A Review of AR RECON Modeling, DA and Impact Studies at the US Naval Research Laboratory

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Outline:

1. **Results from AR RECON dropsonde impact study in the US Navy's Global Model NAVGEM**
2. **Results from AR RECON drifting buoy impact study in NAVGEM**
3. **2019 Valentine's Day case study using adjoint sensitivity and observation impact from the US Navy's mesoscale model COAMPS**

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Atmospheric River Reconnaissance Workshop June 27-29 2023

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Systems and Experimental Design

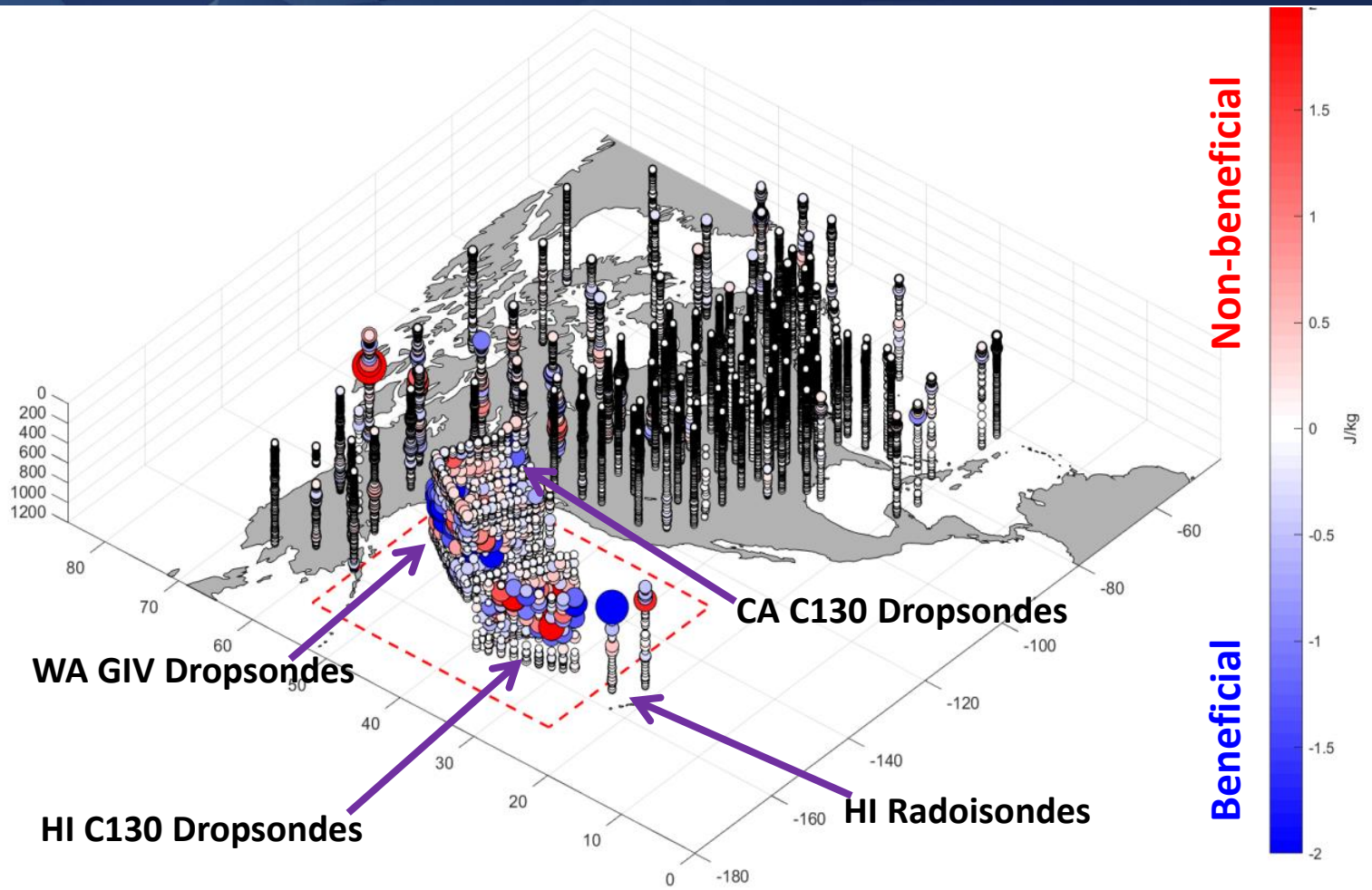
Systems:

- NAVGEM: Navy Global Environmental Model
  - 31-km resolution model, 100-km resolution DA increments
  - Data Assimilation – hybrid 4-d VAR
- COAMPS: Coupled Ocean/Atmosphere Mesoscale Prediction System
  - 15-km resolution
  - Data Assimilation – 3-d VAR and 4-d VAR

Tools:

- Forecast Sensitivity/Observation Impact (FSOI, Langland and Baker 2004): Uses the adjoints of forecast model and DA system to calculate impact of each ob on the 24-h forecast error
- Data Denial Studies: Run the DA-Forecast system with and without AR RECON obs to examine impact on analyses and forecast errors
- Adjoint sensitivity: identify local and remote features that impact storm evolution and precipitation (also used for targeted observations)

1: 2018 Dropsonde Impact in NAVGEM



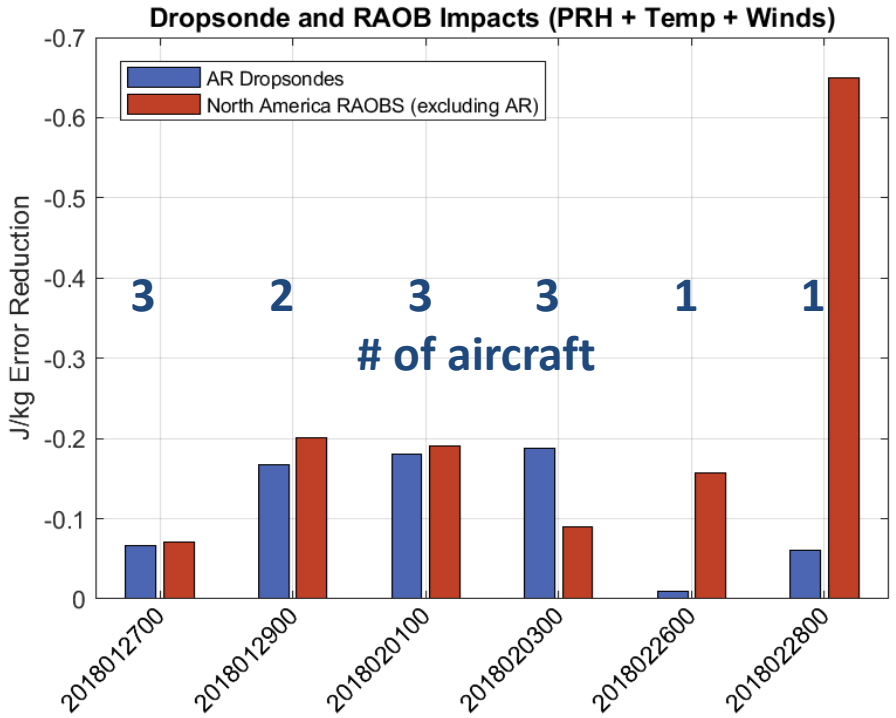
Wind ob impacts (10^{-3} J kg^{-1}) for IOP 2018020300 Size & color of spheres give FSOI value

FSOI allows one to calculate impact of each individual observation. This plot shows the impact from each wind observation as a function of pressure level for each dropsonde and North American Radiosonde.

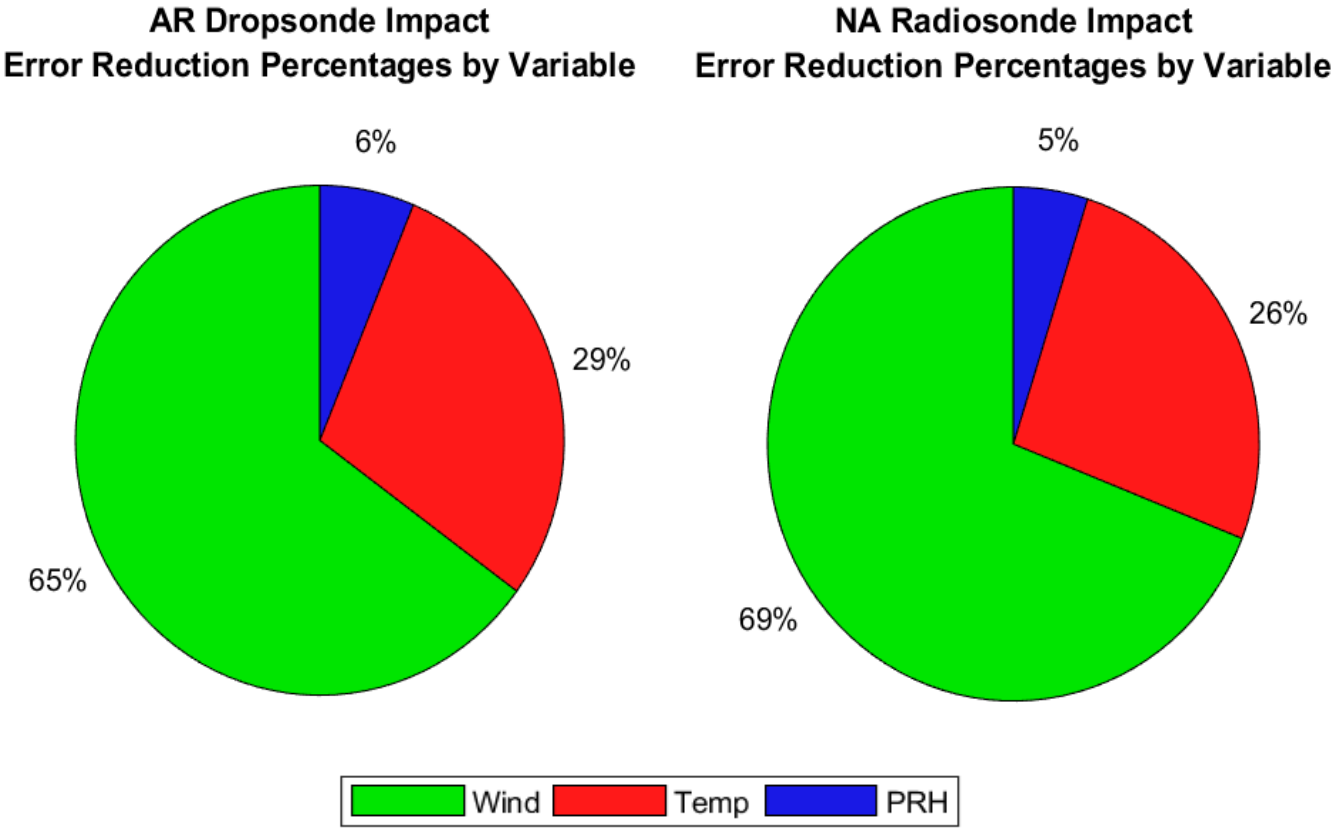
Stone et al. (2020) evaluated FSOI by variable and compared to NA Radiosondes. Also used DA statistics to learn about model error and evaluate assumed error statistics.

Stone, R. E., et al. 2020: Atmospheric River Reconnaissance Observation Impact in the Navy Global Forecast System. Mon. Wea. Rev., 148, 763-782. https://doi.org/10.1175/MWR-D-19-0101.1

1: 2018 Dropsonde Impact in NAVGEM



24-h Forecast Error (global moist TE) reduction for dropsondes (blue), NA RAOBS(red)

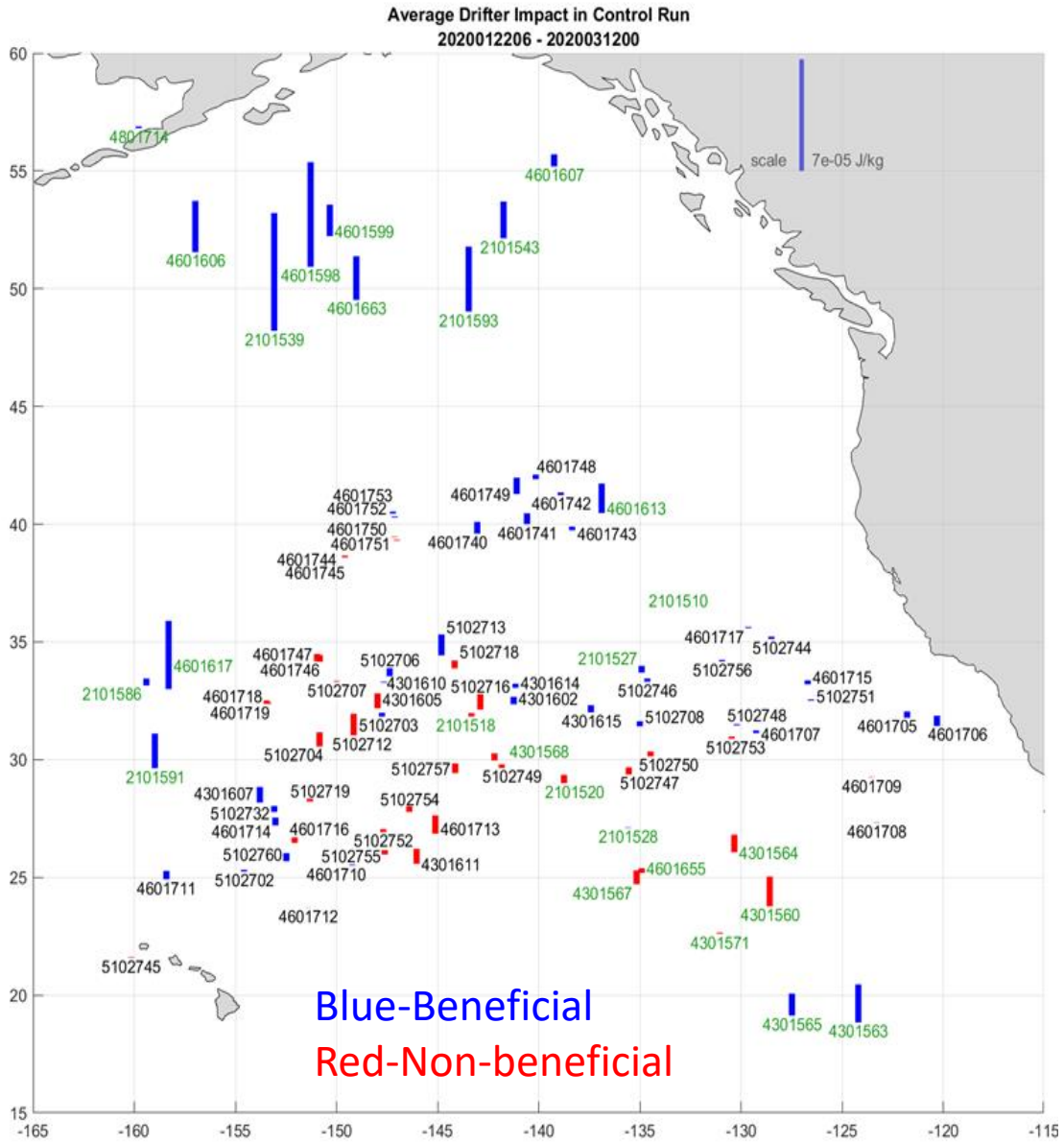


Impact of AR RECON comparable to NA Radiosondes (per ob impact much higher)

Impact of moisture obs smaller than impact of winds or temperature (resolution issue?)

Stone, R. E., et al. 2020: Atmospheric River Reconnaissance Observation Impact in the Navy Global Forecast System. Mon. Wea. Rev., 148, 763-782. https://doi.org/10.1175/MWR-D-19-0101.1

2: 2020 Drifter Impact in NAVGEM



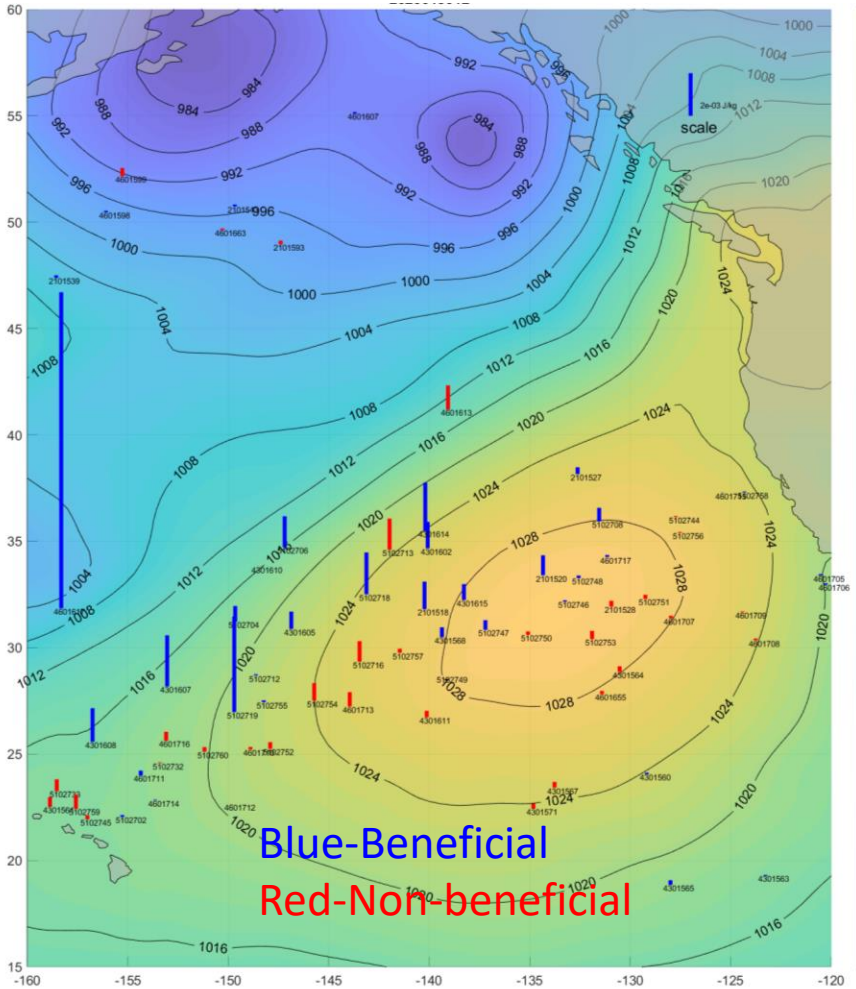
*Average observation impact for AR Recon drifters **(green numbers)** and non-AR drifters **(black numbers).** Units are J kg^{-1}, scale provided in upper right, beneficial-blue, non-beneficial-red.*

- Average over entire season, biggest forecast error reduction (on global 24-h total energy) is for obs in the Gulf of Alaska
- Observation impact tends to be near neutral where observations are clustered tightly together, bigger impact from observations that are not surrounded by other observations (Baker 2000; Baker and Langland 2009)
- Big case to case variability in ob impact

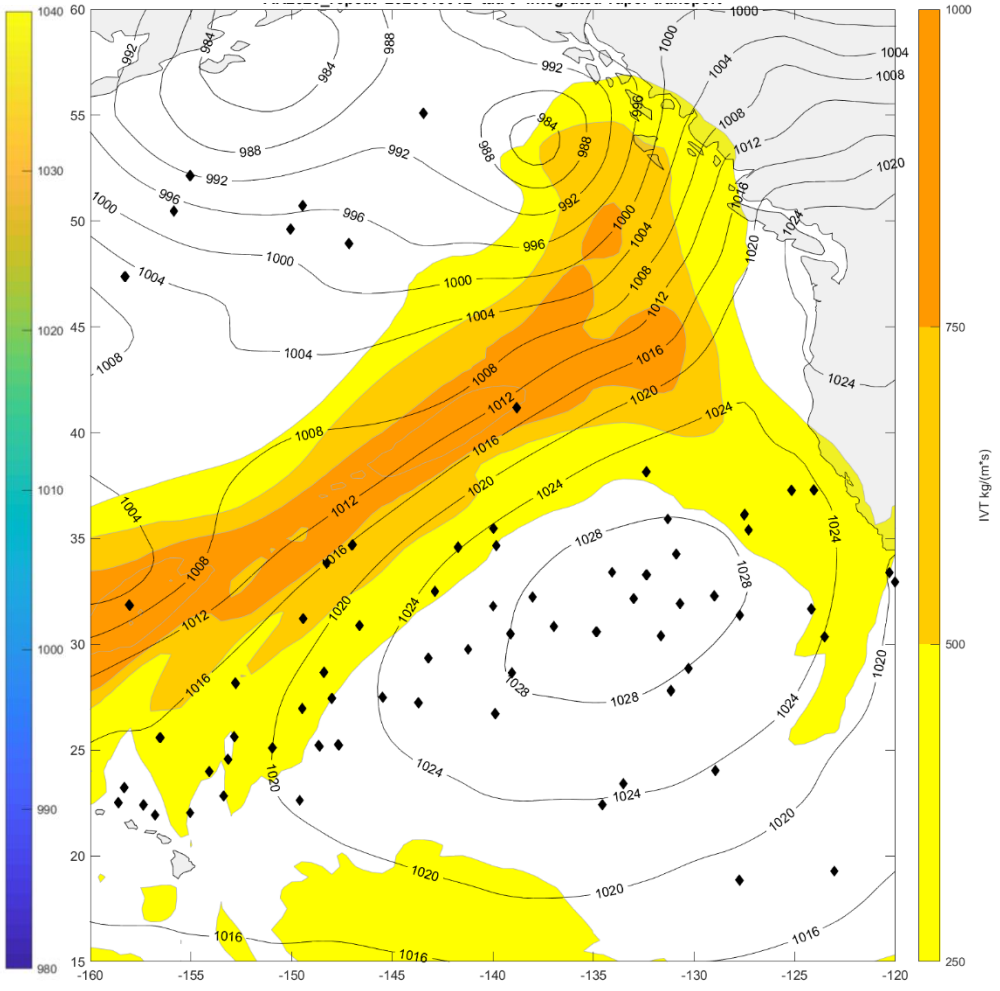
Reynolds, C. A., et al. 2023: Impact of Northeastern Pacific Buoy Surface Pressure Observations. Mon. Wea. Rev., 151, 211-226. https://doi.org/10.1175/MWR-D-22-0124.1

2: 2020 Drifter Impact in NAVGEM

Impact for each drifter (bars), analyzed SLP (contours and shading), 2020013012



SLP (contours), Integrated Vapor Transport (IVT), drifter locations (black dots), 2020013012



- **Biggest impact from obs along the front, (strong pressure gradient, strong IVT)**
- **Obs under the high pressure center have less impact**
- **Obs in Gulf of Alaska not impactful**

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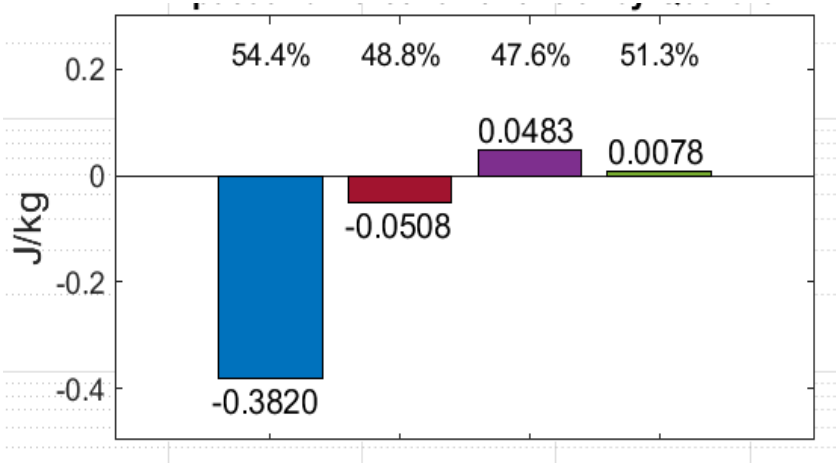
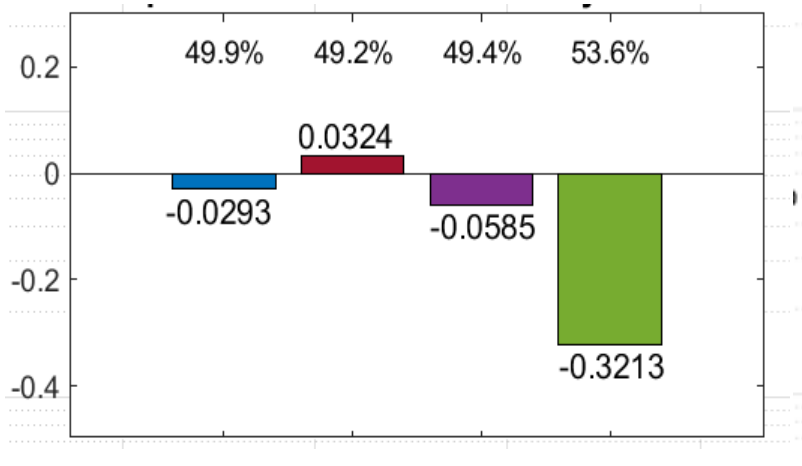
2: 2020 Drifter Impact in NAVGEM

Beneficial non-beneficial

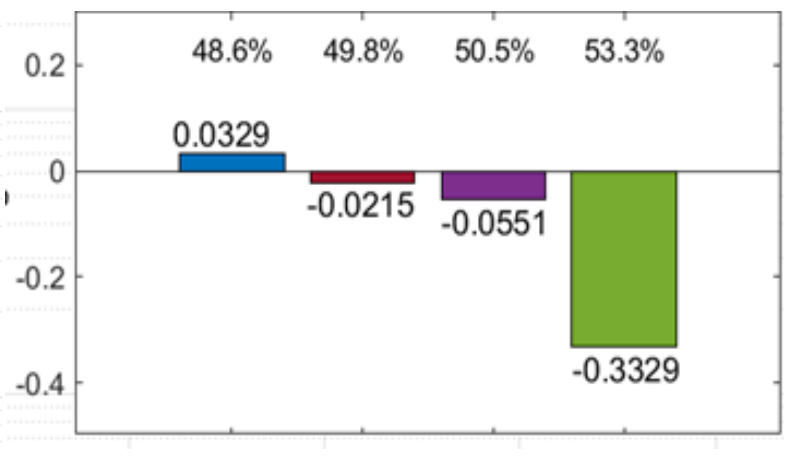
Impact by Obs. Pressure Quartile



Impact by Isolation Quartile



Impact by IVT Quartile



The lowest pressure obs (blue) have the largest beneficial average impact, and largest fraction of beneficial obs.

Obs in regions of large pressure gradients (e.g., fronts), are also very beneficial (not shown).

Obs that are more isolated (green) have the largest beneficial average impact, and largest fraction of beneficial obs.

Defined as average distance to four nearest neighbors.

Obs that are taken in regions of high integrated vapor transport (IVT), often associated with Atmospheric Rivers (ARs), have the largest beneficial average impact and largest fraction of beneficial obs.

Other results show that obs taken later in the DA window are more impactful

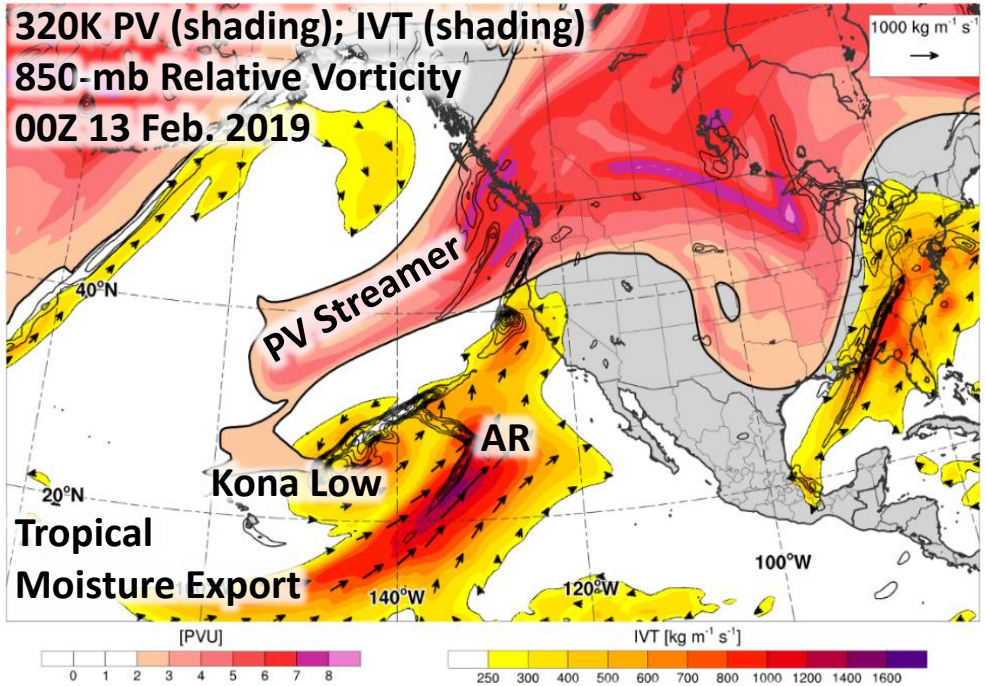
2: 2020 Drifter Impact in NAVGEM

Reference	Level	Metric	Variable	Region	0	24	48	72	96	120
ECMWF Analysis	200.0	RMS Error	Geopotential Height	North America	😐	😐	😐	😐	🙂	😐
ECMWF Analysis	200.0	RMS Error	Geopotential Height	Northern Hemisphere	☹	😐	😐	🙂	🙂	😐
ECMWF Analysis	200.0	Vector RMS Error	Wind	Northern Hemisphere	😐	😐	😐	😐	😐	😐
ECMWF Analysis	500.0	Anomaly Correlation	Geopotential Height	North America	😐	😐	😐	🙂	🙂	🙂
ECMWF Analysis	500.0	Anomaly Correlation	Geopotential Height	Northern Hemisphere	😐	😐	😐	🙂	🙂	😐
ECMWF Analysis	500.0	Vector RMS Error	Wind	Northern Hemisphere	😐	😐	🙂	🙂	🙂	😐
ECMWF Analysis	850.0	Vector RMS Error	Wind	Northern Hemisphere	😐	😐	😐	🙂	🙂	😐
ECMWF Analysis	1000.0	Anomaly Correlation	Geopotential Height	North America	😐	🙂	😐	🙂	🙂	🙂
ECMWF Analysis	1000.0	Anomaly Correlation	Geopotential Height	Northern Hemisphere	🙂	😐	😐	😐	🙂	😐

Green (red) indicates improvement (degradation) due to the AR drifter observations significant at the 95% level.

Assimilation of AR drifters results in a (small but) statistically significant reduction in several standard metrics at 72 and 96 hours over N. America and the NH

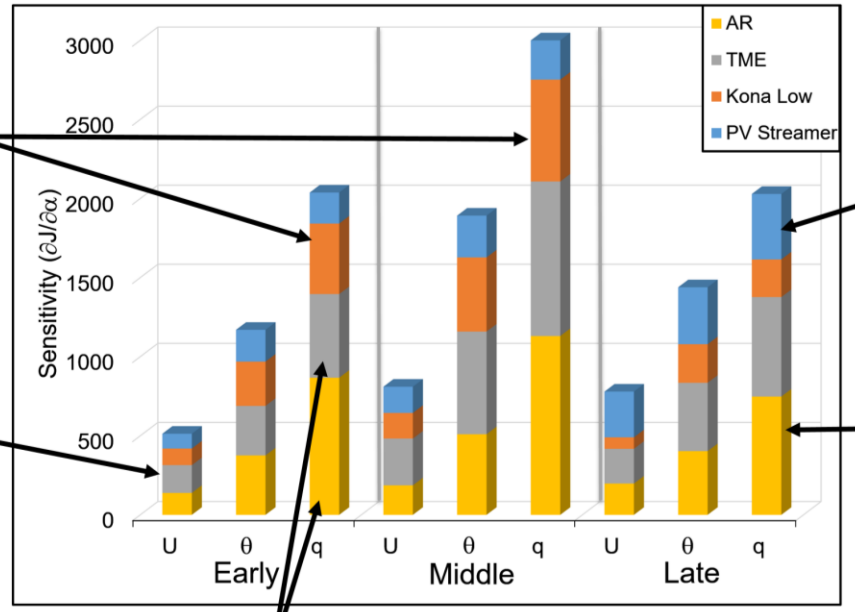
3: 2019 Valentine's Day Storm with COAMPS



Modified from Philippe Papin

Kona Low sensitivity greatest in the early and middle periods

- Wind sensitivity smaller than θ and q sensitivity
- Moisture is most sensitive variable



PV Streamer has growing importance in late period

Moisture sensitivity is less dominant during late stage

AR sensitivity is largest followed by TME sensitivity

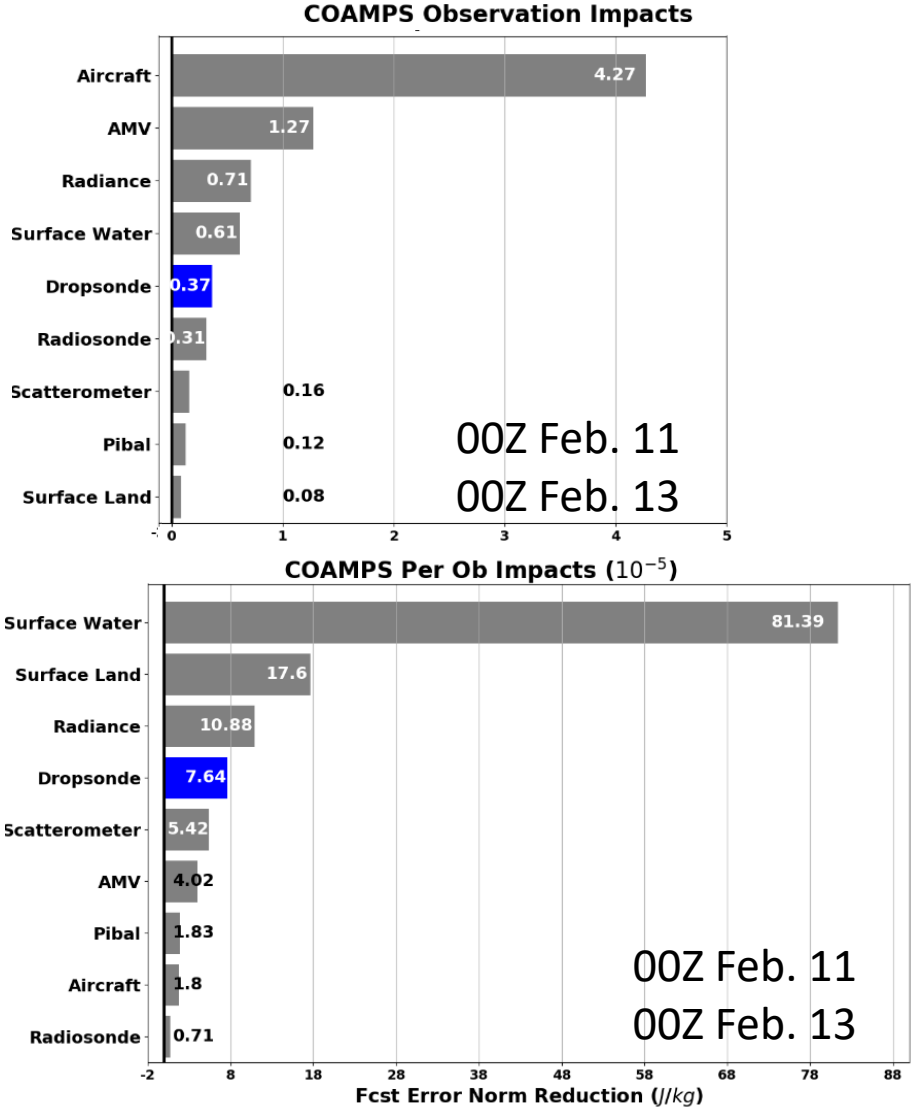
Middle period has strongest sensitivities

- In the Valentine's Day 2019 event, we find sensitivities in the AR and TME are largest, followed by the Kona Low and PV streamer. Later in the period, the PV streamer becomes more important.
- Motivates the need for multiple AR Recon aircraft to observe the high-latitude features (e.g., PV streamers, troughs) as well as the ARs and TMEs. AR Recon dropsonde impacts were very beneficial in this case.
- Moisture sensitivity in the AR and TME is especially large and act as "seeds" for error growth that impact downstream precipitation forecasts. Fast perturbation growth occurs in diabatically active regions (WCBs, ARs).

3: 2019 Valentine's Day Storm with COAMPS

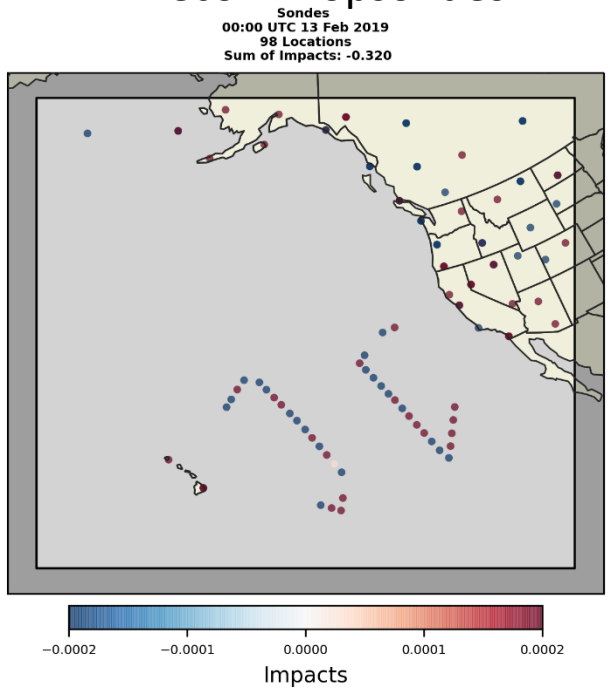
COAMPS 24-h Observation Impacts

Moist Energy Error Norm

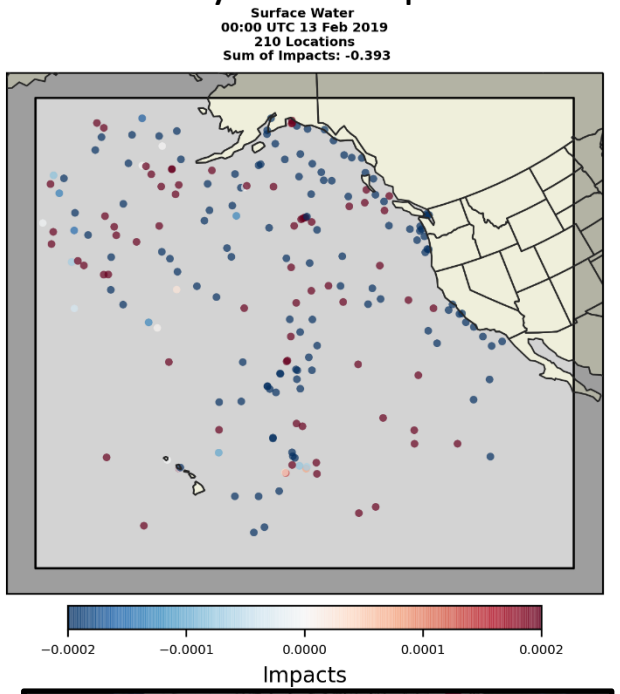


COAMPS 24 h Observation Impacts 00Z 13 Feb. 2019

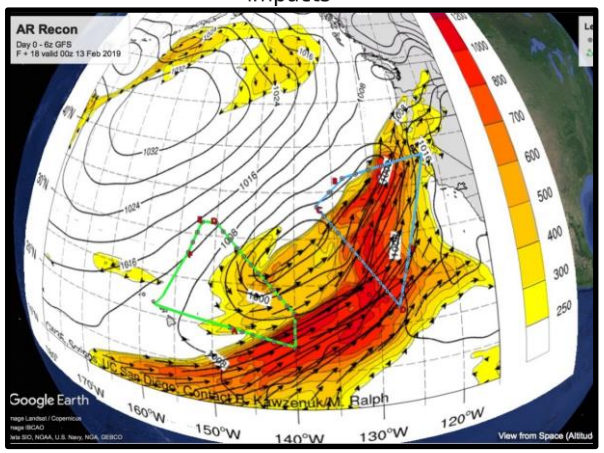
AR Recon Dropsondes



Buoys and Ships



AR Recon Dropsondes are the most beneficial *in situ* profile observation (per observation and overall for the 11 & 13 Feb. IOPs)



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Summary

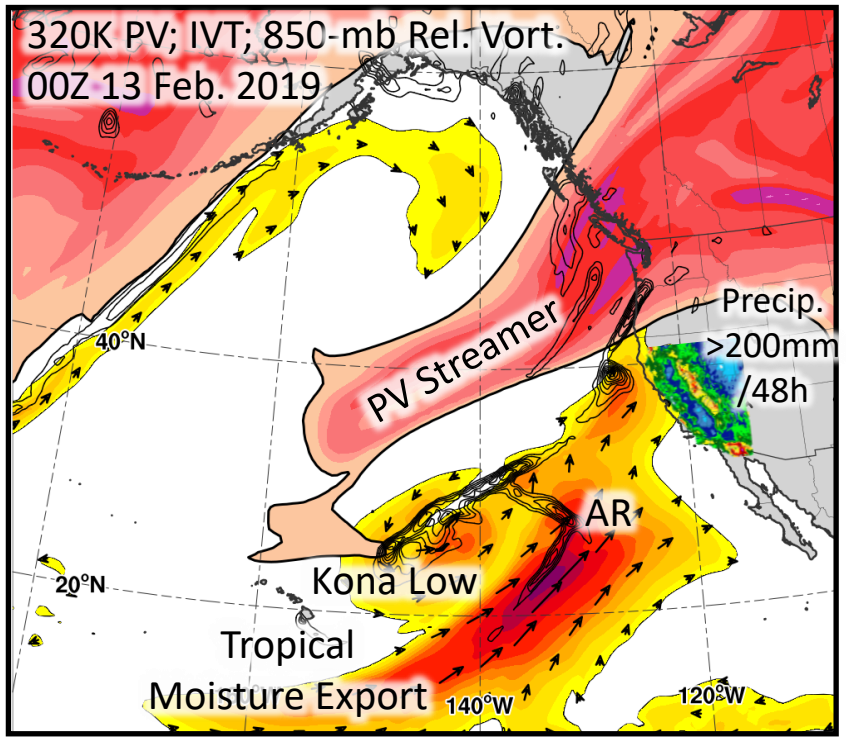
- NAVGEM Observation Impact Results:
  - With at least 2 aircraft, AR RECON Dropsonde impact comparable to NA Radiosonde impact.
  - Drifter surface pressure observation impact: largest for obs of low pressures, in vicinity of pressure gradients (fronts) and ARs, and for more isolated obs. Big case-to-case variability.

- NAVGEM Drifter Data Denial Results
  - Assimilation of the AR drifter observation results in statistically significant forecast improvements at 72 and 96 h.
  - Improvements may be greater with subsequent deployment of additional AR drifter.

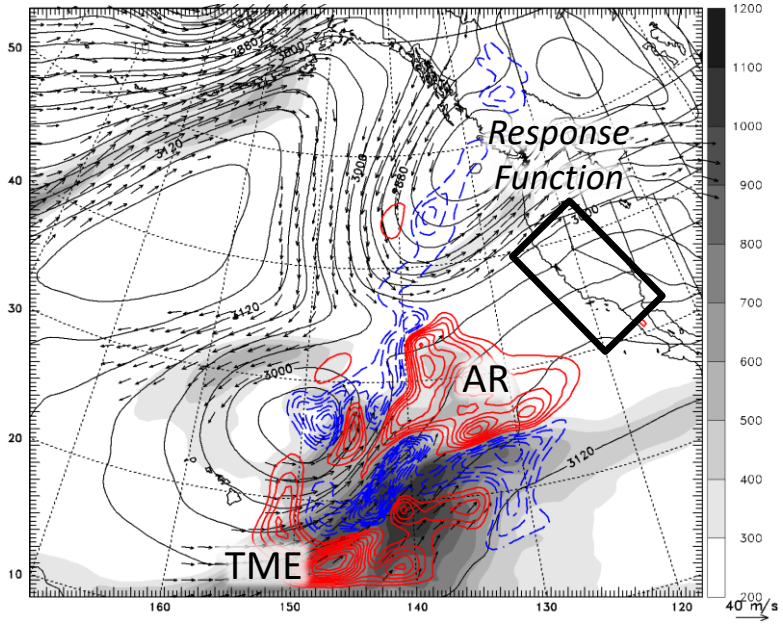
- COAMPS 2019 Valentine's Day Storm
  - Adjoint sensitivity illustrates how multiple phenomena impact storm evolution.
  - FSOI shows dropsondes and surface obs have relatively high impact.

3: 2019 Valentine's Day Storm with COAMPS

- High-impact forecasts associated with ARs can be very sensitive to the initial state, even for short-range forecasts
- We focus on a high-impact event during the AR Recon from Feb. 11-15, 2019 and utilize the NRL COAMPS® mesoscale model and moist adjoint system to explore the predictability of this heavy precipitation event.
- Goal is to quantify the predictability of this heavy precipitation event (Feb. 2019) along U.S. West Coast that featured an AR, Tropical Moisture Export (TME), Kona Low, and PV streamer
- How do multi-scale dynamics: PV Streamer, Kona Low, Tropical Moisture Export (TME), and AR impact the predictability of the downstream heavy precipitation in California?



700-hPa q_v Sensitivity (red/blue), IVT (gray), 700-hPa Heights, Winds
00Z 12 Feb. 2019



300-hPa PV Adjoint Perturbation, PV (gray), 300-hPa Heights, Winds
00Z 12 Feb. 2019