USV-based estimation of upper-ocean vertical velocity in the equatorial Pacific

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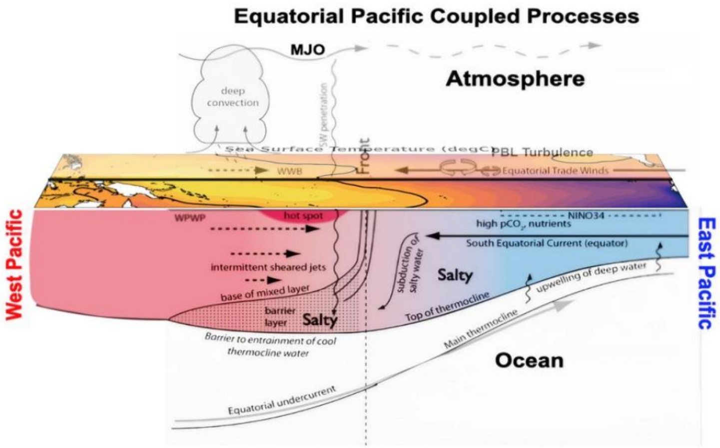
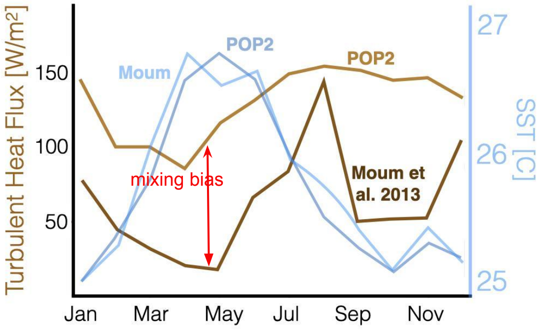
Why Vertical Velocity?

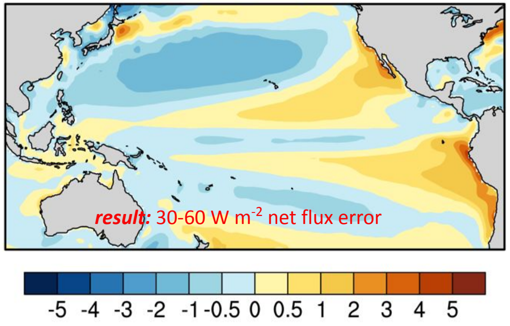


Borrowed from the TEPEX Science Plan (Figure 1. Illustration of air-sea interaction processes of the equatorial Pacific)

Model Biases



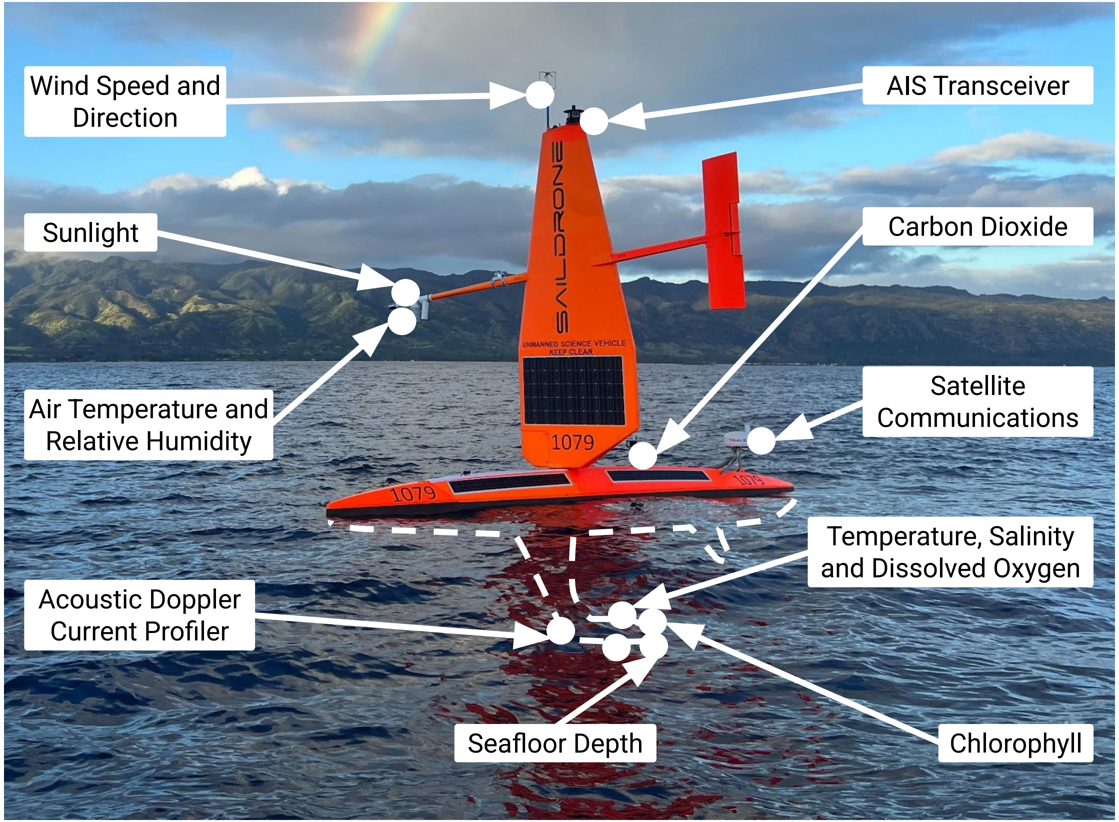
Modified from Deppenmeier et al 2022



Newman and Sardeshmukh 2017

- transports cold, nutrient-rich water from the deep ocean to the surface layer
- close connection to major climate patterns like the ENSO
- difficult to measure directly
- biases in modelled ocean mixing arising from incomplete process understanding

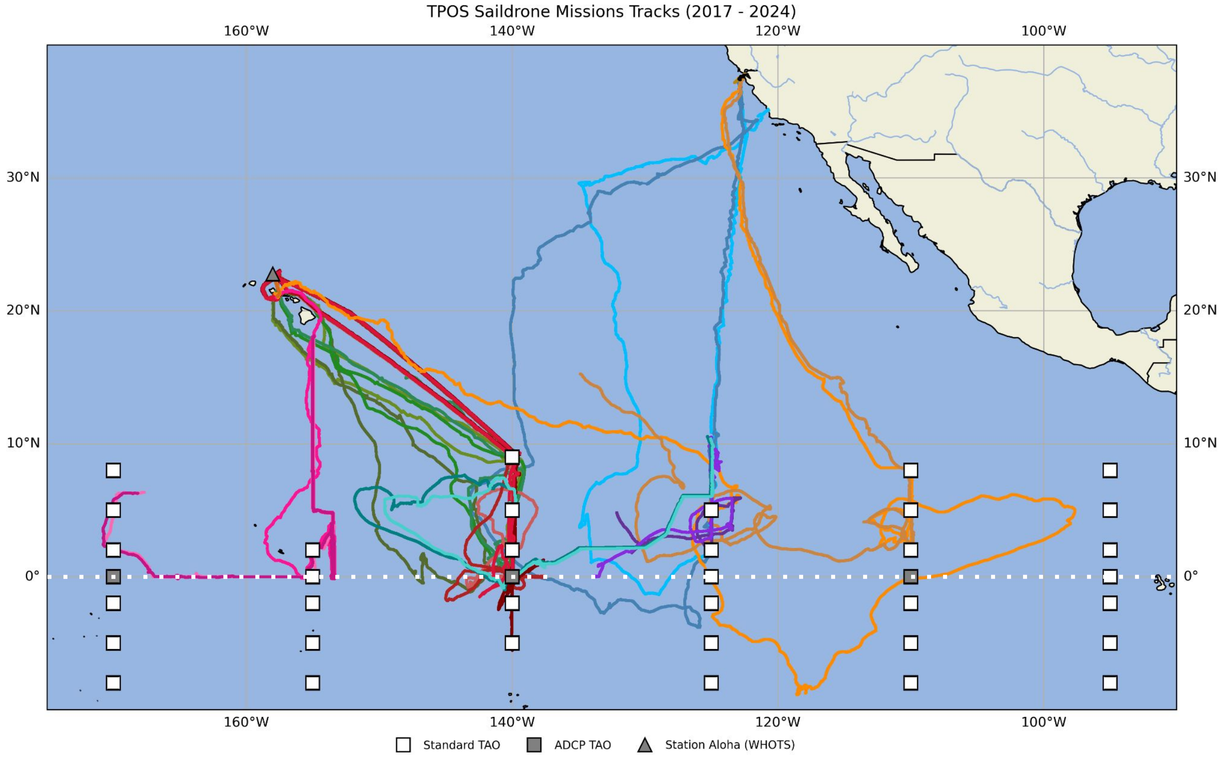
How to “Measure” Vertical Velocity from a USV



Sensors mounted on a 2019 saildrone. Photo courtesy of Saildrone. Used with permission.

Saildrone Explorer USV

- Wind-powered
- Missions can last up to 6 months
- Fully equipped with suite of sensors including ADCP

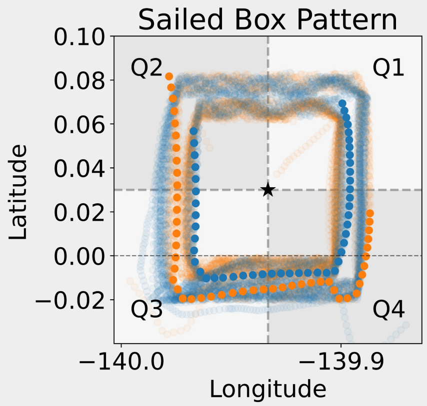


TPOS Saildrone Missions

- 7 years
- Missions have 2-4 drones
- Focus in tropical Pacific

Method to calculate plane-fit upwelling from ADCP

- The USV's ADCP measures horizontal currents (*u* and *v*).
- Sailing the "box" pattern allows us to estimate the horizontal gradients (*du/dx*, *dv/dy*).
- Assuming vertical velocity at the surface is zero, we integrate downwards to find *w* at every depth.



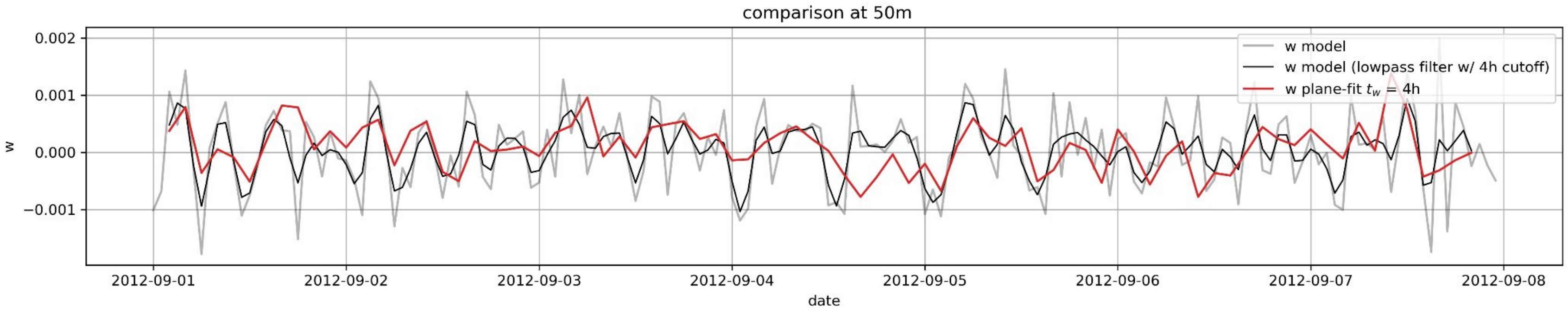
Vertical Velocity Algorithm

Drones sail box pattern from time t_0 to t_n. Select a time window, t_w, and time slide, t_s. Set k=0.

1. Store $t_k + ½ t_w$, the timestamp for the middle of the interval.
2. *Aggregate data:* Collect *u*, *v* during $[t_k, t_k + t_w)$. Check how well the box is covered, and store this information.
3. *Gradient estimate:* For each depth, use the aggregated u, v from around the box to estimate *u*, *v*, u_x and v_y at the box centre by fitting a plane at each depth level.
4. *Continuity:* Calculate w_z by continuity: $w_z=-(u_x + v_y)$
5. Integration: Integrate vertically from the surface to determine *w(z)*. Note *w(0) = 0*.
6. *Stopping condition:* If $t_k+t_w > t_n$, STOP. Else, *k = k+1*, return to step 1.

Method verification

- Use synthetic drone ADCP data in high resolution model (MITgcm)
- Test variety of settings
- This successful test gave us confidence that our method is robust for use with real-world data.

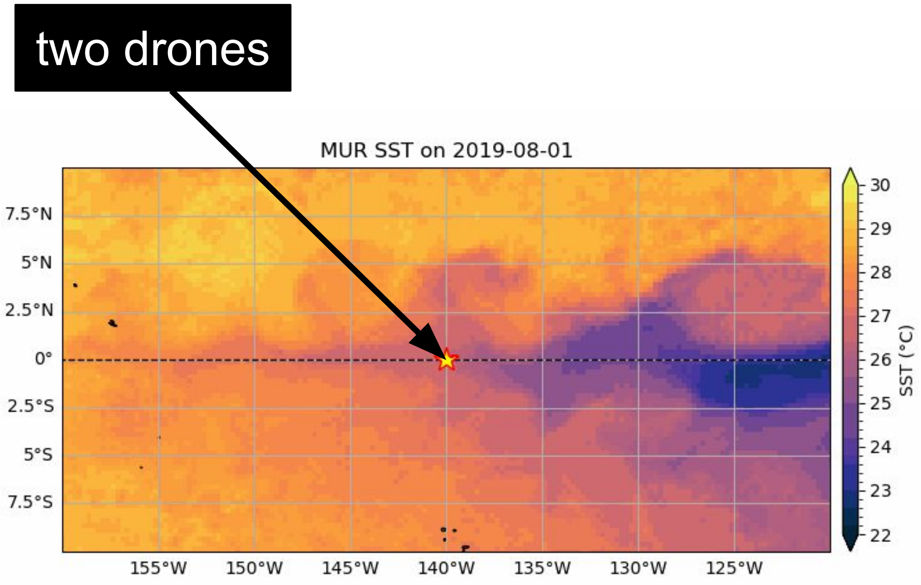


Comparison of model *w* with box-fit *w*

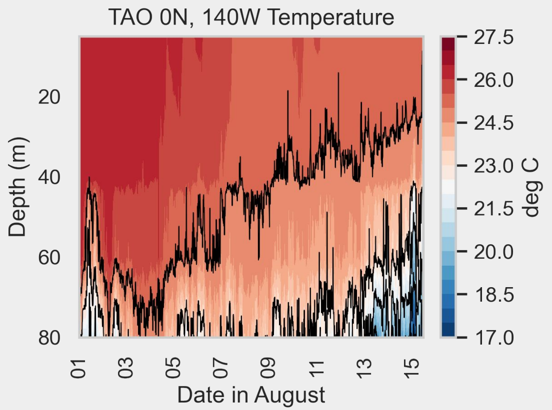
Estimation of Vertical Velocity in the Equatorial Pacific from Observations

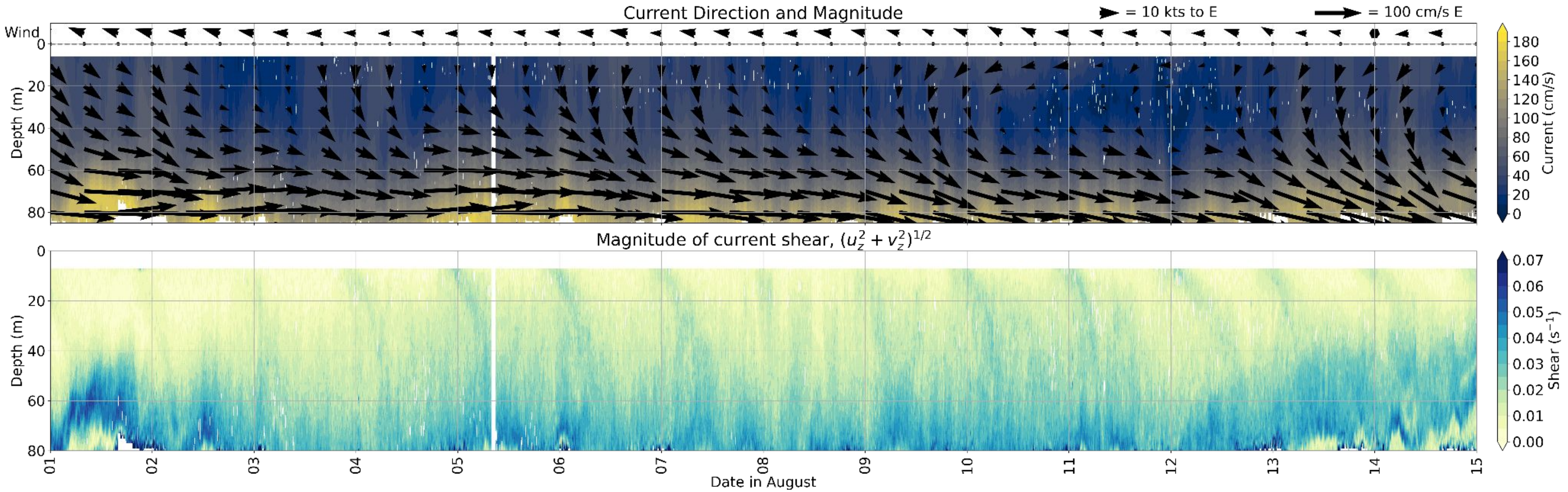
(2019 Case Study)

2019 Box-Experiment

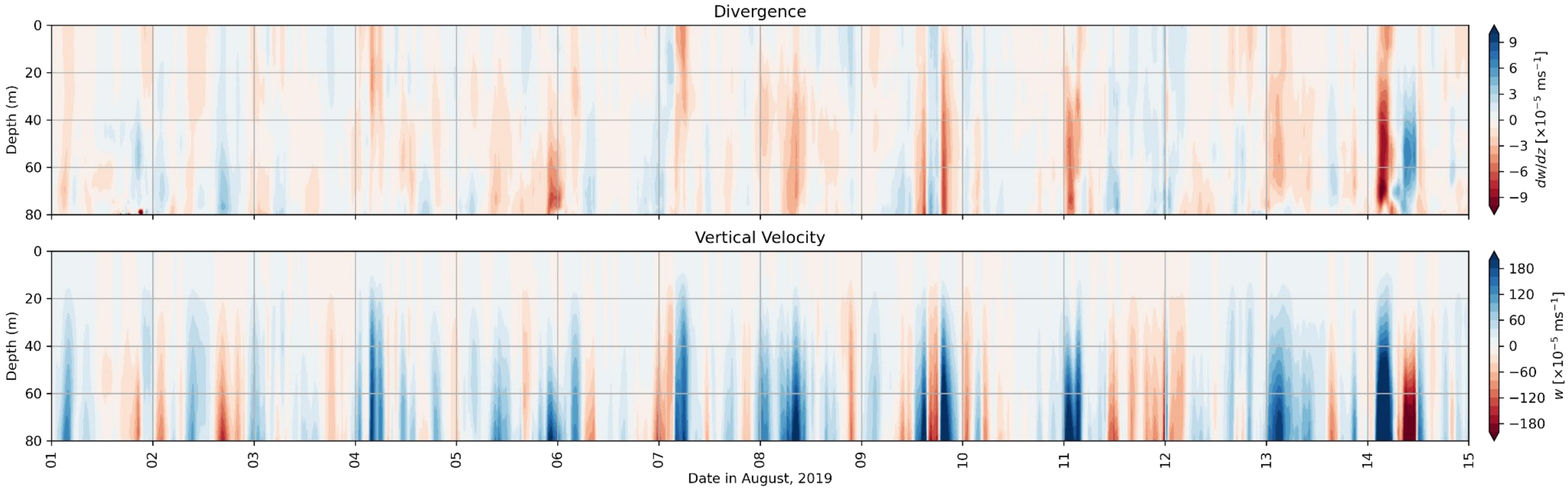


- two drones
- both with ADCP
- sail a box pattern
- 0N, 140W
- two weeks

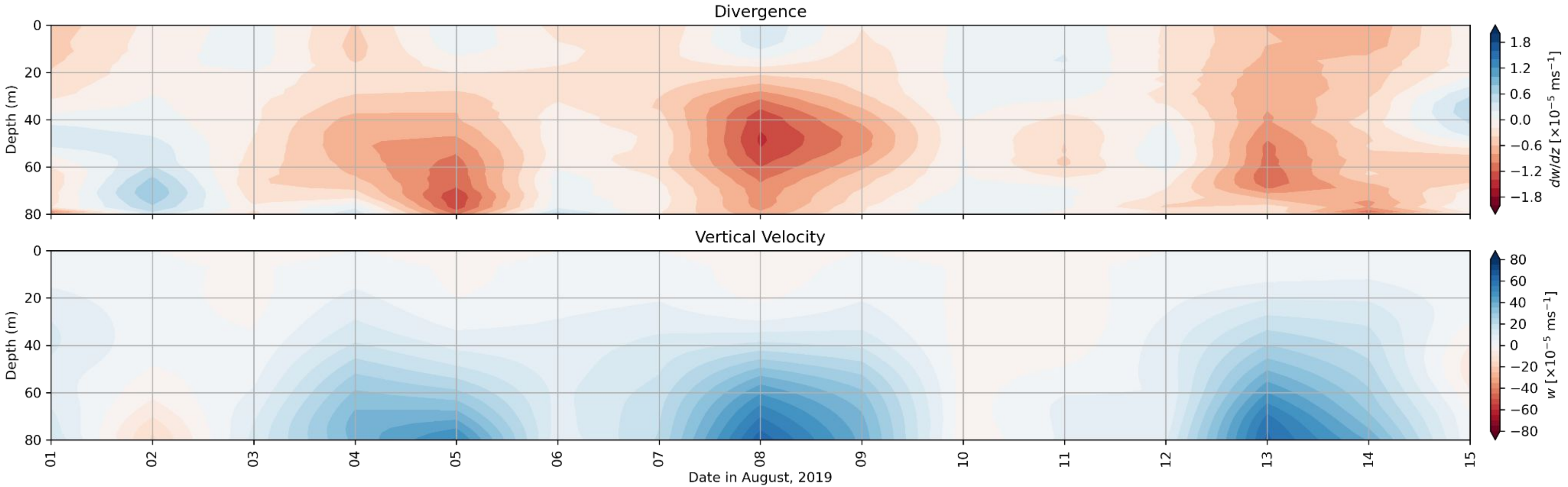




Current Direction and Magnitude
= 10 kts to E
= 100 cm/s E
Wind
Depth (m)
Current (cm/s)
Magnitude of current shear, $(u_z^2 + v_z^2)^{1/2}$
Depth (m)
Shear (s^{-1})
Date in August



Divergence
Depth (m)
0
20
40
60
80
9
6
3
0
−3
−6
−9
dw/dz [×10^{-5} ms^{-1}]
Vertical Velocity
Depth (m)
180
120
60
0
−60
−120
−180
w [×10^{-5} ms^{-1}]
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
Date in August, 2019


Divergence
Vertical Velocity
Depth (m)
Date in August, 2019
dw/dz [$\times10^{-5}$ ms^{-1}]
w [$\times10^{-5}$ ms^{-1}]
01
02
03
04
05
06
07
08
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15

Key Takeaways

- validated a method to estimate vertical velocity from a USV
- high-resolution estimation vertical velocity in the equatorial Pacific
- USVs provide a powerful new tool for observing a critical, yet difficult-to-measure, ocean parameter.

Future directions

- Experiment with other sailing patterns within model context.
- Integrating other sensor data (like temperature, salinity, SW+LW radiation) for a more complete picture of ocean dynamics.

- Coordinated fleets of USVs for even larger-scale mapping.
- Longer-term deployments to capture seasonal or interannual variability.