Impacts of Northeastern Pacific Buoy Surface Pressure Observations

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GOALS: Use Atmospheric River Reconnaissance (AR RECON) and other drifting buoy (drifter) surface pressure observations to:

- **Understand how observation impact varies by location, large-scale environment, time within the data assimilation window**
- **Perform AR RECON drifter data denial experiments for data impact studies**
- **Learn about the characteristics & biases of our global data assimilation (DA) and forecast system**

Reynolds, C. A., and Coauthors, 2023: Impacts of Northeastern Pacific Buoy Surface Pressure Observations. *Mon. Wea. Rev.*, **151**, 211–226, https://doi.org/10.1175/MWR-D-22-0124.1.

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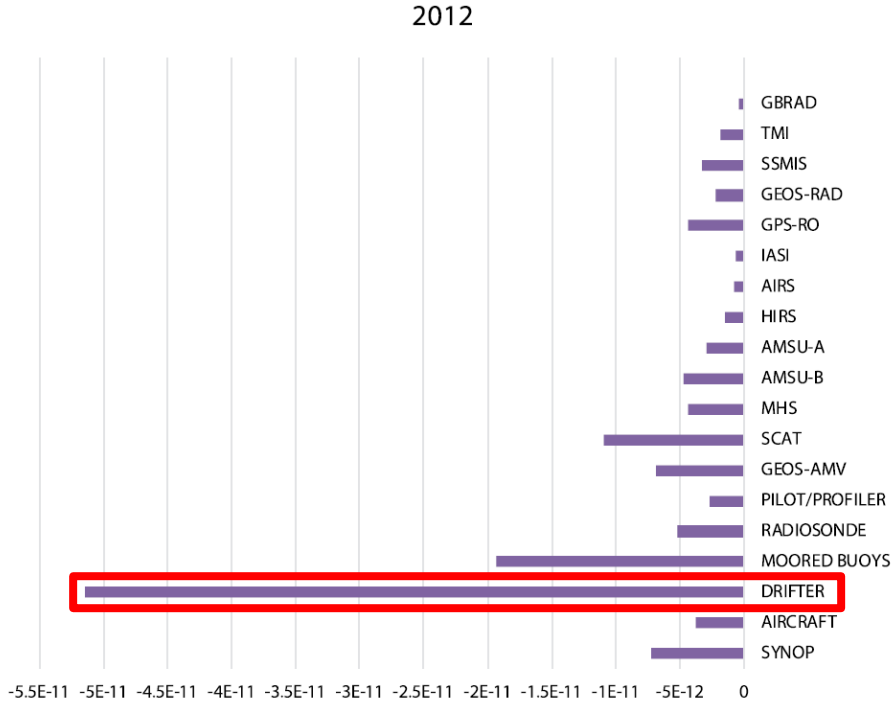
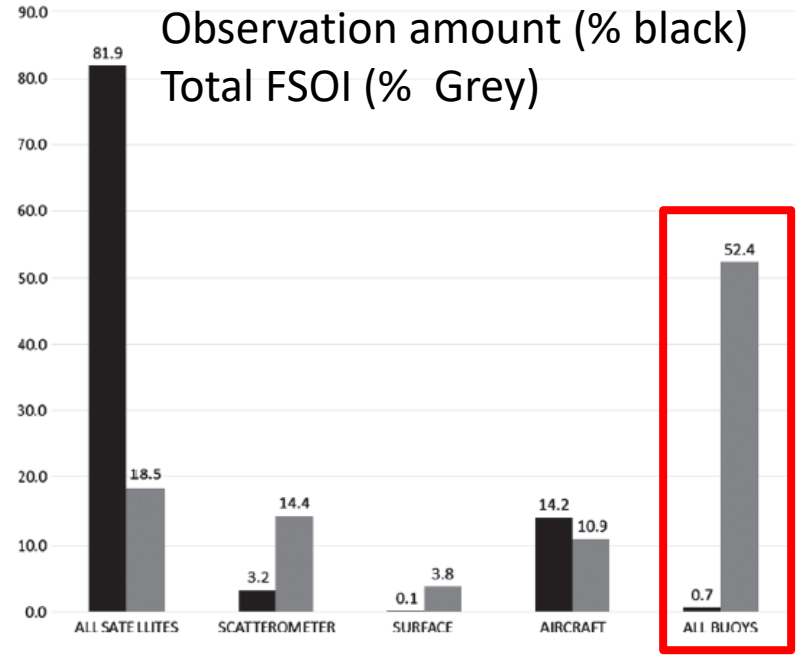
Background: Drifter Surface Pressure Observations

- Surface pressure observations are impactful - provide information on the mass of the atmospheric column, reflect synoptic-scale variability, through DA influence tropospheric circulation
- Drifter observations are impactful - usually in regions with few other in-situ observations
- Eyre and Reid 2014 cost-benefit studies for ob impact: Best is aircraft obs, 2nd best is drifter obs



Centurioni et al., 2017: Drifter observations have biggest per-ob FSOI impact in ECMWF IFS.



Horanyi et al, 2017: N. Atlantic case study of rapid cyclogenesis: biggest FSOI is from drifters

FSOI: Forecast Sensitivity Observation Impact

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Experimental Design

The Navy Global Environmental Model (NAVGEM) is used to look at impact of AR-RECON and non-AR RECON drifter surface pressure observations on the analysis and short term forecasts

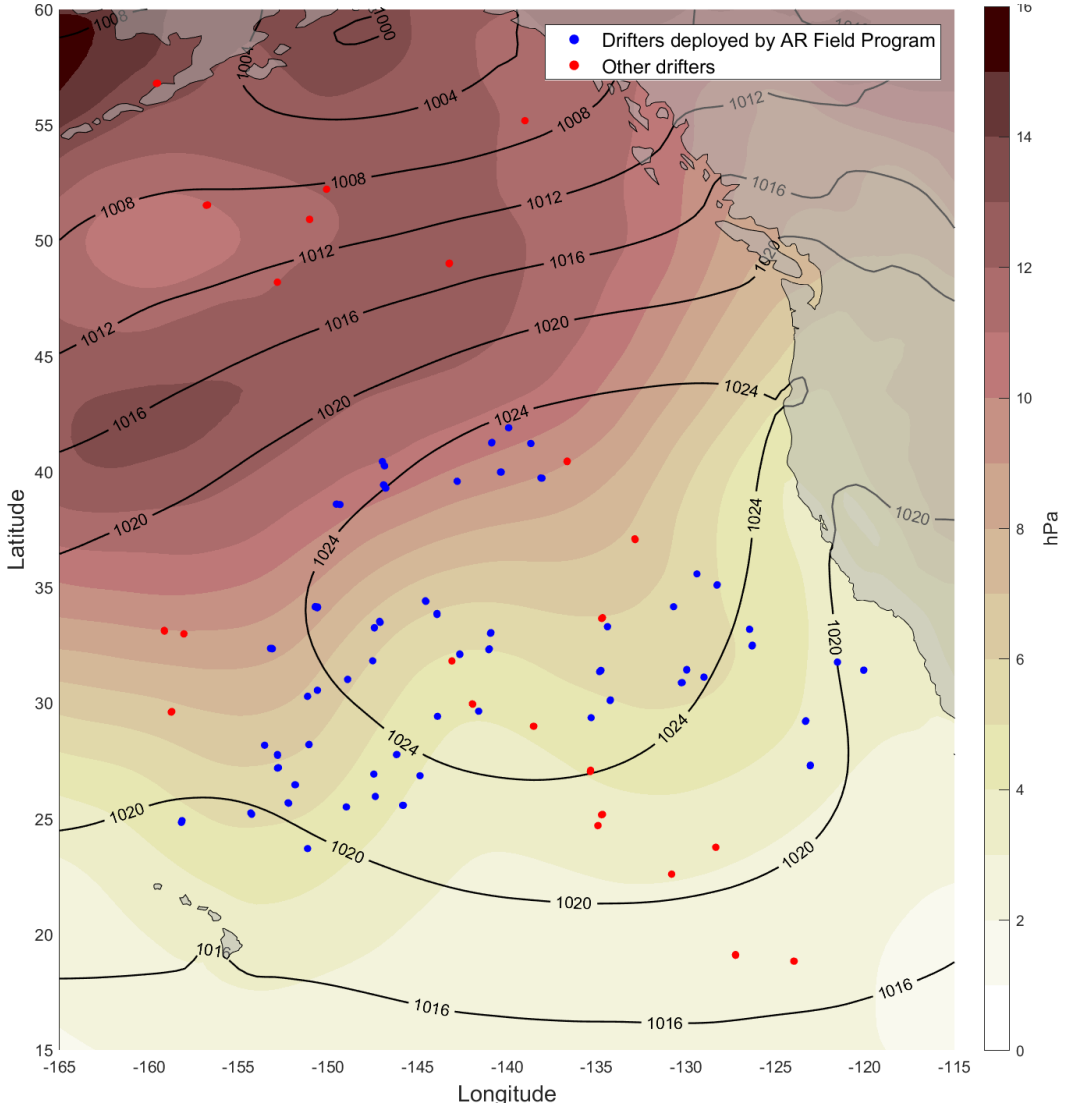
Forecast Sensitivity/Observation Impact (FSOI, Langland and Baker 2004): Uses the adjoints of forecast model and the hybrid 4-d VAR DA system to calculate impact of each observation on the 24-h forecast error

- **Model is at a 31km resolution, and DA increments are at a 100 km resolution**
- **Forecast error is measured in terms of global total moist energy**
- **Consider 2020 AR Recon Season: 22JAN-13MAR 2020**

Data Denial Studies: Run the DA-Forecast system with and without the AR RECON observations

- **Examine impact of AR drifter assimilation on analyses and forecast errors**

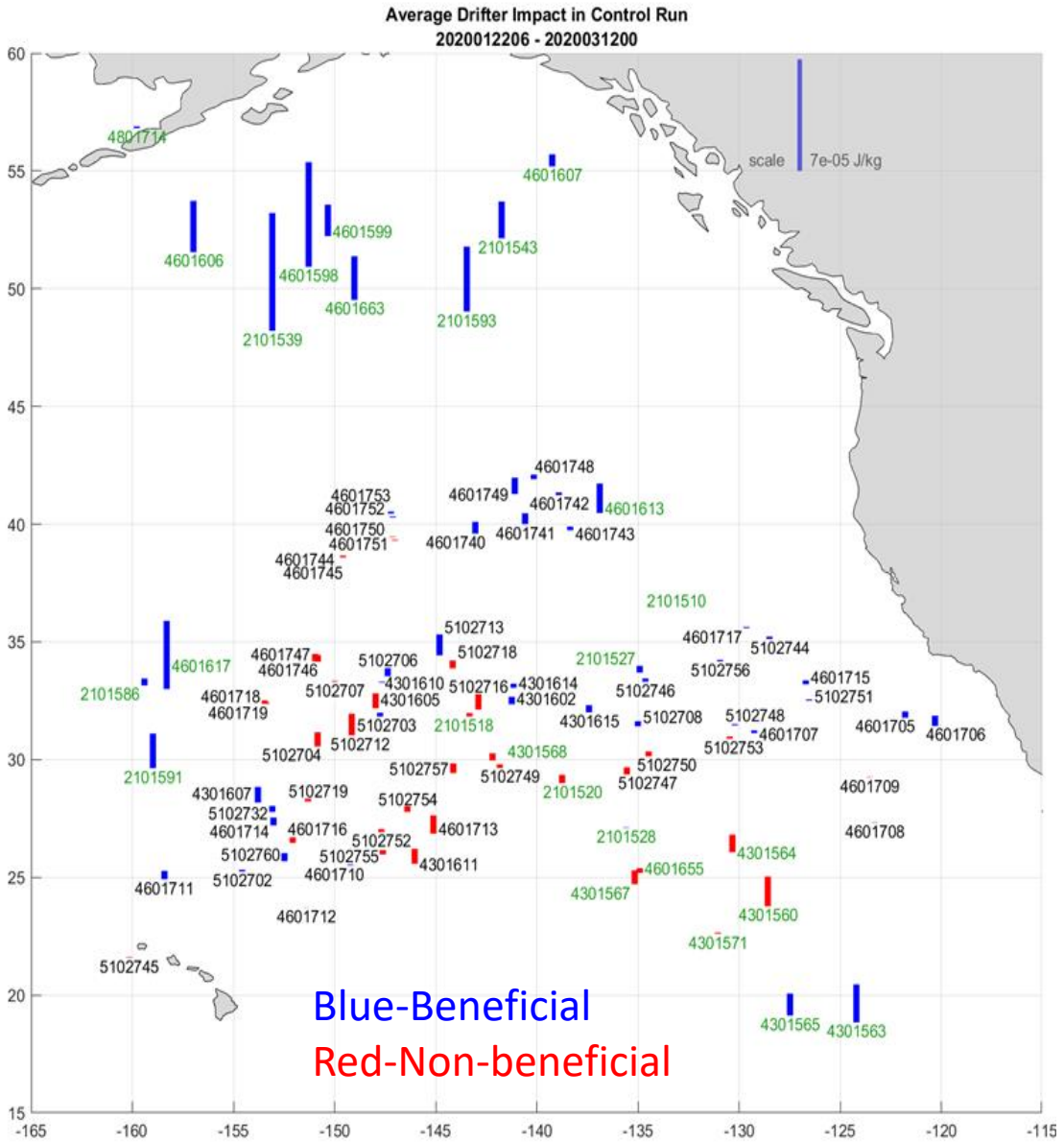
Location of AR and Non-AR Drifters Providing Surface Pressure Observations



Location of the AR (blue) drifters and non-AR (red) drifters (by NOAA-Global Drifter Program) at the end of the AR RECON 2020 season (20200312) in the NE Pacific. NAVGEM analyzed sea level pressure (SLP, hPa) average(contours) and std. dev (shading) from 2020012200-2020031300.

- **AR drifters (54) predominantly in the area between Hawaii and the US West Coast, positioned to occur under ARs that will impact the US West Coast, although in a time-mean sense the observations occur under high pressure during this season**
- **The non-AR drifters (23) that provide surface pressure observations occur throughout the NE Pacific and are not as clustered as the AR drifters**

Observation Impact by Location



*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 observation impact (later slide)**

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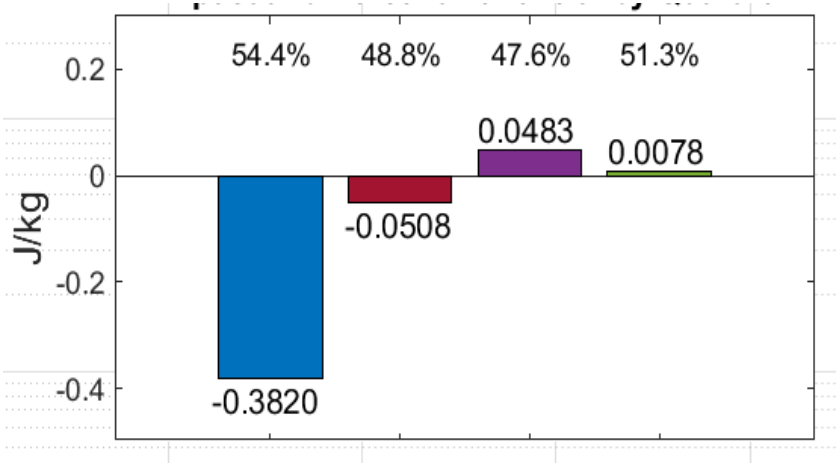
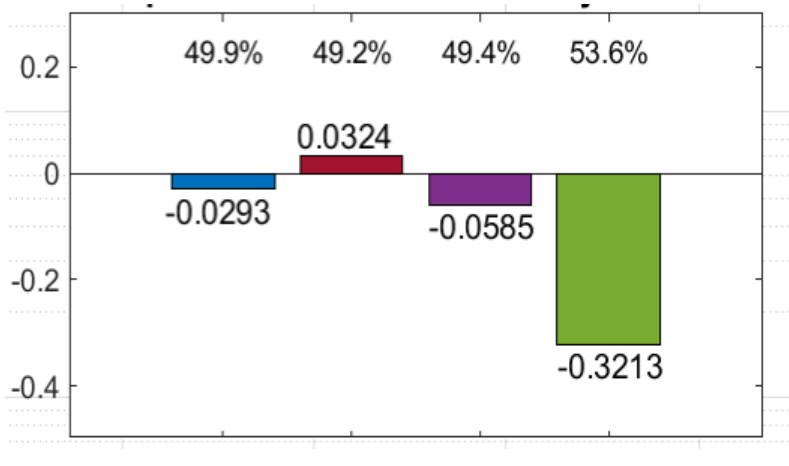
Observation Impact Varies by Environment

Beneficial non-beneficial

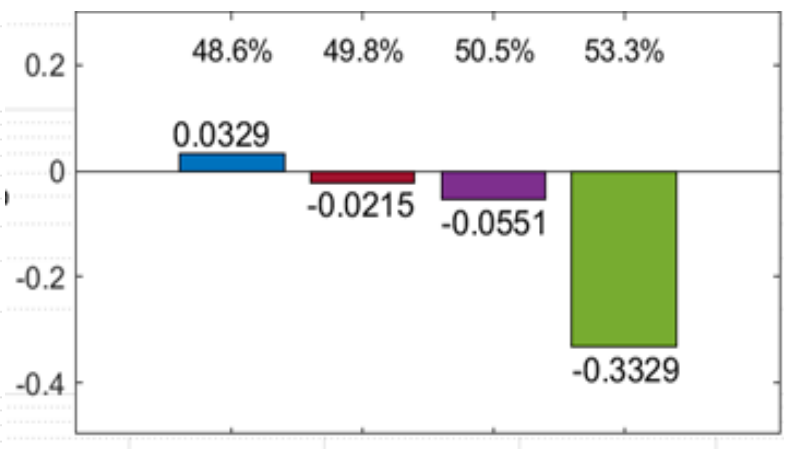
Impact by Obs. Pressure Quartile



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.

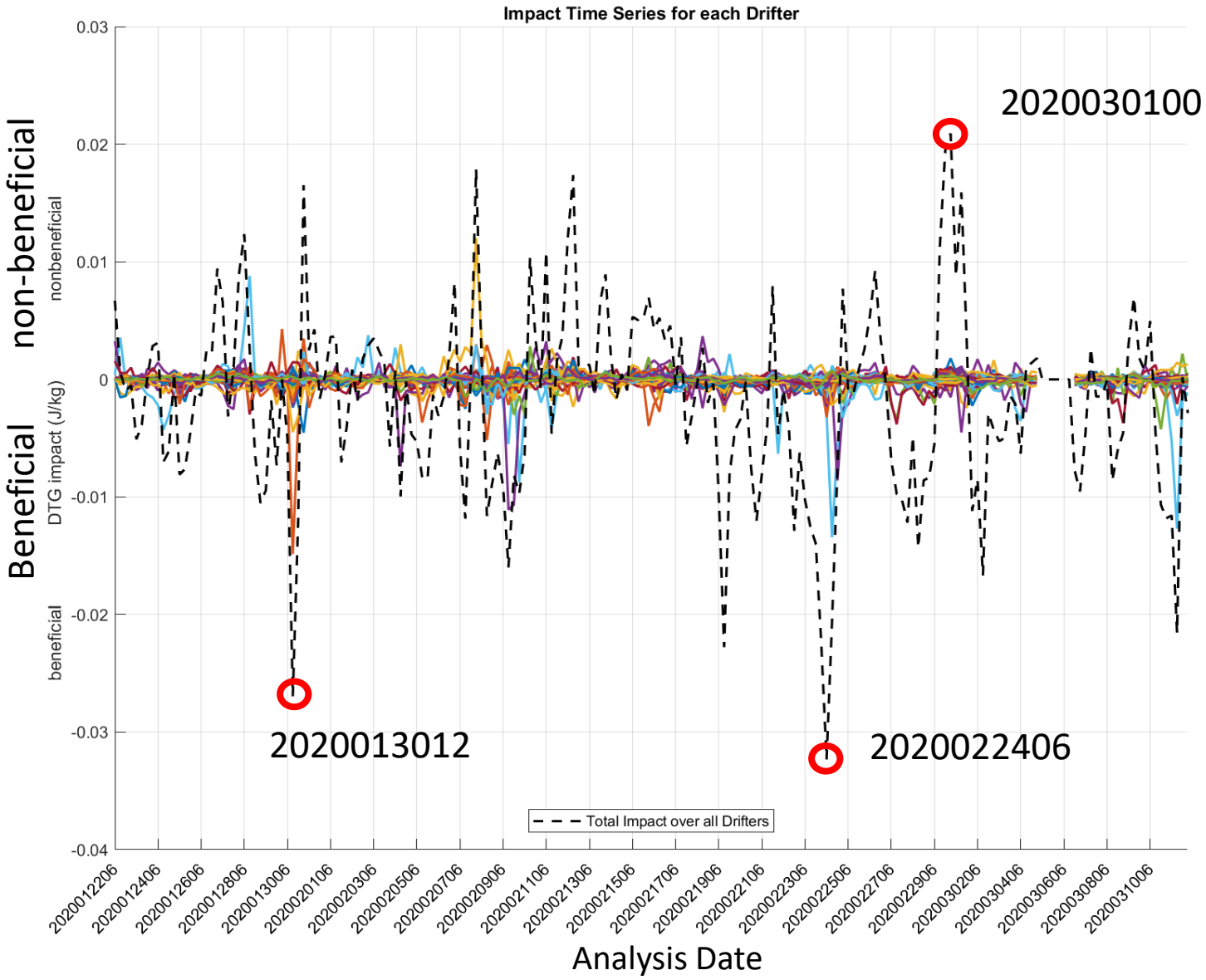
Obs in regions of large pressure gradients (e.g., fronts), are also very beneficial (not shown).

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.

Observation Impact as a function of Analysis Time

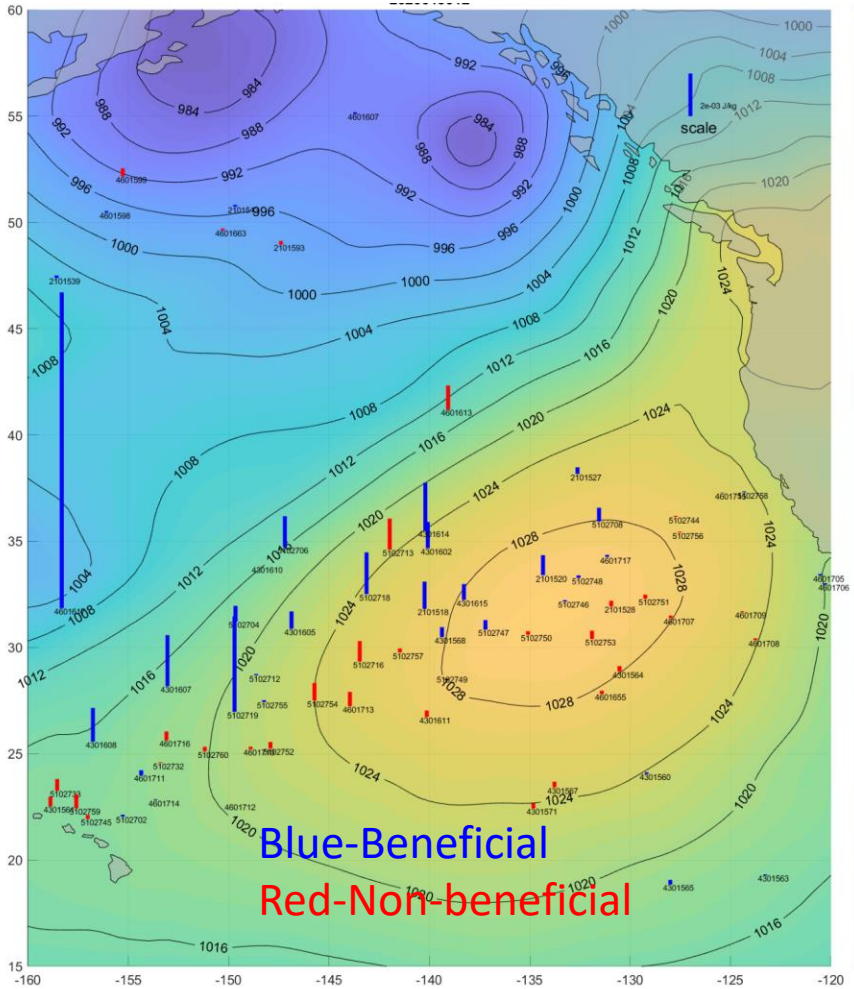


Impact for all NE Pacific drifter surface pressure obs (dashed line) as a function of the analysis time. The impact from the individual drifters is denoted by individual solid curves.

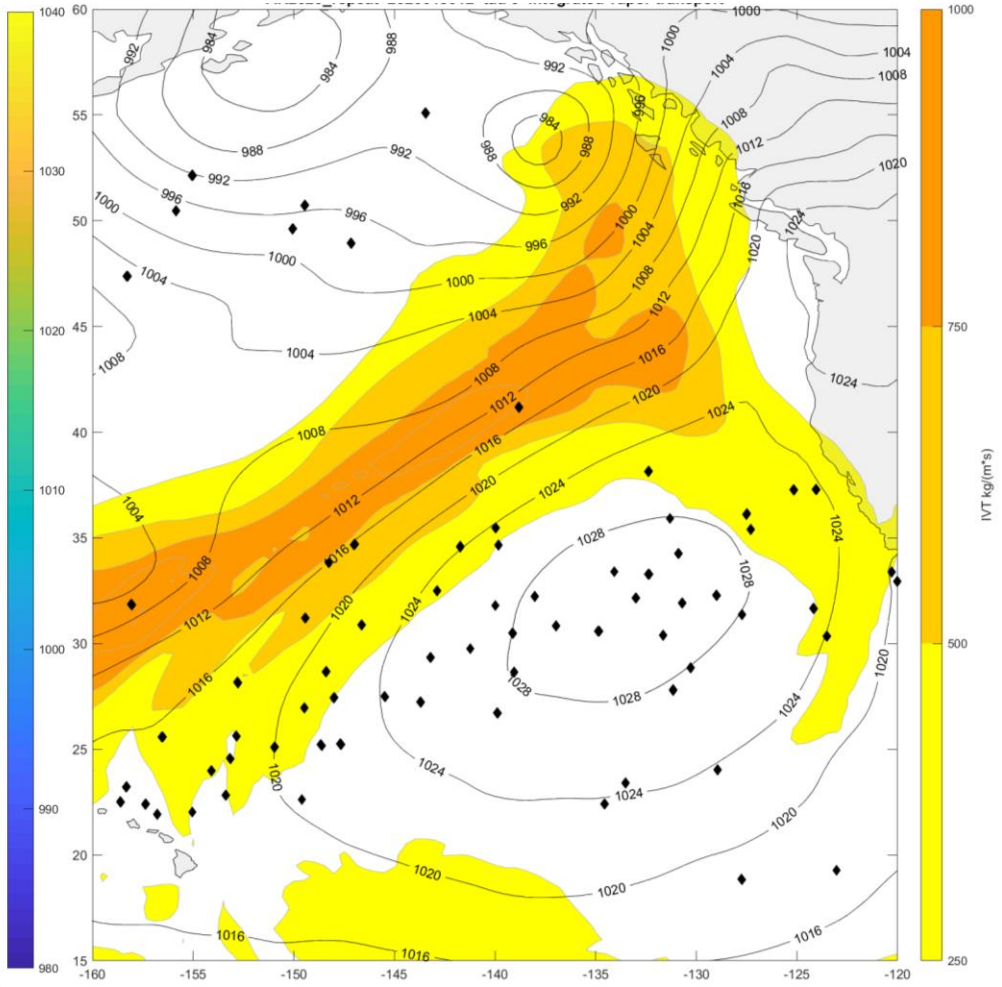
- **Large case-to-case variability in total observation impact**
- **The circled dates are those with the two largest beneficial impacts (2020013012 and 2020022406) and the largest non-beneficial impact (2020030100). Will show 2020013012 in next slide (2020022406 and 2020030100 in extra slides).**

Observation Impact for 2020013012 (Large Beneficial Impact)

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 observations along the front, (strong pressure gradient, strong IVT)**
- **Observation under the high have less impact**
- **Observations in Gulf of Alaska not impactful**

Data Denial Experiments: Impacts on Forecast Errors

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

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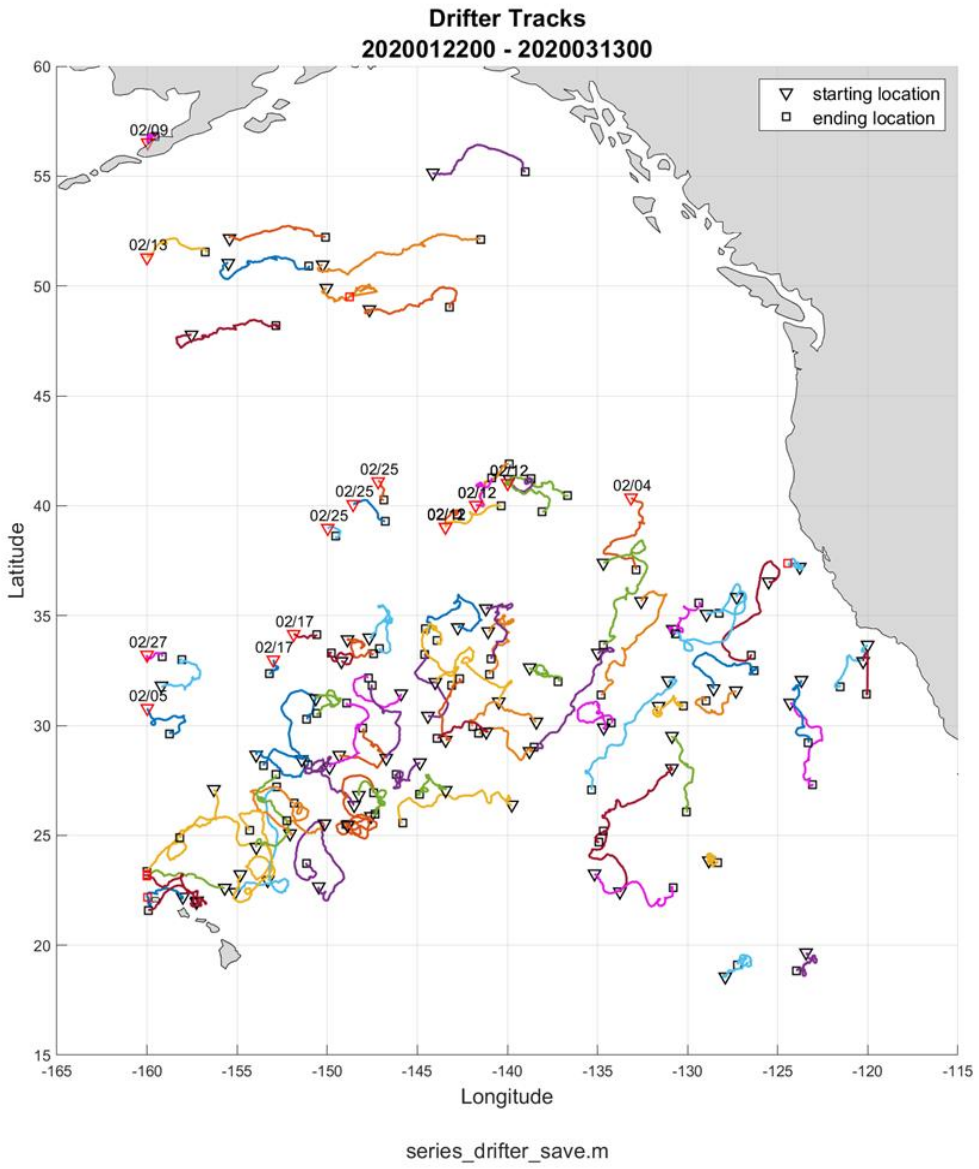
What We Have Learned

- 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.
- The large impact from Gulf of Alaska drifters led to subsequent AR drifter deployment farther north than in previous seasons.
- Data Denial Results
  - Assimilation of the AR drifter observation results in statistically significant forecast improvements at 72 and 96 h.
  - One might expect these improvements to be even greater with subsequent deployment of additional AR drifters in later years.
- Results not shown (in Reynolds et al., 2022)
  - DA statistics show that NAVGEM is biased low for high pressures -> impacts utility of pressure observations under high pressure systems.
  - Observations taken later in the data assimilation window are most impactful.
  - Assimilation of AR drifter observations better constrains Eastern Pacific analyses and corrects for NAVGEM low bias at high surface pressures.

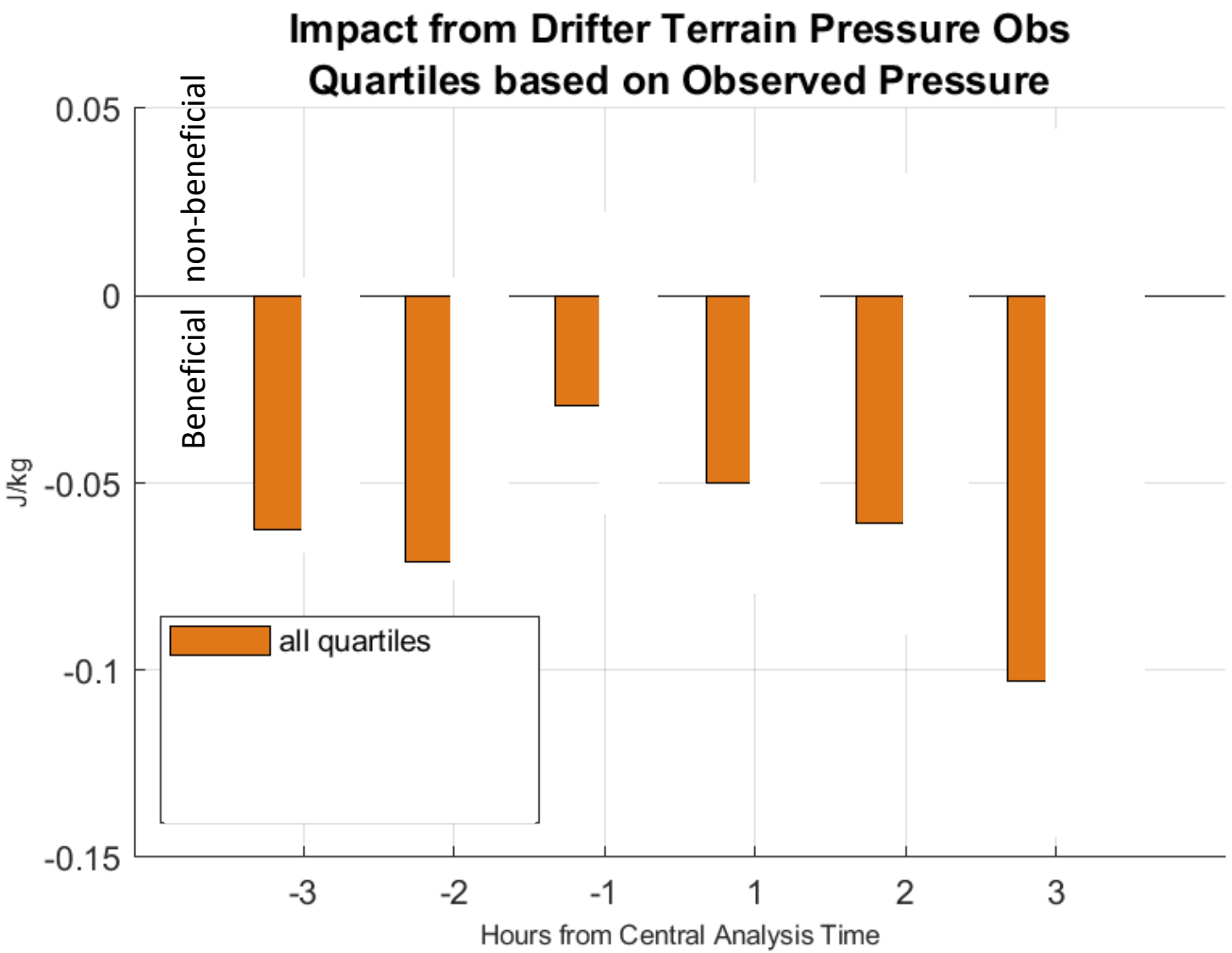
Drift of the Drifters



Drifter tracks over the AR Recon 2020 time period. Staring locations depicted by triangles and ending locations depicted by squares. Dates indicate the starting reporting dates of drifters deployed during the AR Recon time period.

- **Buoys do drift, but usually less than 600 km over the AR Recon time period (22 Jan through 13 March)**
- **Buoys in Gulf of Alaska drift westward, buoys on eastern side of subtropical high drift southward**

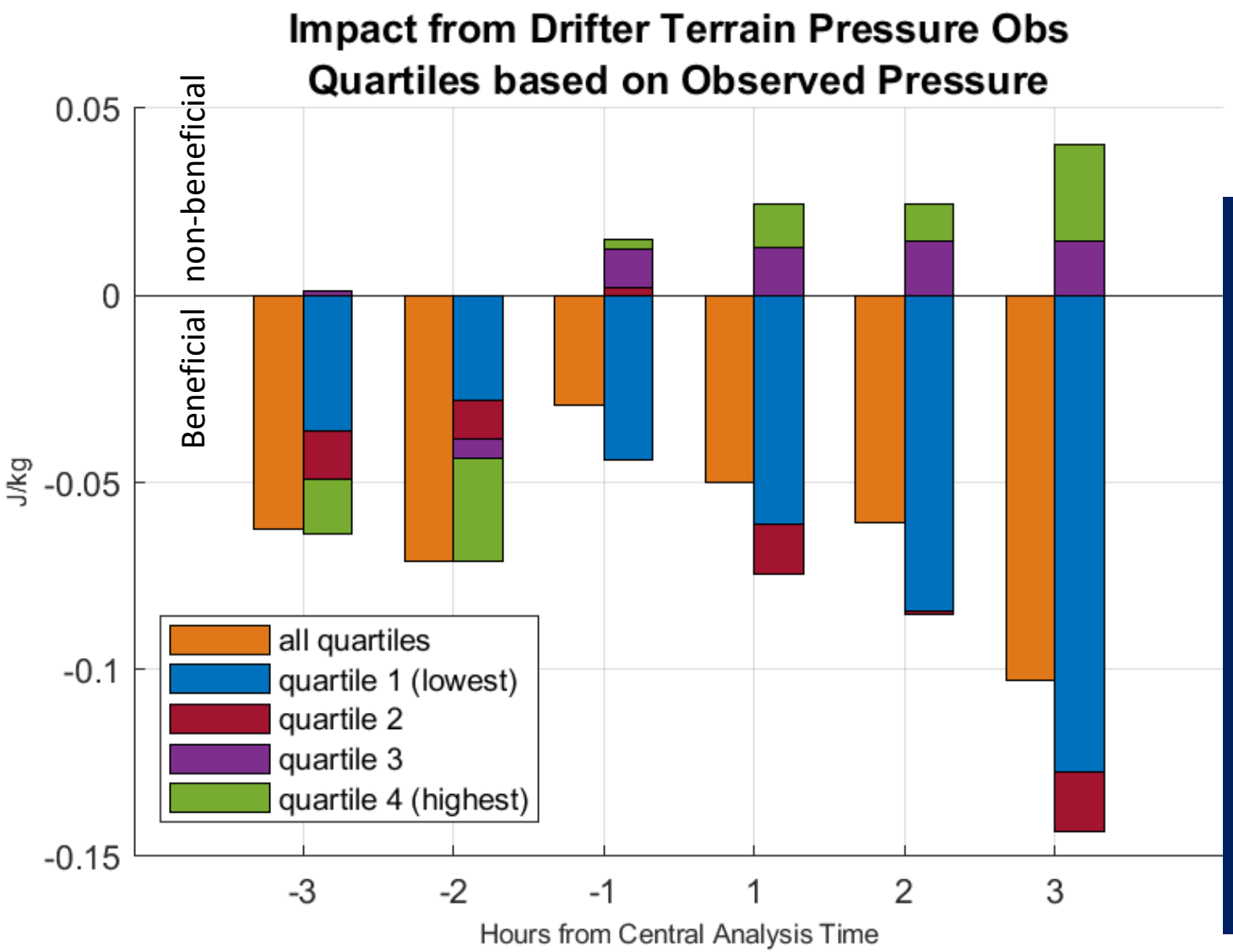
Observation Impact by Quartile and Hour Within DA Window



Total impact from all NE Pacific drifter surface observations (orange) as a function of hour within the six-hour data assimilation cycle. Impact is also broken out by surface pressure ob quartile.

- **Average forecast error reduction is largest for obs in the last hour of the DA window (similar to McNally 2019 for satellite obs), perhaps related to 4DVAR ability to evolve covariances over the window**
- **Smallest mean impact comes from the middle of the window**

Observation Impact by Quartile and Hour Within DA Window

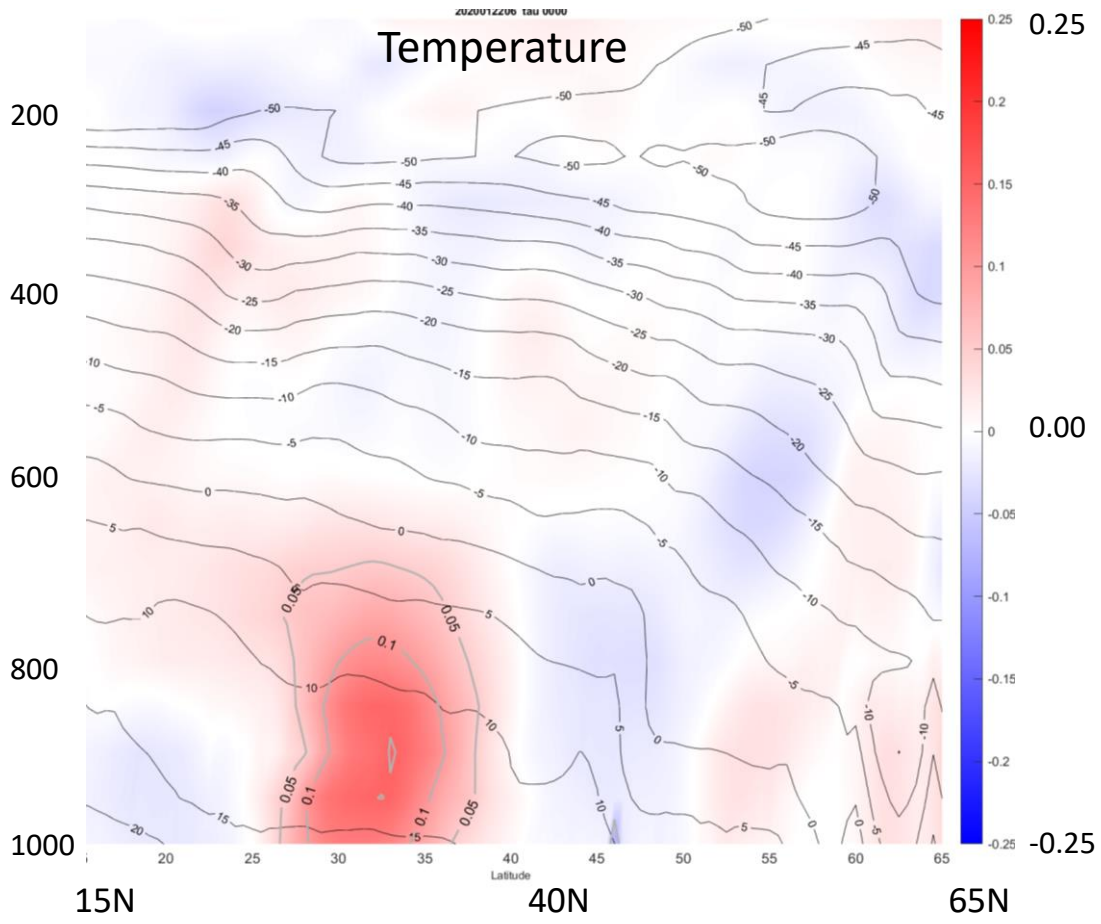


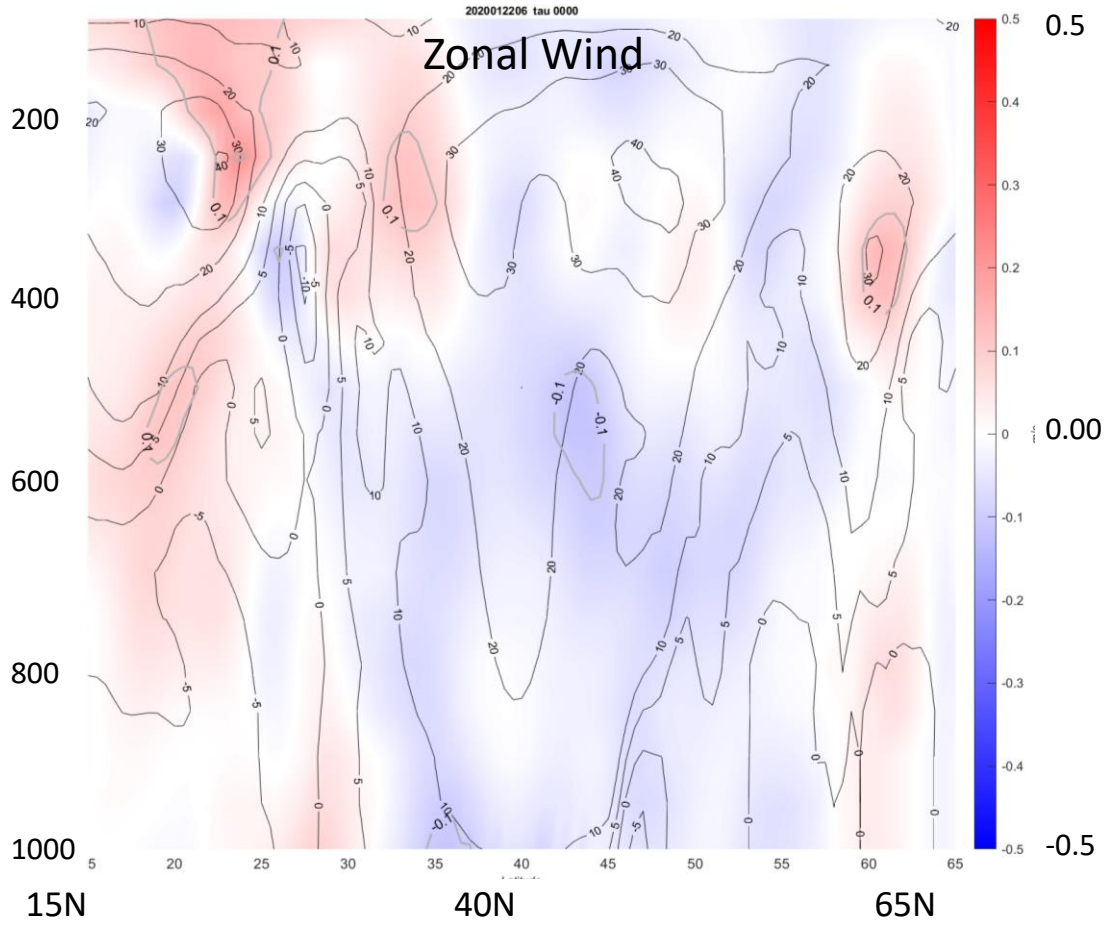
Total impact from all NE Pacific drifter surface observations (orange) as a function of hour within the six-hour data assimilation cycle. Impact is also broken out by surface pressure ob quartile.

- **Lowest quartile obs most beneficial, larger benefits in 2nd half of window**
- **Obs in the upper quartiles are beneficial in first 2 hours, non-beneficial later in the window**
- **Plausible that model bias at high pressures makes it difficult for DA system to use these observations effectively**
- **Minimum impact in middle of the window is from beneficial + non-beneficial cancellations**

Data Denial Experiments: Impact on Analyses

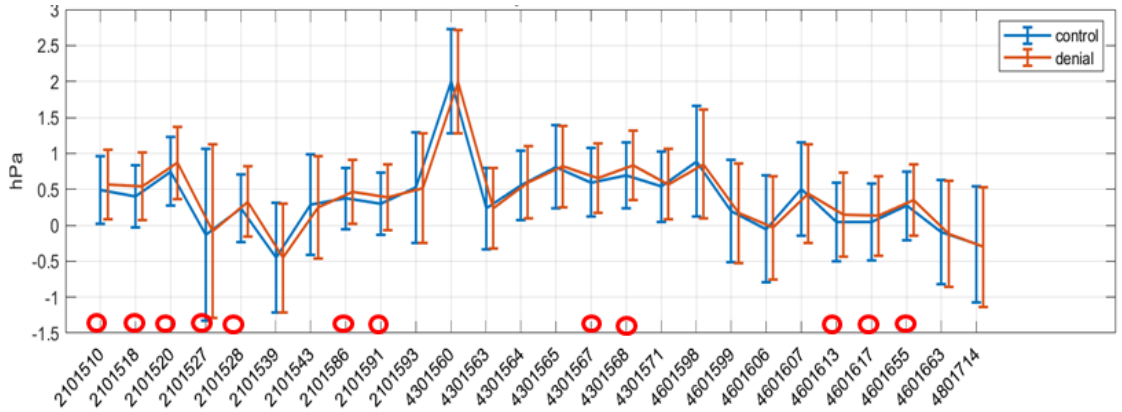
Vertical cross sections at 135 W showing control analysis (contours) and difference between control and AR Recon drifter denial analysis (shading) on 2022012206 (first update cycle in the series)



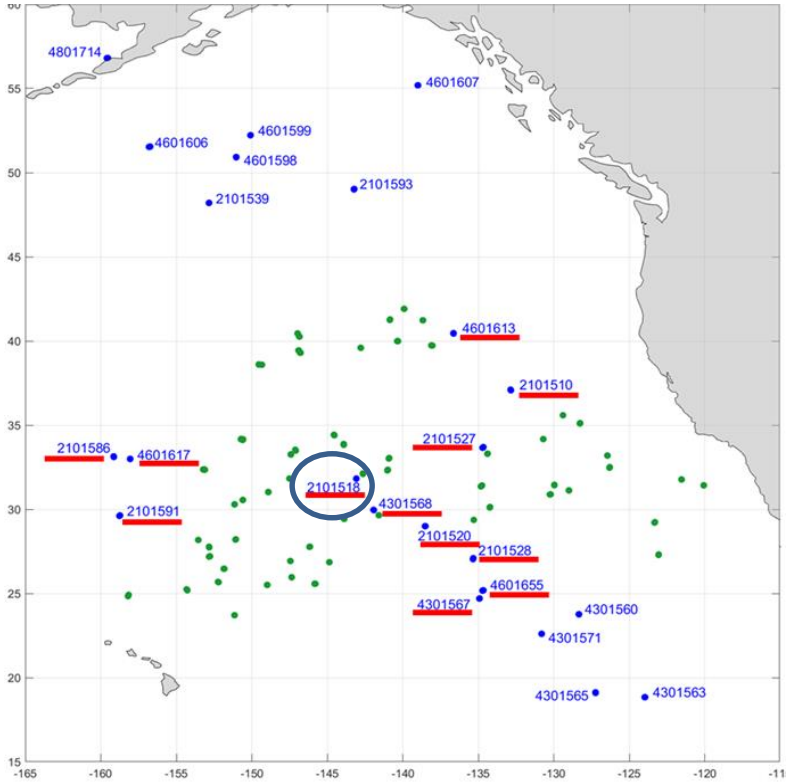


The DA spreads information from the AR-Recon surface pressure observations through the depth of the troposphere

Data Denial Experiments: Impact on Analyses



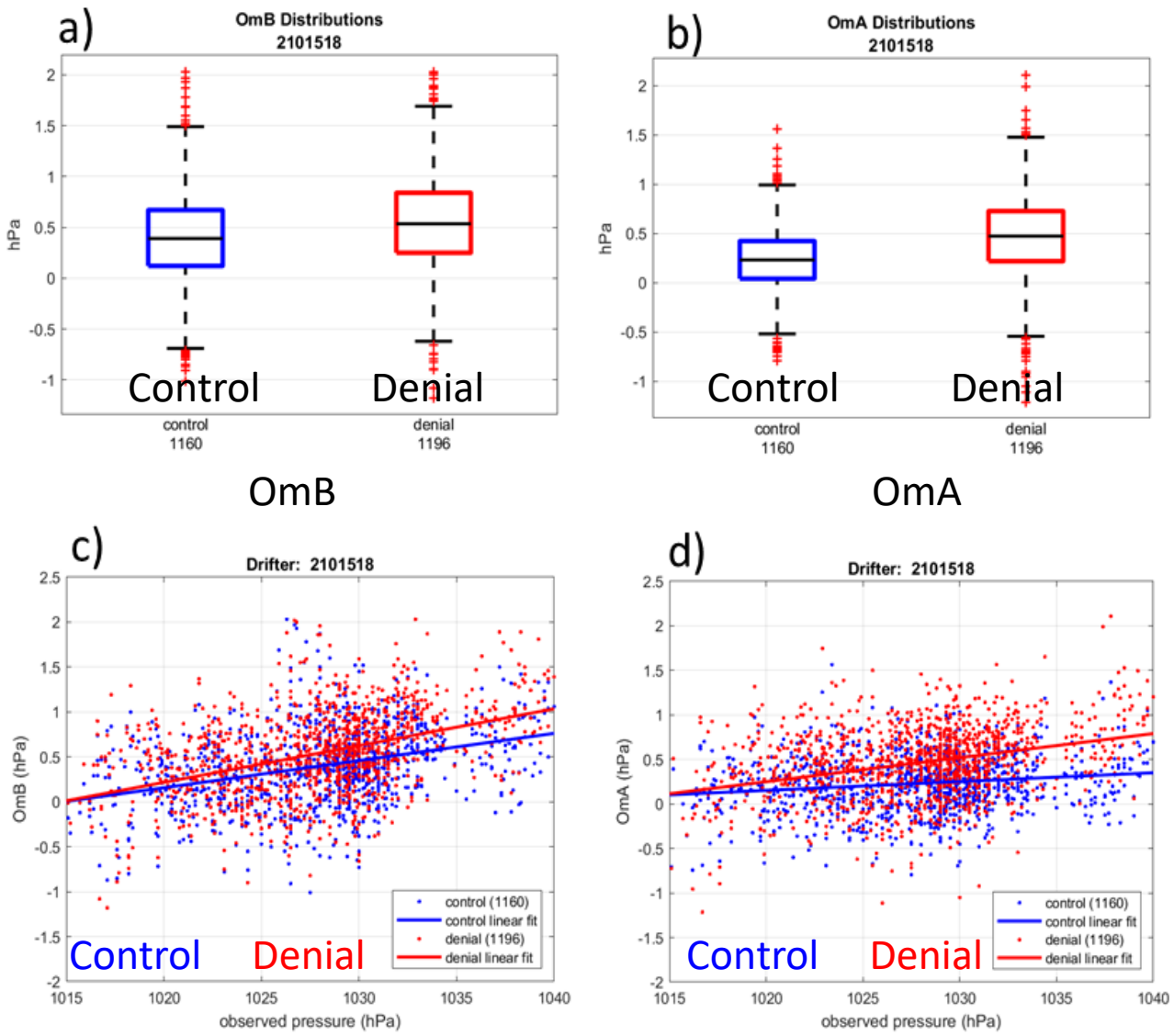
Mean and standard deviation of innovations at each non-AR Recon drifter when AR Recon drifters are assimilated (blue) and not assimilated (orange).



AR Recon (green dots) and non-AR Recon (blue dots and numbers) drifters.

- **The red dots and red underlines correspond to the non-AR Recon drifters where assimilation of AR Recon drifters impacts the innovations**
- **This occurs for the non-AR Recon drifters that are in the vicinity of the AR Recon drifters**
- **Look at circled drifter in detail in next slide**

Data Denial Experiments: Impact on Analyses



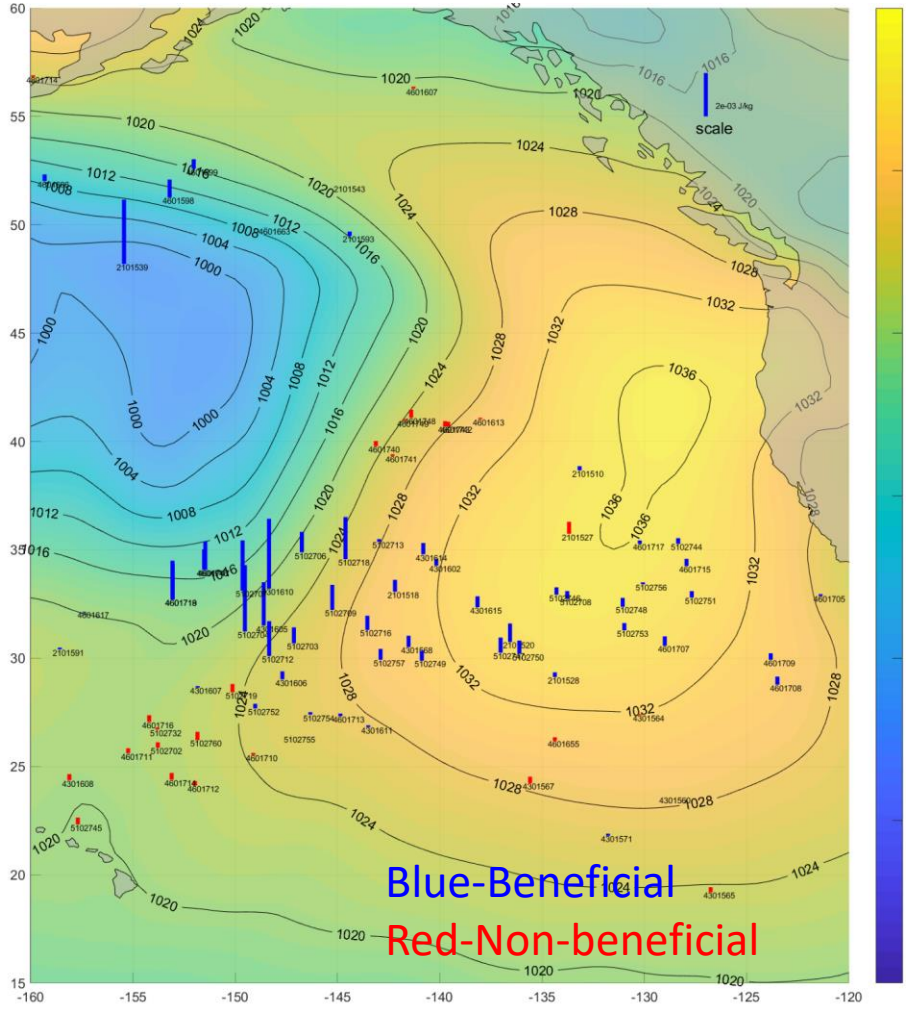
OmB (left) and OmA (right) at non-AR Recon drifter 210518 when AR Recon drifters are assimilated (blue) and are not assimilated (red)

Assimilation of the AR Recon drifter observations:

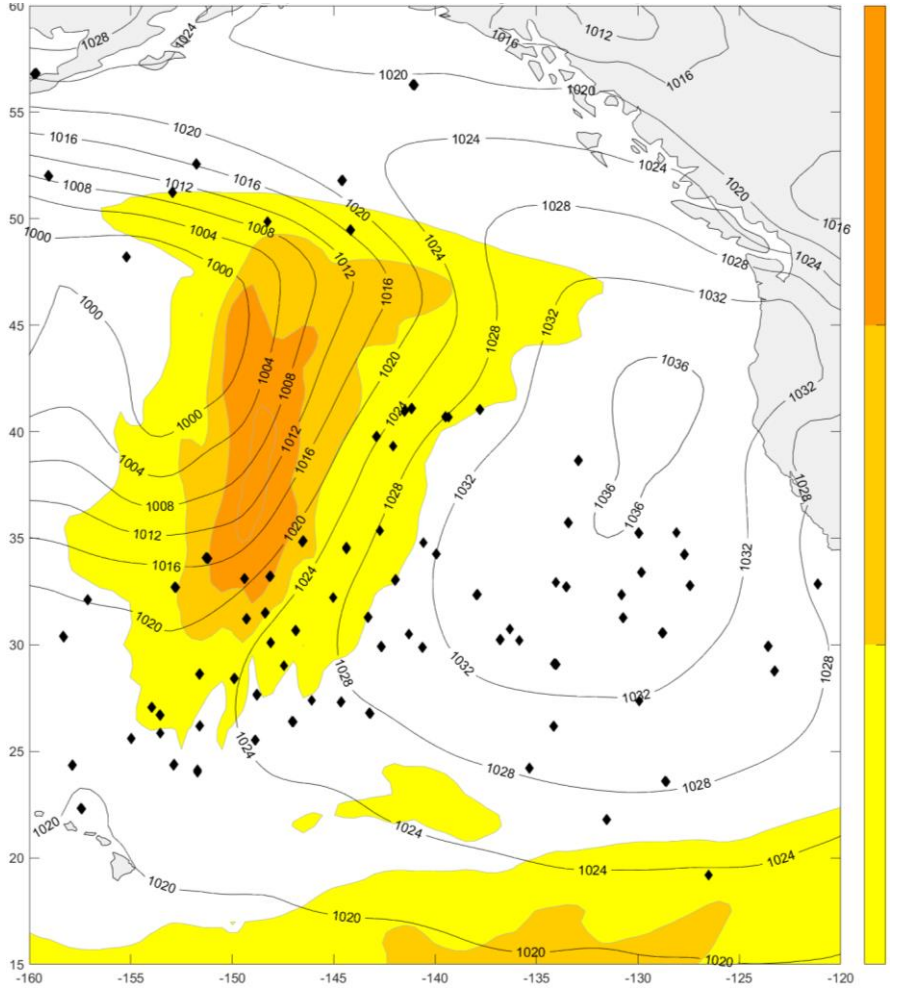
- **decreases the average and spread of both the OmA and OmB distributions**
- **Linear trend lines show that the assimilation of the AR Recon drifters is particularly effective at reducing the model low bias at high pressures**
- **Bigger impact for OmA than for OmB**

Observation Impact for 2020022406 (Large Beneficial Impact)

Impact for each drifter (bars), analyzed SLP (contours and shading), 2020022406



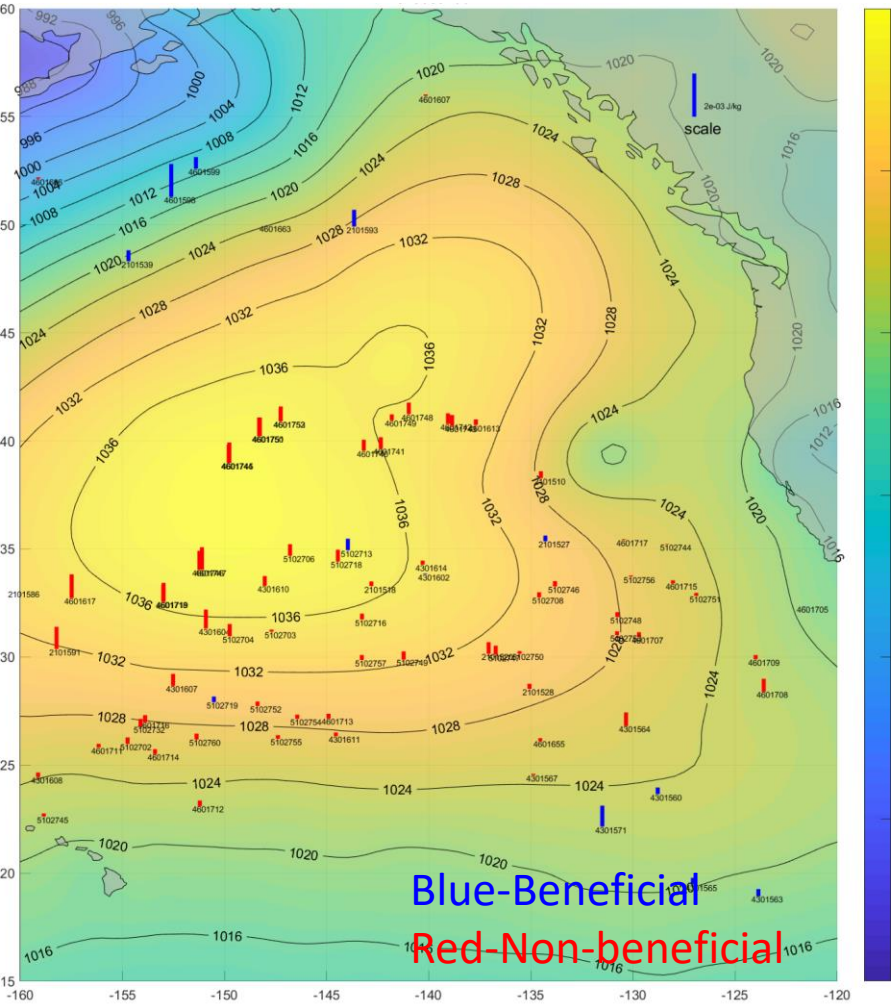
SLP (contours), Integrated Vapor Transport (IVT), drifter locations (black dots), 2020022406



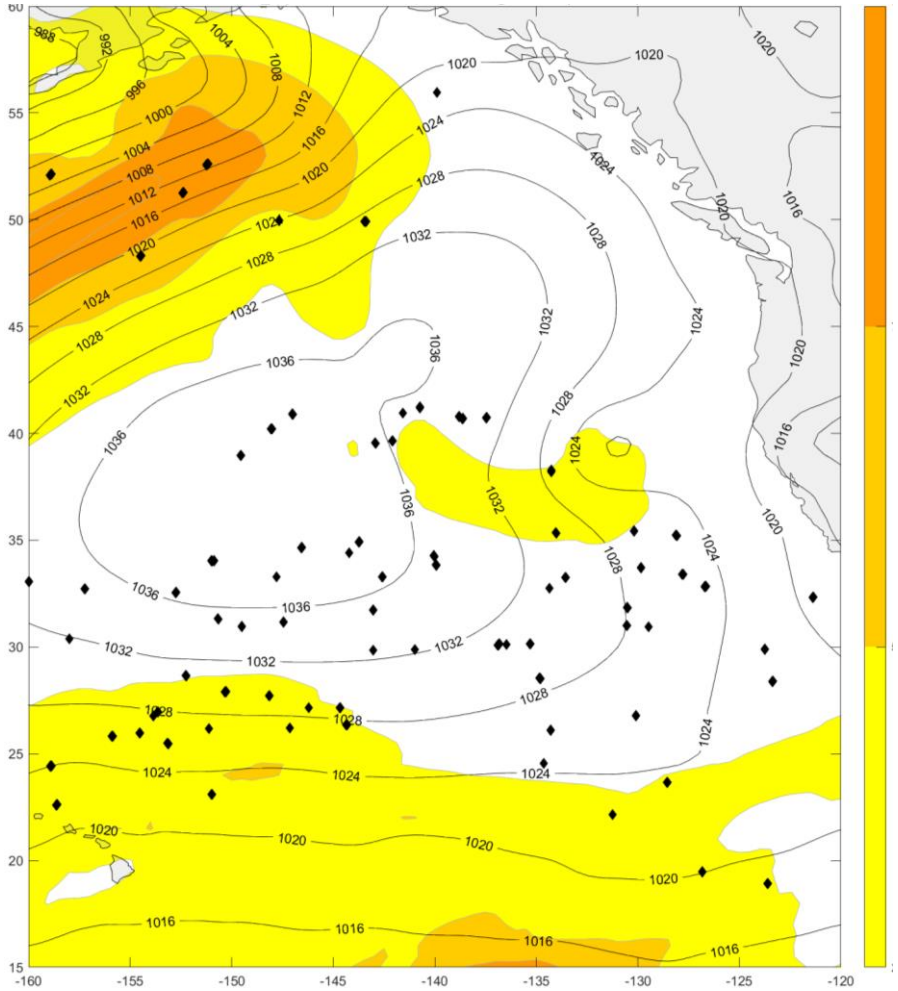
- **Biggest impact from observations along the front, (strong pressure gradient, base of AR)**
- **Observation under the high have less impact**
- **Gulf of Alaska observation in low pressure center impactful**

Observation Impact for 2020030100 (Large Non-Beneficial Impact)

Impact for each drifter (bars), analyzed SLP (contours and shading), 2020030100



SLP (contours), Integrated Vapor Transport (IVT), drifter locations (black dots), 2020030100



- **Total non-beneficial impact not dominated by a few drifters, rather most drifters under the high pressure center have small non-beneficial impacts**
- **Some beneficial impacts from drifters in the Gulf of Alaska (strong pressure gradient region)**