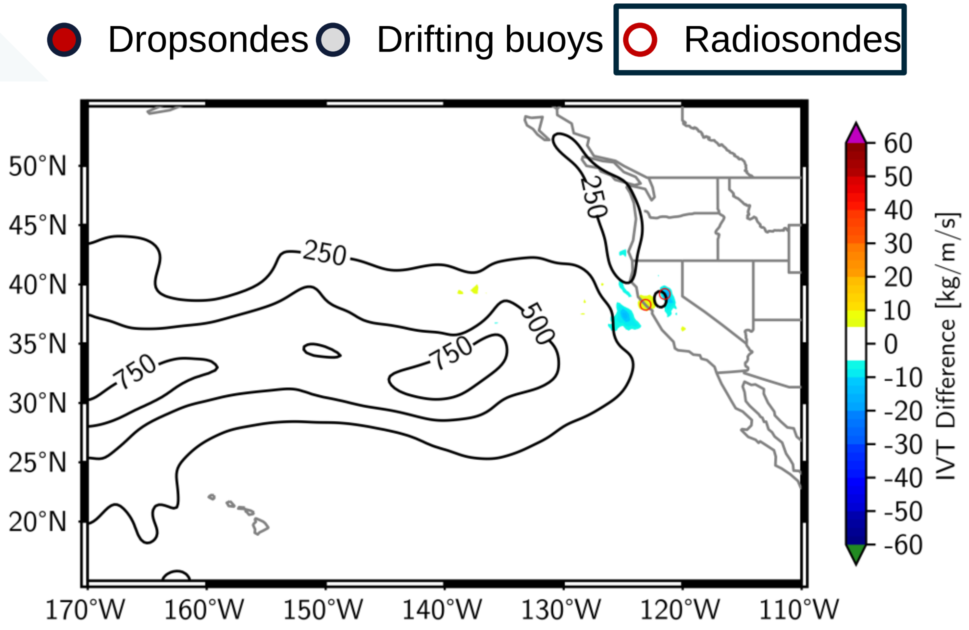

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2. Zheng, M., Delle Monache, L., Cornuelle, B. D., Ralph, F. M., Tallapragada, V. S., Subramanian, A., Haase, J. S., Zhang, Z., et al., 2021. Improved Forecast Skill through the Assimilation of Dropsonde Observations from the Atmospheric River Reconnaissance Program. Journal of Geophysical Research: Atmospheres, 126(21), p.e2021JD034967.
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Acknowledgements

The dropsonde data were collected during several field campaigns involving many scientists, engineers, air crews, project managers, program managers, including individuals from ***NOAA, NASA, the U.S. Air Force (USAF)****, and* ***elsewhere****. Thanks to the entire AR Recon operational team, including all those who contributed to this project. Special thanks to the AR Recon quantitative tool team.*

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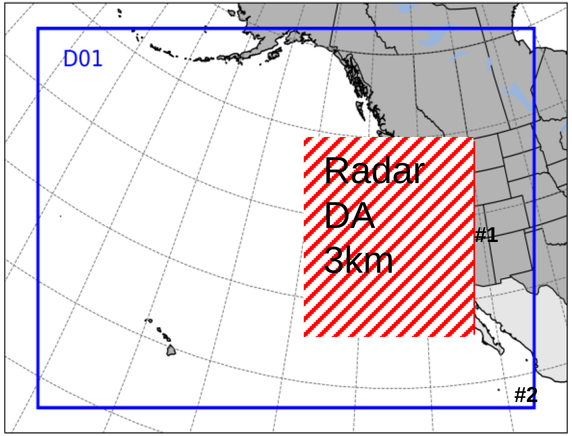
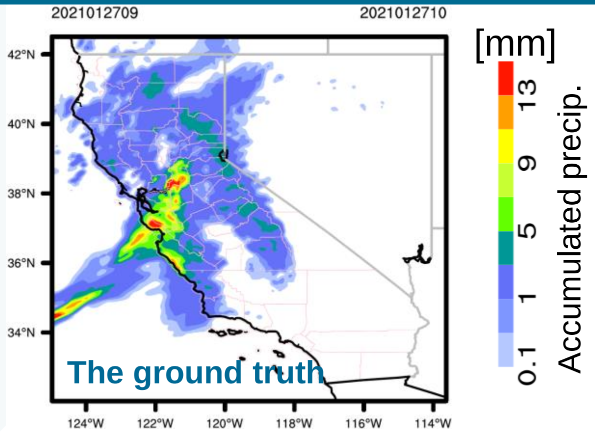
- Extra slides

Highlight 4: the Development of Radar DA Framework for West-WRF



DA run:
- NEXRAD reflectivity (dominate)
- Conventional data
- AMVs

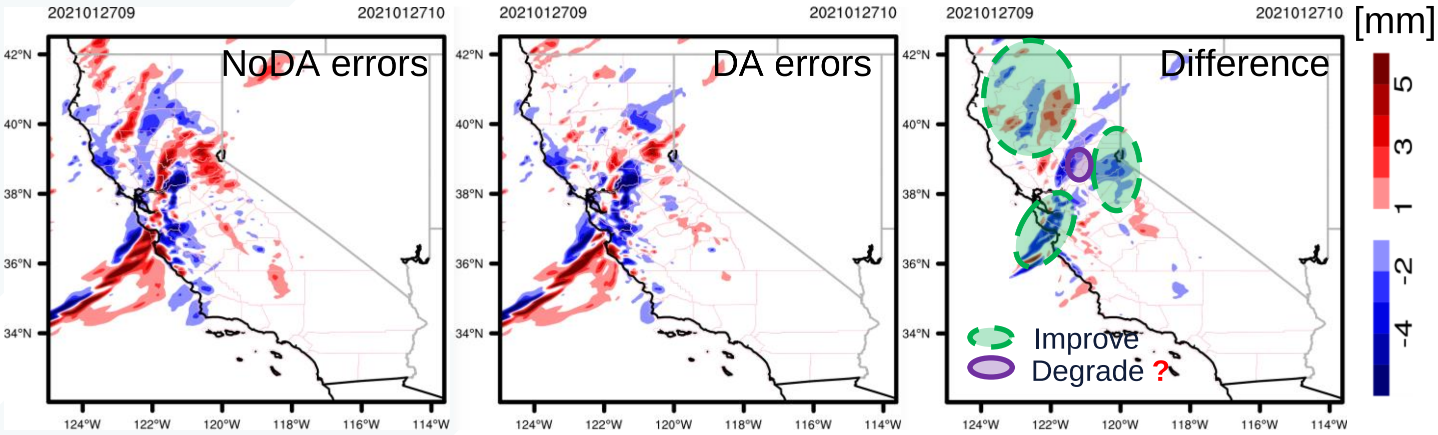


An example:
1-h accumulated precip.
from 0900 UTC to 1000 UTC
on Jan 27, 2021

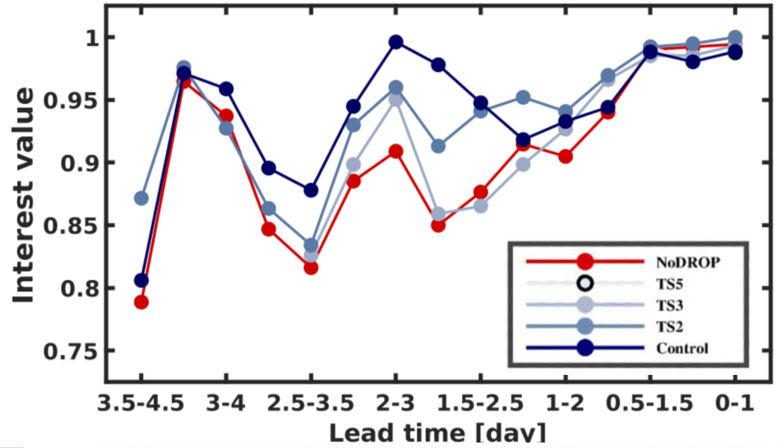
MRMS hourly data - truth

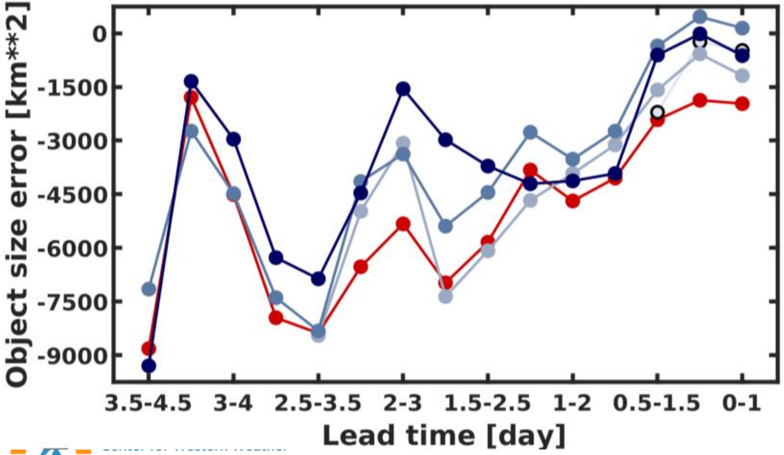
Preliminary findings:
1. Positive impact on weak-moderate precip.
2. Mixed results for heavy precip.

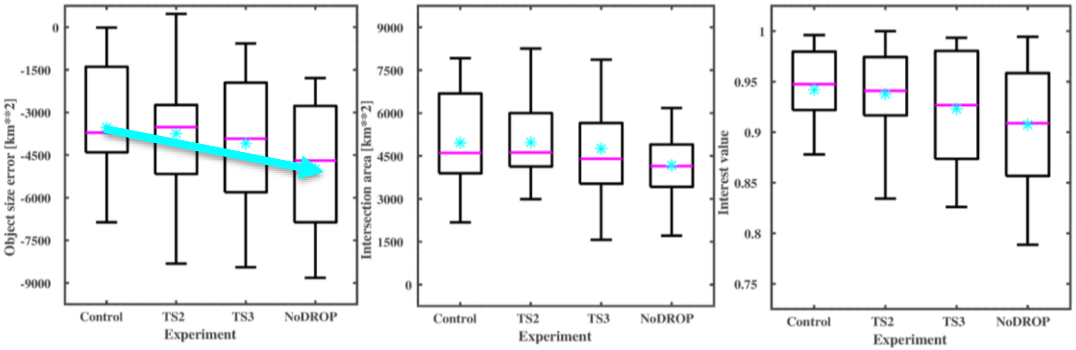
Expected impact from TDR radar data:
Improve mid-upper tropospheric dynamics and moisture, & short-term precipitation skill.



Results from TS EXPs — precipitation forecasts







	(Control, TS2)	(Control TS3)	(Control NoDROP)	(TS2, TS3)	(TS2, NoDROP)	(TS3, NoDROP)
Object size	0.82	0.59	**0.12**	0.74	**0.19**	0.36
Intersection area	0.99	0.77	**0.19**	0.74	**0.15**	0.37
Interest Value	0.82	0.39	**0.11**	0.50	**0.16**	0.53

The 1st Exp. has less errors

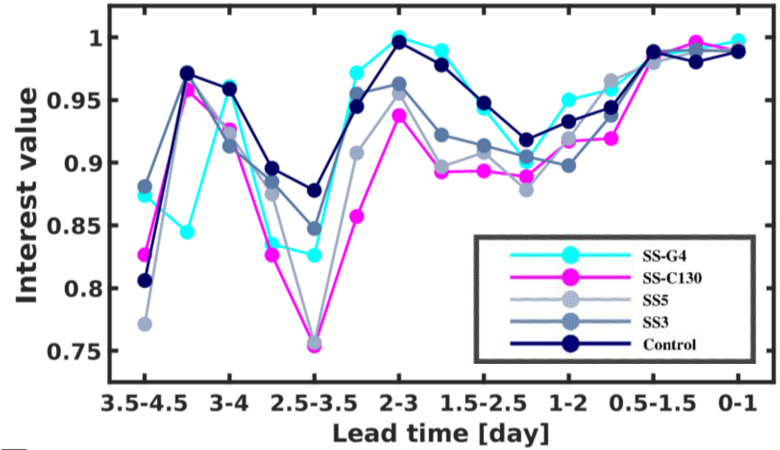
P-value 0.0 0.2 0.4 0.6 0.8 1.0

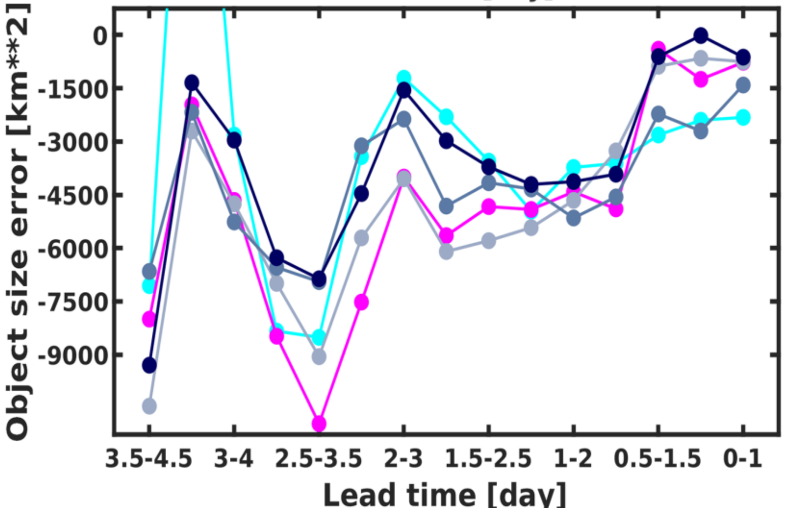
The 2nd Exp. has less errors

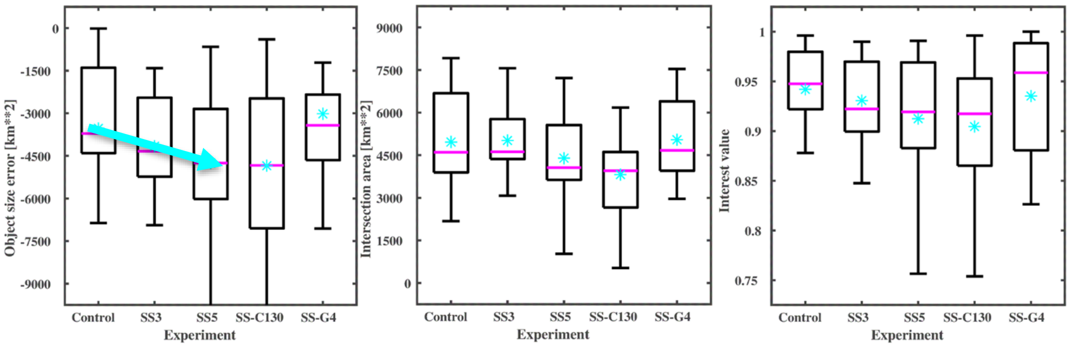
P-value 0.0 0.2 0.4 0.6 0.8 1.0

Greater significance ← → Lower significance

Results from SS EXPs — precipitation forecasts







	(Control, SS3)	(Control, SS5)	(Control, SS-C130)	(SS3, SS5)	(SS3, SS-C130)	(SS5, SS-C130)
Object size	0.44	0.23	0.21	0.51	0.45	0.93
Intersection area	0.92	0.36	**0.08**	0.25	0.40	0.36
Interest Value	0.53	**0.20**	**0.10**	0.41	0.22	0.76

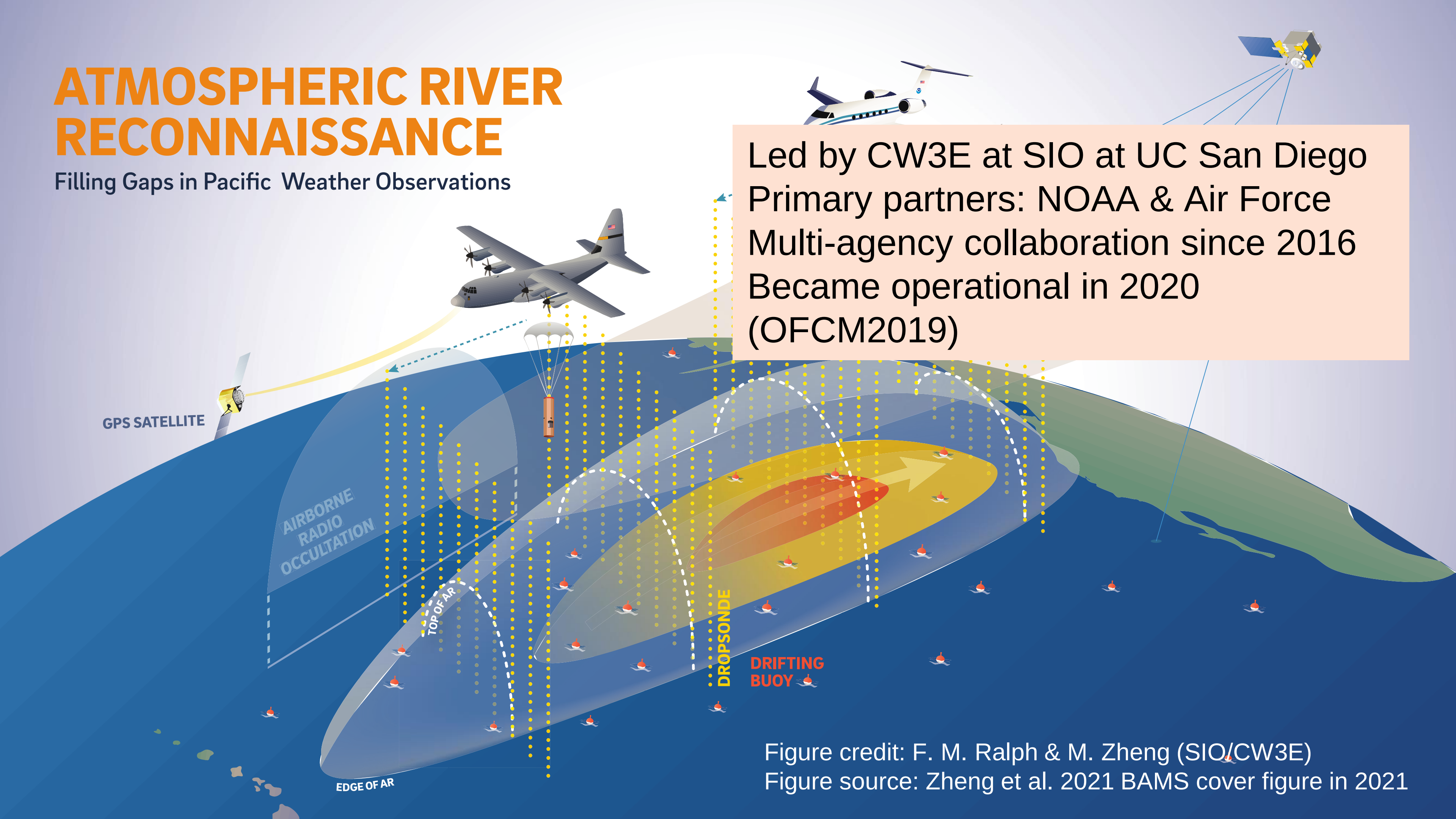
The 1st Exp. has less errors

P-value 0.0 0.2 0.4 0.6 0.8 1.0

The 2nd Exp. has less errors

P-value 0.0 0.2 0.4 0.6 0.8 1.0

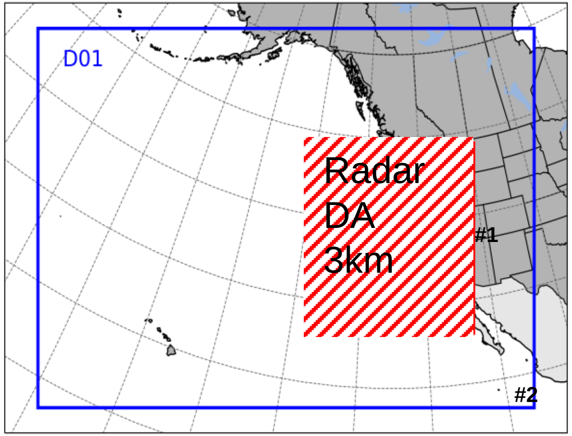
Greater significance ← → Lower significance



Led by CW3E at SIO at UC San Diego
Primary partners: NOAA & Air Force
Multi-agency collaboration since 2016
Became operational in 2020 (OFCM2019)

Figure credit: F. M. Ralph & M. Zheng (SIO/CW3E)
Figure source: Zheng et al. 2021 BAMS cover figure in 2021

Highlight 4: the Development of Radar DA Framework for West-WRF



The **first** radar DA framework with direct reflectivity assimilation capability for ARs in the West Coast

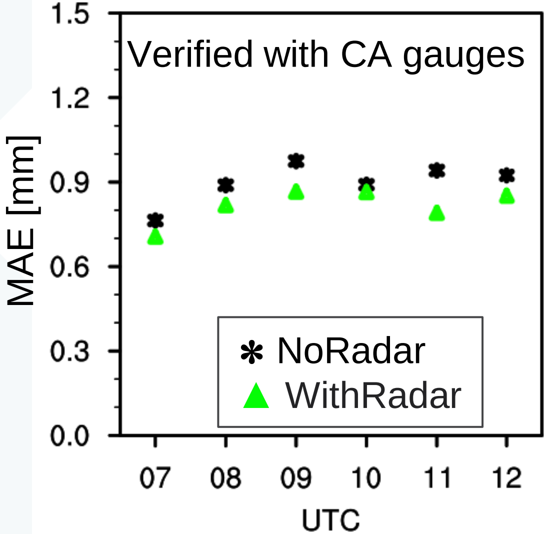
Assimilated observations

- NEXRAD reflectivity & radial wind
- Conventional data
- AMVs

Experiment set-up

- "*NoRadar*": assimilate all conventional data and AMVs
- "*WithRadar*": similar as "NoRadar" but adding radar reflectivity and radial wind

Verify hourly precipitation forecasts for the initial time from 0600 UTC to 1100 UTC on Jan 27, 2021



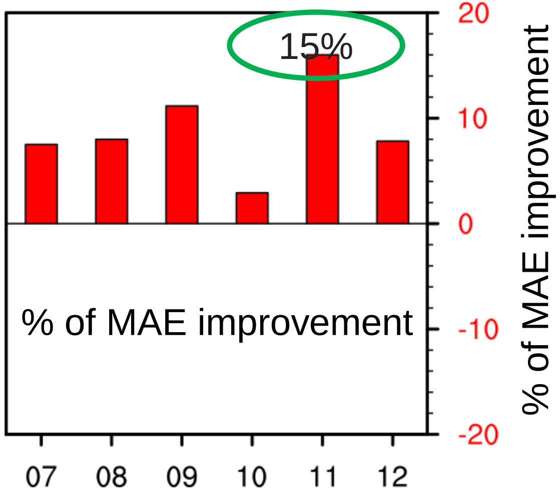


Figure credit: Jia Wang (CW3E)

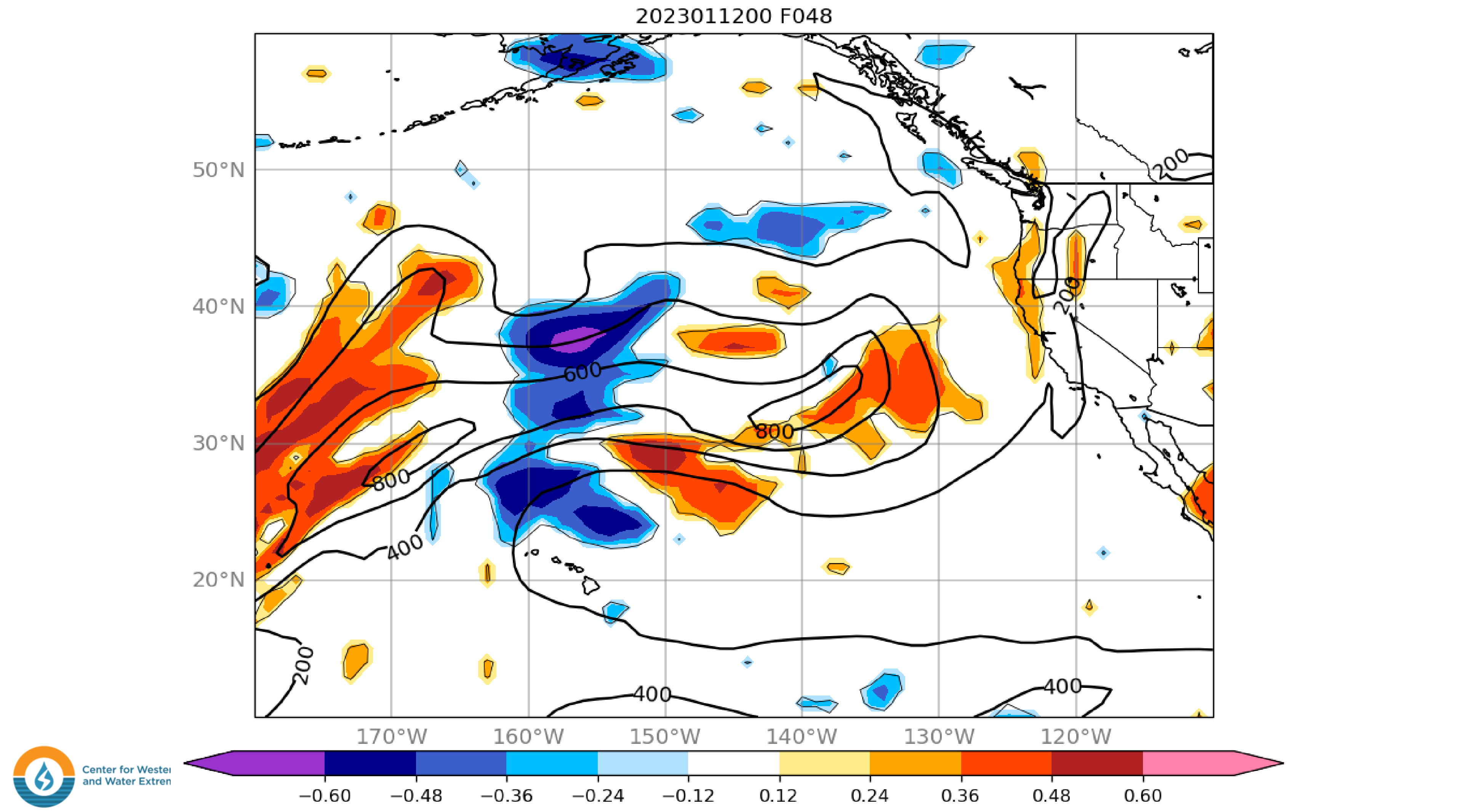
Preliminary findings:

1. Overall Positive impact on weak-moderate precip.
2. Large uncertainty appears in QPE products (Stage-IV vs. .

Expected impact from Tail-Doppler Radar data:

Improve mid-upper tropospheric dynamics and moisture, & short-term precipitation skill.

Center for Western Weather and Water Extremes


2023011200 F048
50°N
40°N
30°N
20°N
170°W
160°W
150°W
140°W
130°W
120°W
200
400
600
800
−0.60
−0.48
−0.36
−0.24
−0.12
0.12
0.24
0.36
0.48
0.60
Center for Wester
and Water Extren