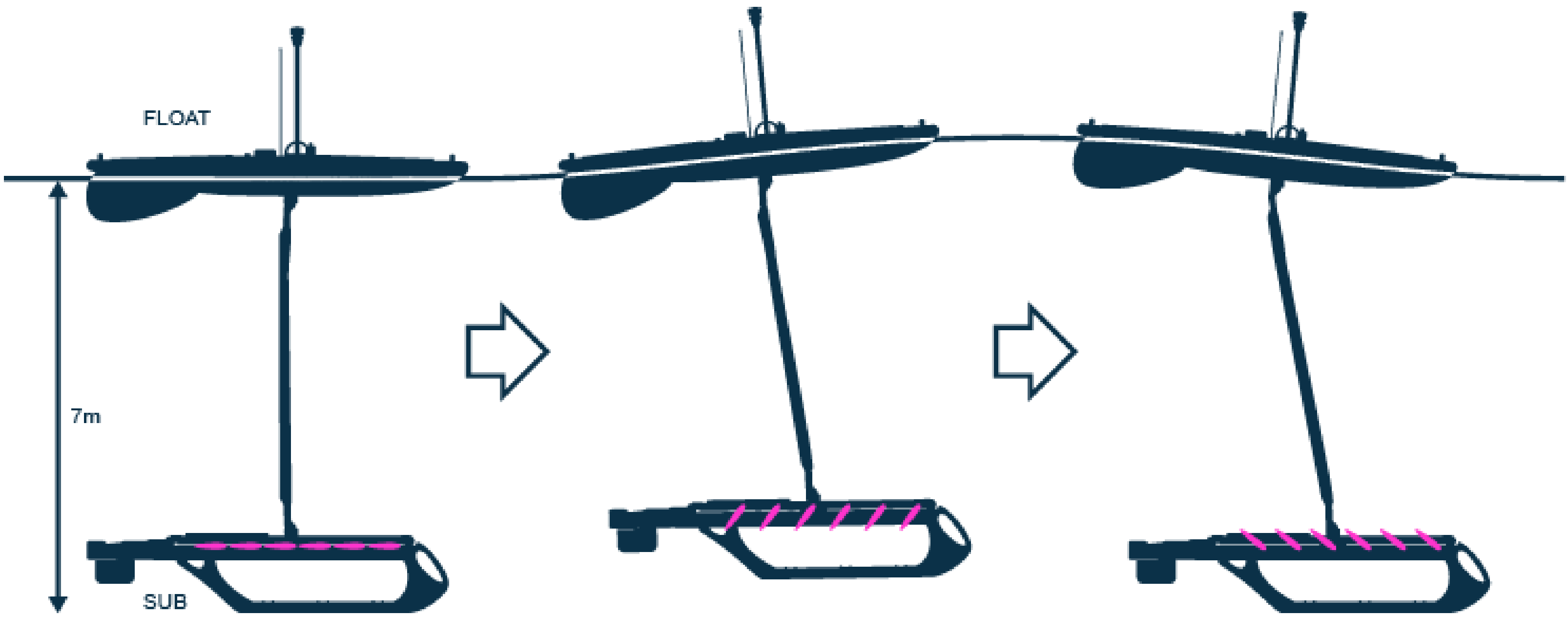
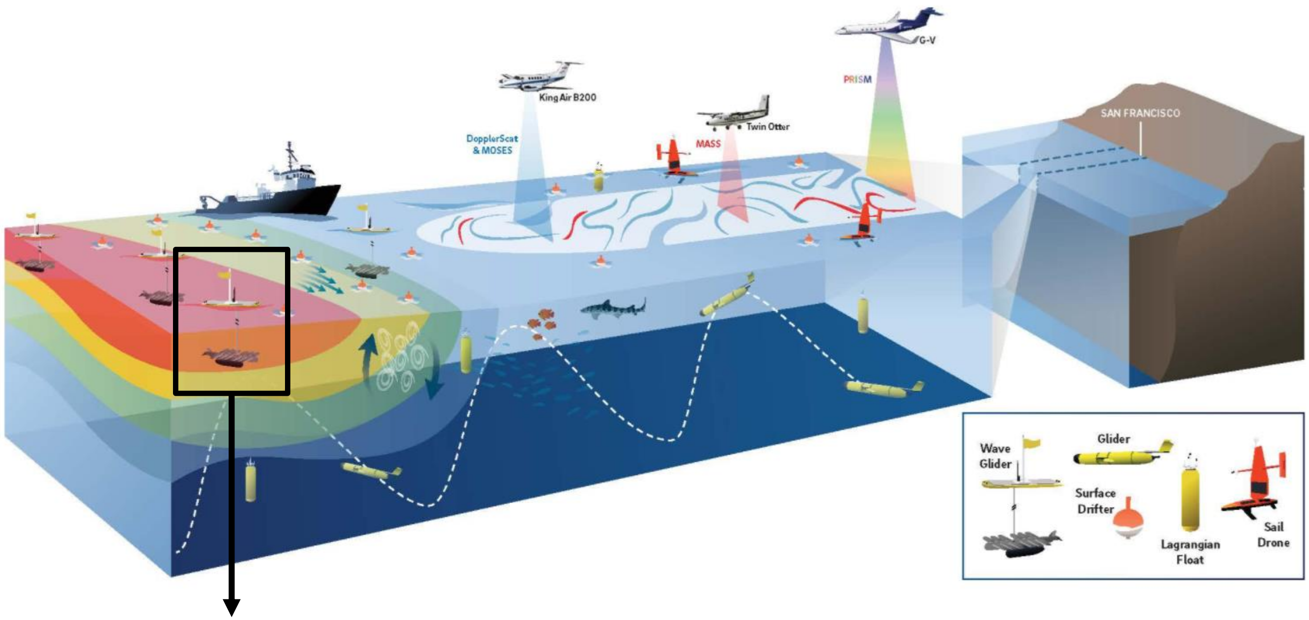
Upper ocean current measurements using Wave Gliders during the S-MODE Pilot

Hugo Peyrière – Visiting Graduate Student, Air-Sea Interaction Laboratory, SIO

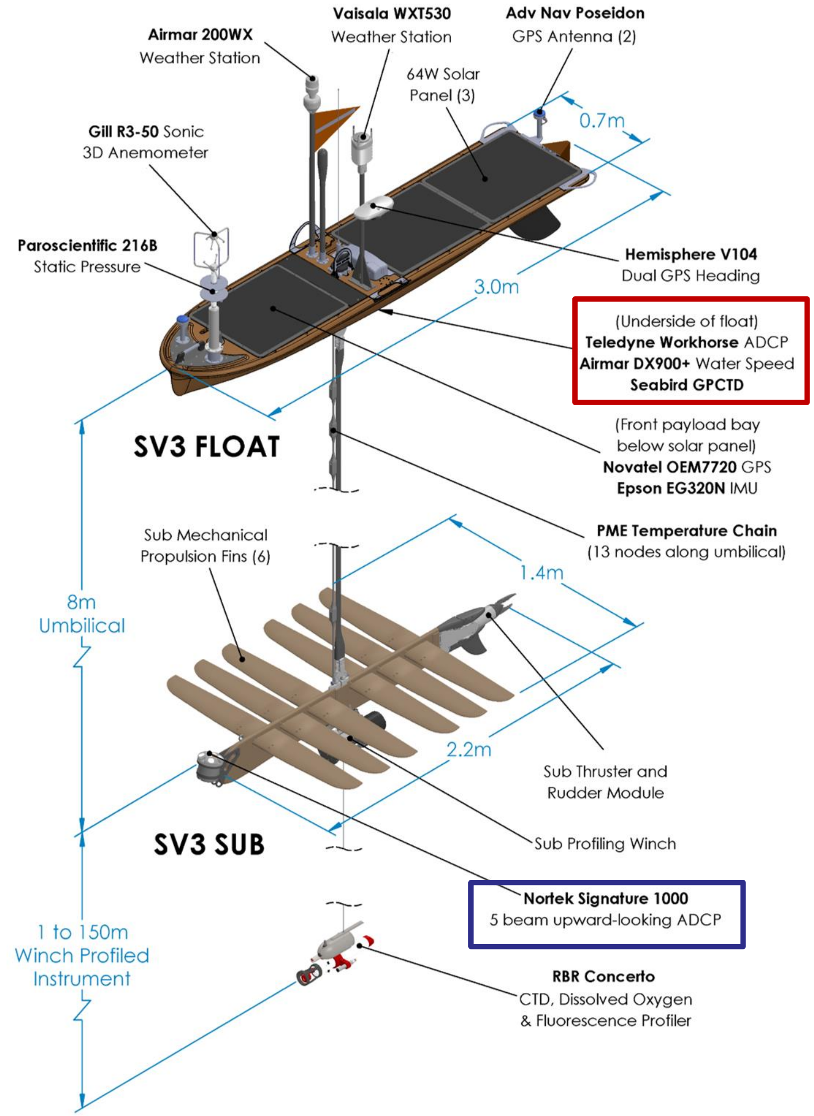
L. Lenain, L. Grare, N. Pizzo, N. Statom, L. Colosi, T. Farrar



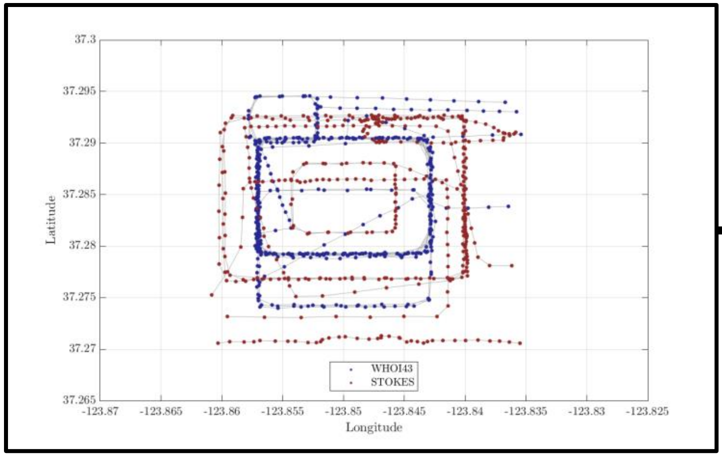


- How to correct for platform motion?
- How to consider wave effects?
- How to interpret Wave Glider based current measurements?
- How to compare them to remote current measurements?

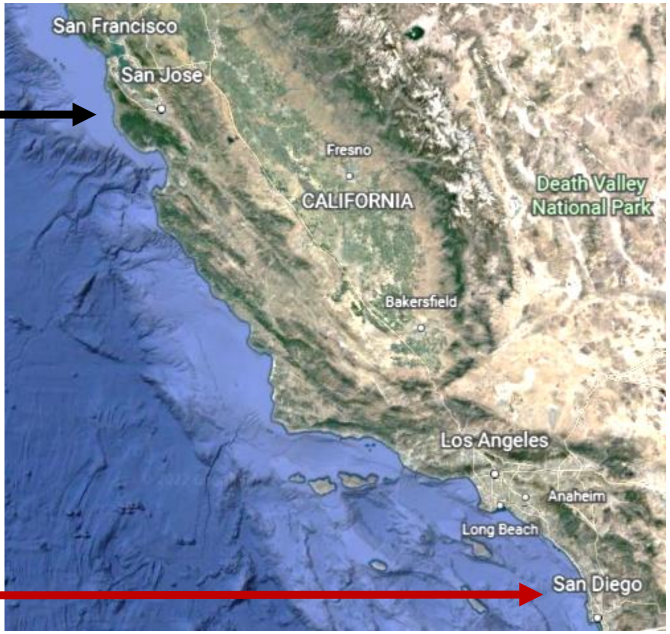
- Current profiles:
  - **Float downward ADCP**, *Teledyne Workhorse 300kHz*,
  - **Sub upward ADCP**, *Nortek Signature 1000*.
- Float position and movement: GPS/IMU, *Novatel OEM7720 + Epson EG320N*.
- Sub position, movement and pressure: IMU/pressure sensor, *Nortek Signature 1000*.



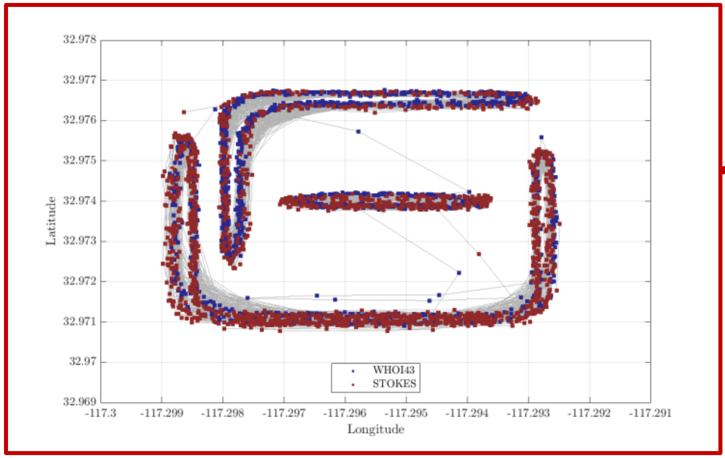
S-MODE Pilot: November 3rd to 5th, 2021.



3 km x 3 km



Del Mar 2021: March 4th to 11th, 2021.



0.7 km x 0.7 km

How to correct for platform motion?

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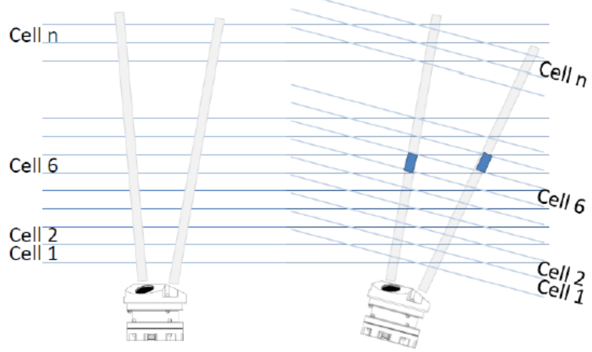
1. Depth cell remapping for pitch, roll, depth



2. Vehicle frame transformation

3. Earth frame transformation

4. Platform speed correction

- Downward ADCP:

$$\boldsymbol{U}_{motion\ corrected} = \boldsymbol{U}_{downward\ ADCP} + \boldsymbol{U}_{float\ GPS/IMU} + \overbrace{\boldsymbol{\omega} \wedge \boldsymbol{r}}^{\text{Effect of rotation through GPS/IMU-ADCP lever arm}}$$

- Upward ADCP:

$$\boldsymbol{U}_{motion\ corrected} = \boldsymbol{U}_{upward\ ADCP} + \boldsymbol{U}_{sub\ IMU}^{High\ Freq.} + \boldsymbol{U}_{float\ GPS/IMU}^{Low\ Freq.}$$

Notes: Heading bias correction was also applied, in order to account for the bias between the measured and real heading for float and sub. Cut-off frequency used in the upward ADCP platform speed correction was 0.05 Hz.

Consistent ADCPs and Wave Gliders

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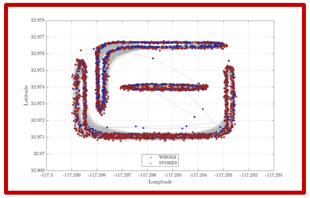


Del Mar 2021:
March 4th to 11th, 2021.

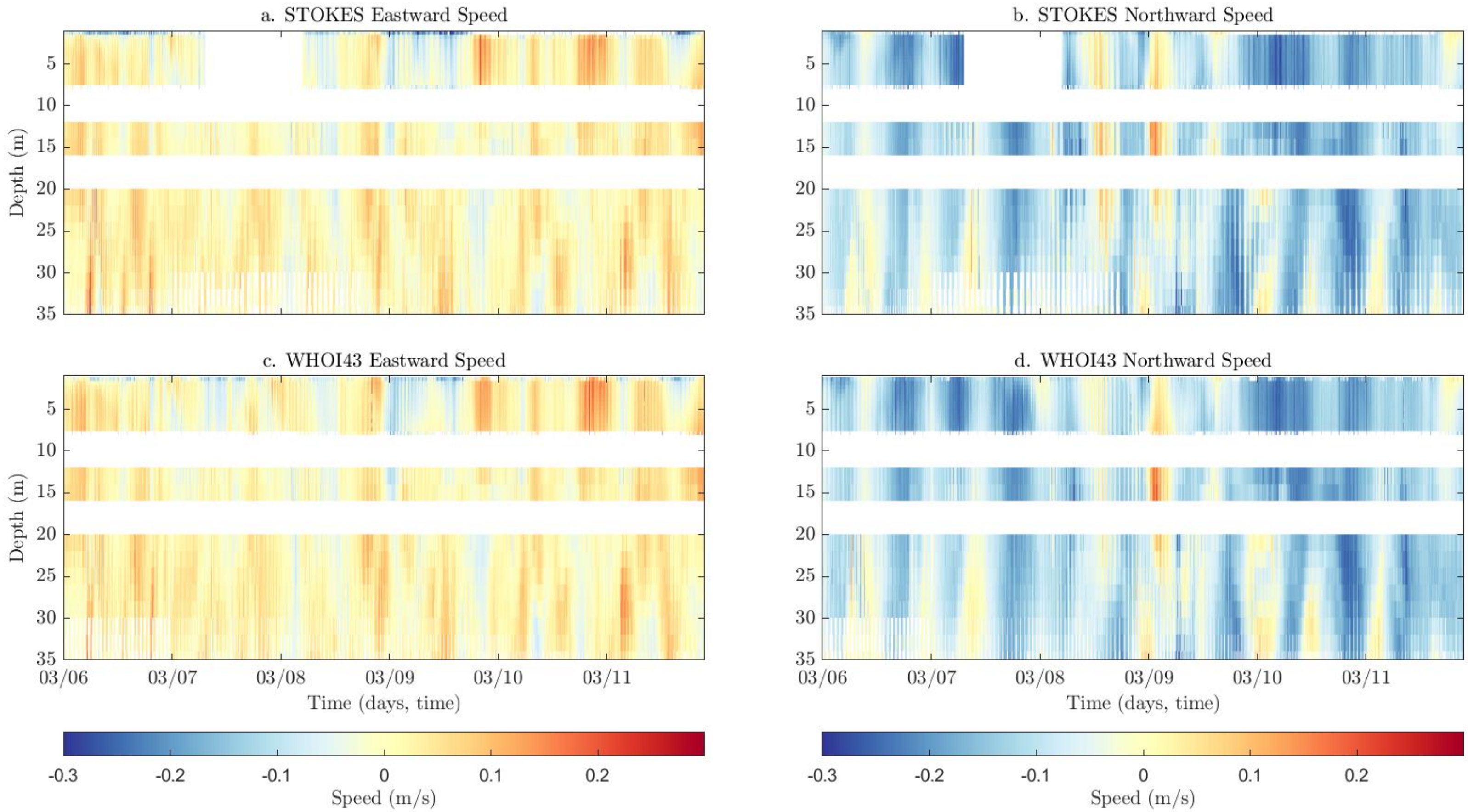
- Consistency between ADCPs.
- Consistency between Wave Gliders (STOKES and WHOI43).

Upward float ADCP

Downward sub ADCP

Upward float ADCP

Downward sub ADCP



Consistent ADCPs and Wave Gliders

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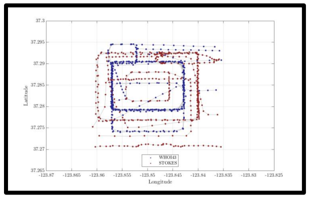

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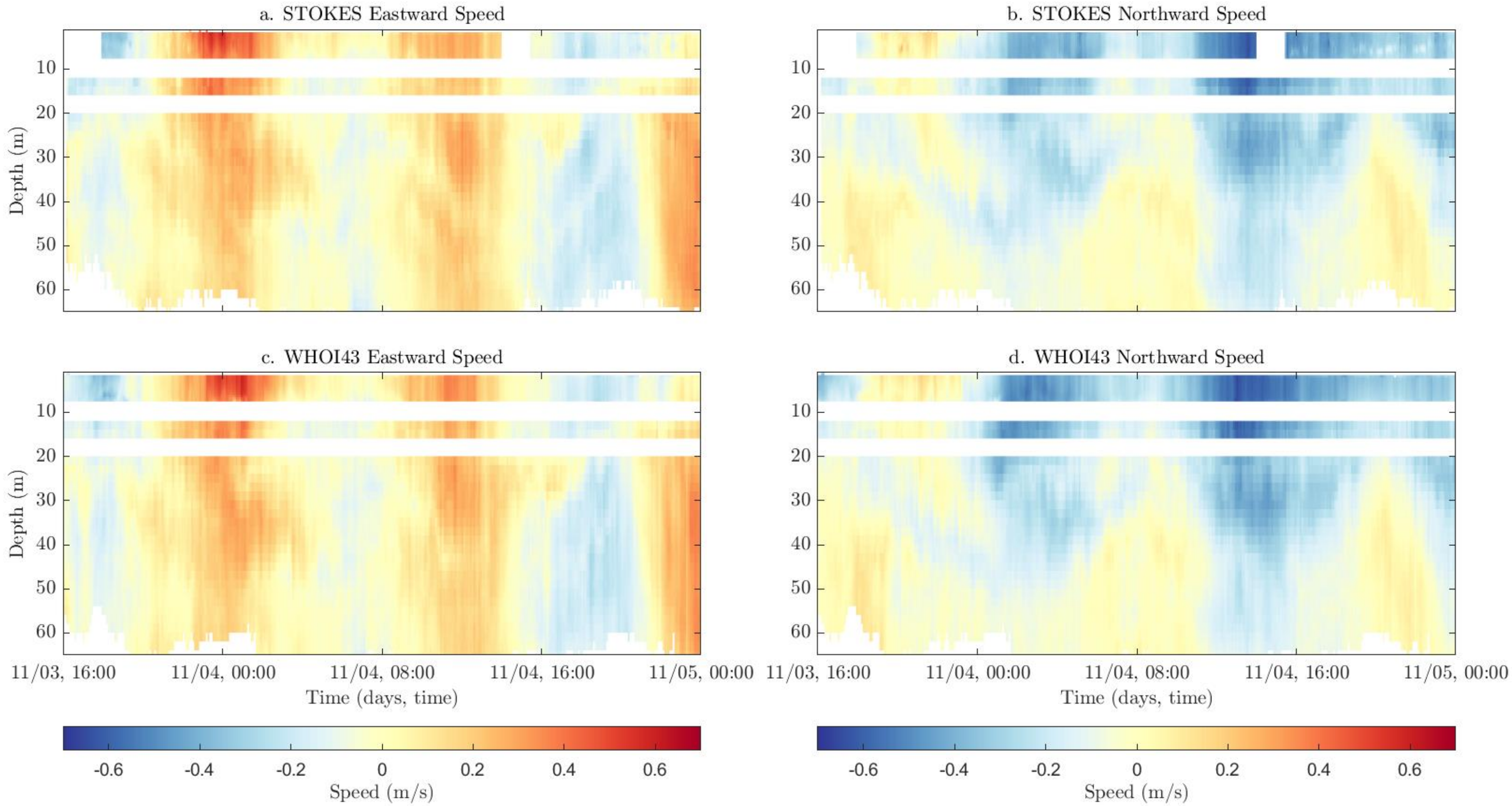

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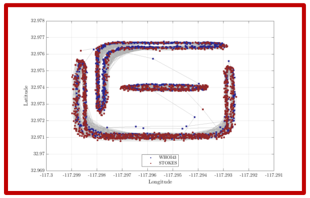


Mean
WHOI43 upward looking ADCP
STOKES upward looking ADCP
WHOI43 downward looking ADCP
STOKES downward looking ADCP

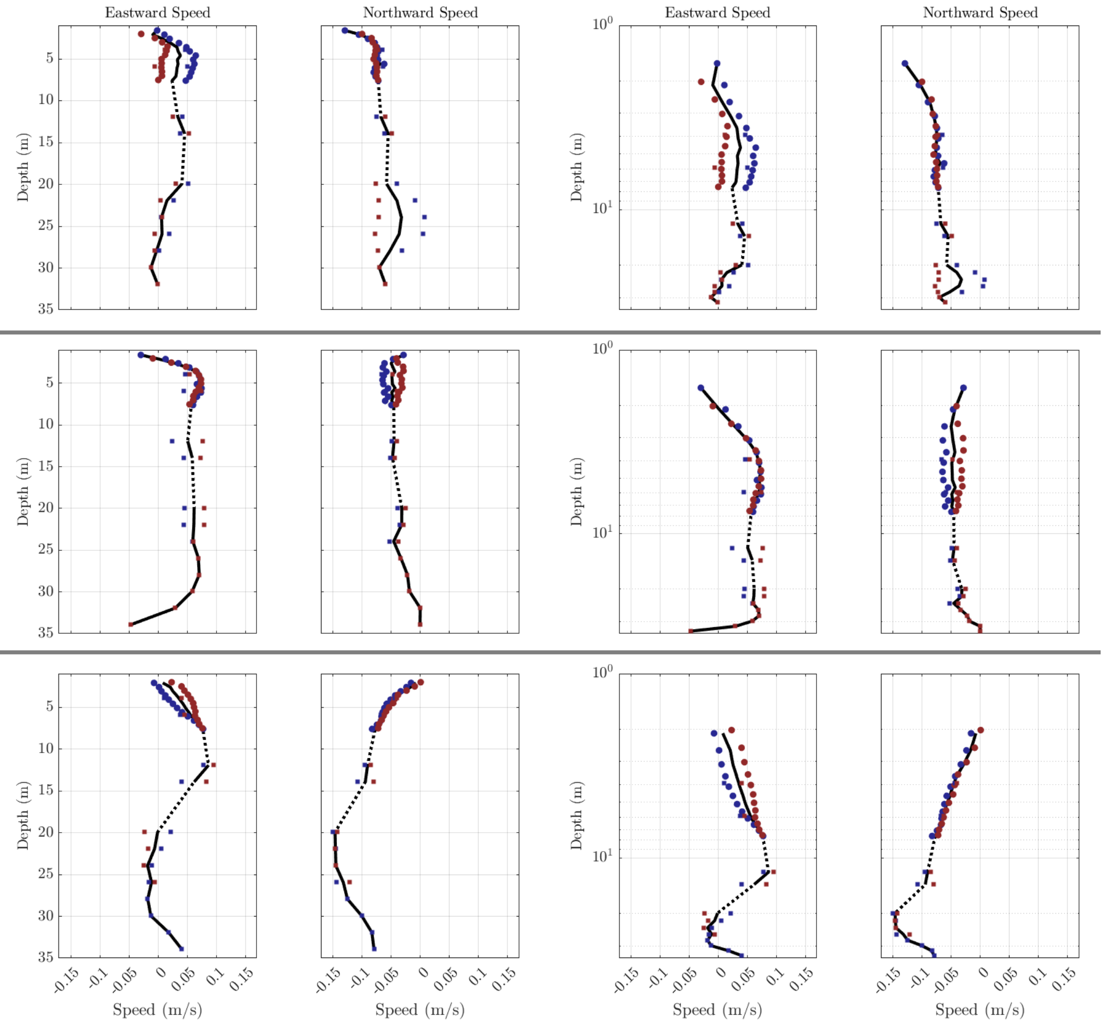
- Broad range of profiles spatially and temporally.
- Natural spatial variability between Wave Gliders.

Linear Depth **Log Depth**

03/06
00:45
143m WG distance

03/06
08:15
411m WG distance

03/11
19:55
635m WG distance



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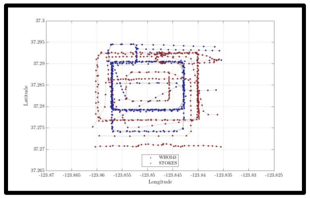
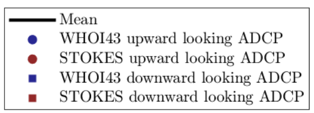




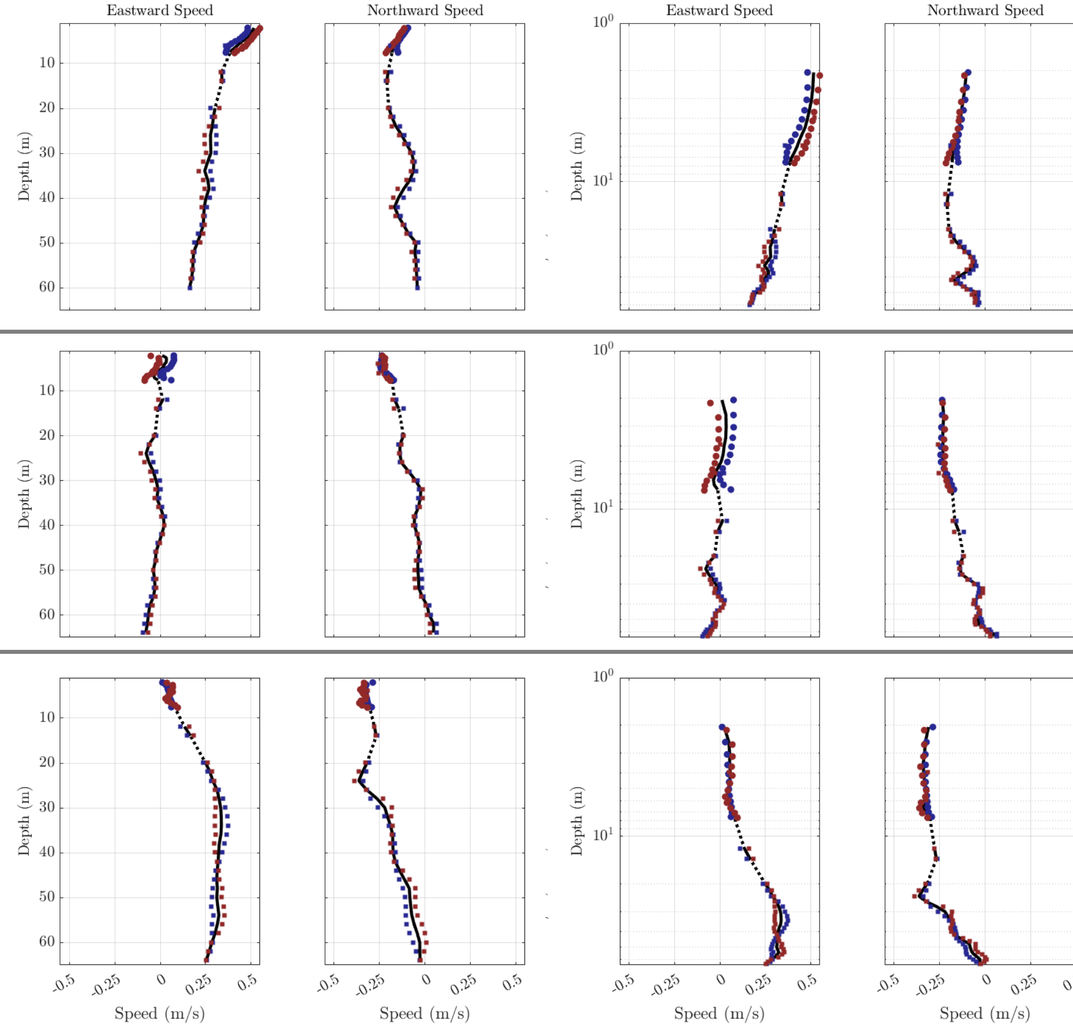
- Broad range of profiles spatially and temporally.
- Natural spatial variability between Wave Gliders.

Linear Depth | Log Depth

11/04
00:45
766m WG distance

11/04
08:15
647m WG distance

11/04
23:25
1264m WG distance



Consistent upward/downward ADCPs

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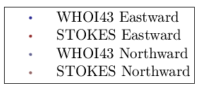
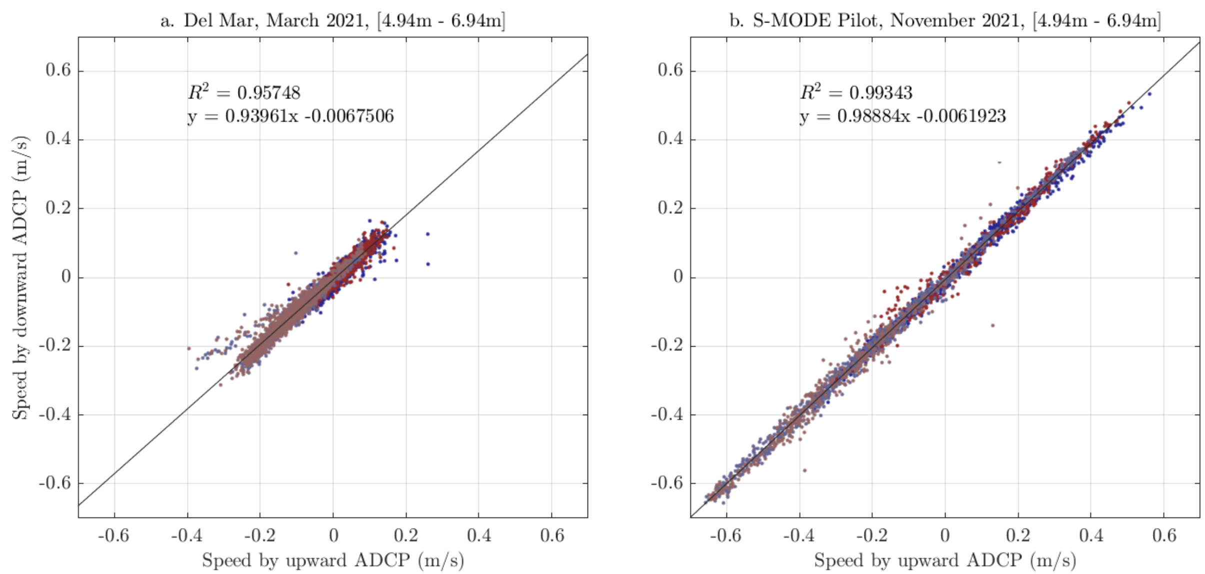
- **Regression:**



- Excellent fit between upward & downward ADCP.



- **Statistics:**

- Deviation between upward & downward ADCP at the cm/s scale.

TABLE 1. Comparison statistics between upward and downward looking ADCP speed measurements (cm/s).

Deployment	Vehicle	Direction	Mean Bias	RMSE	Mean Absolute Speed
Del Mar, March 2021	WHOI43	Eastward	1.09	2.47	4.26
		Northward	0.14	2.25	12.08
	STOKES	Eastward	0.60	1.98	3.48
		Northward	0.34	2.30	10.35
S-MODE Pilot, November 2021	WHOI43	Eastward	0.39	3.86	15.34
		Northward	2.42	6.48	26.05
	STOKES	Eastward	-0.17	2.86	8.22
		Northward	0.65	3.09	14.56

Vorticity, Divergence and Strain

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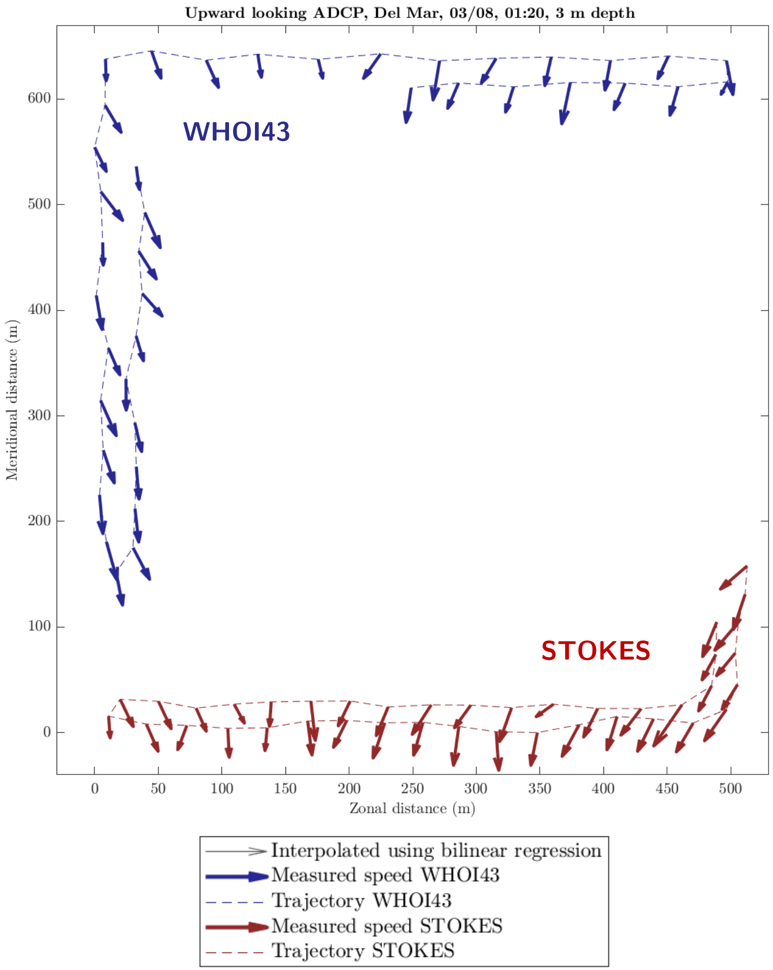
Inspired from Shcherbina et al. (2013)

- **Bilinear regression:**

$$\boldsymbol{U} = a_0 + a_1\boldsymbol{X} + a_2\boldsymbol{Y}$$
$$\boldsymbol{V} = b_0 + b_1\boldsymbol{X} + b_2\boldsymbol{Y}$$

- **Vectorial operators:**

$$Vertical\ Vorticity = V_x - U_y = b_1 - a_2$$
$$Horizontal\ Divergence = U_x + V_y = a_1 + b_2$$
$$Strain\ Rate = \left[\left(U_x - V_y\right)^2 + \left(V_x + U_y\right)^2\right]^{1/2}$$
$$= [(a_1 - b_2)^2 + (b_1 + a_2)^2]^{1/2}$$



Note: See '***Statistics of vertical vorticity, divergence, and strain in a developed submesoscale turbulence field, Shcherbina, D'Asaro, Lee, Klymak, Jeroen Molemaker and McWilliams, 2013***'.

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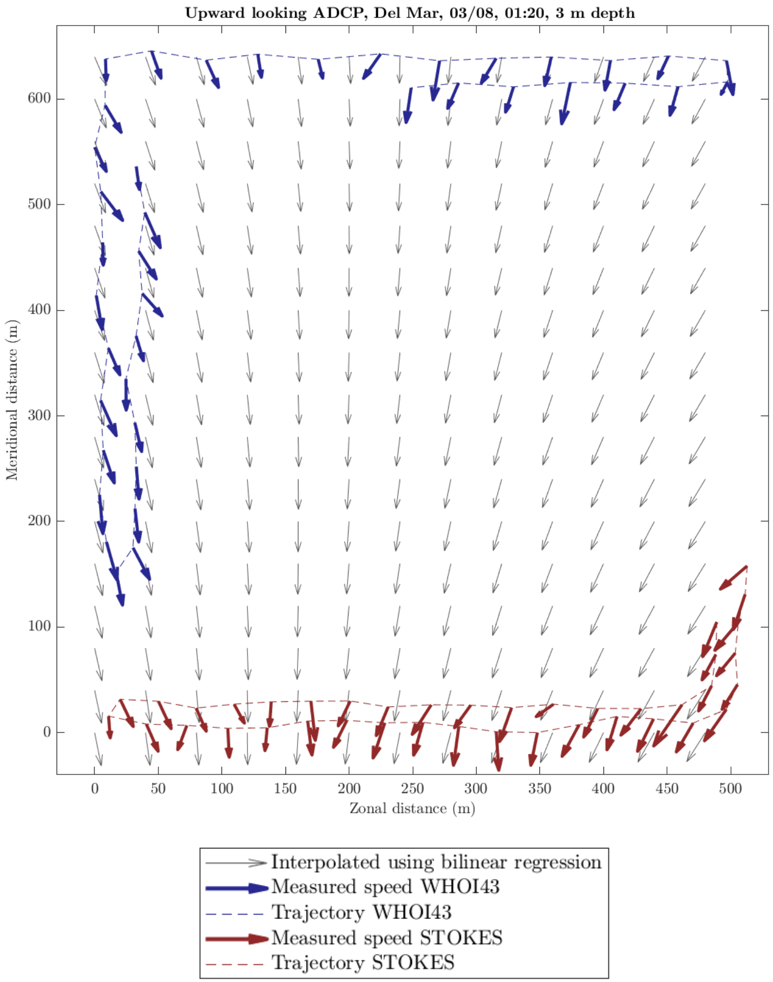

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Vorticity, Divergence and Strain

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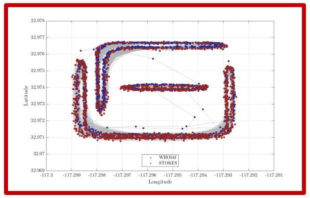
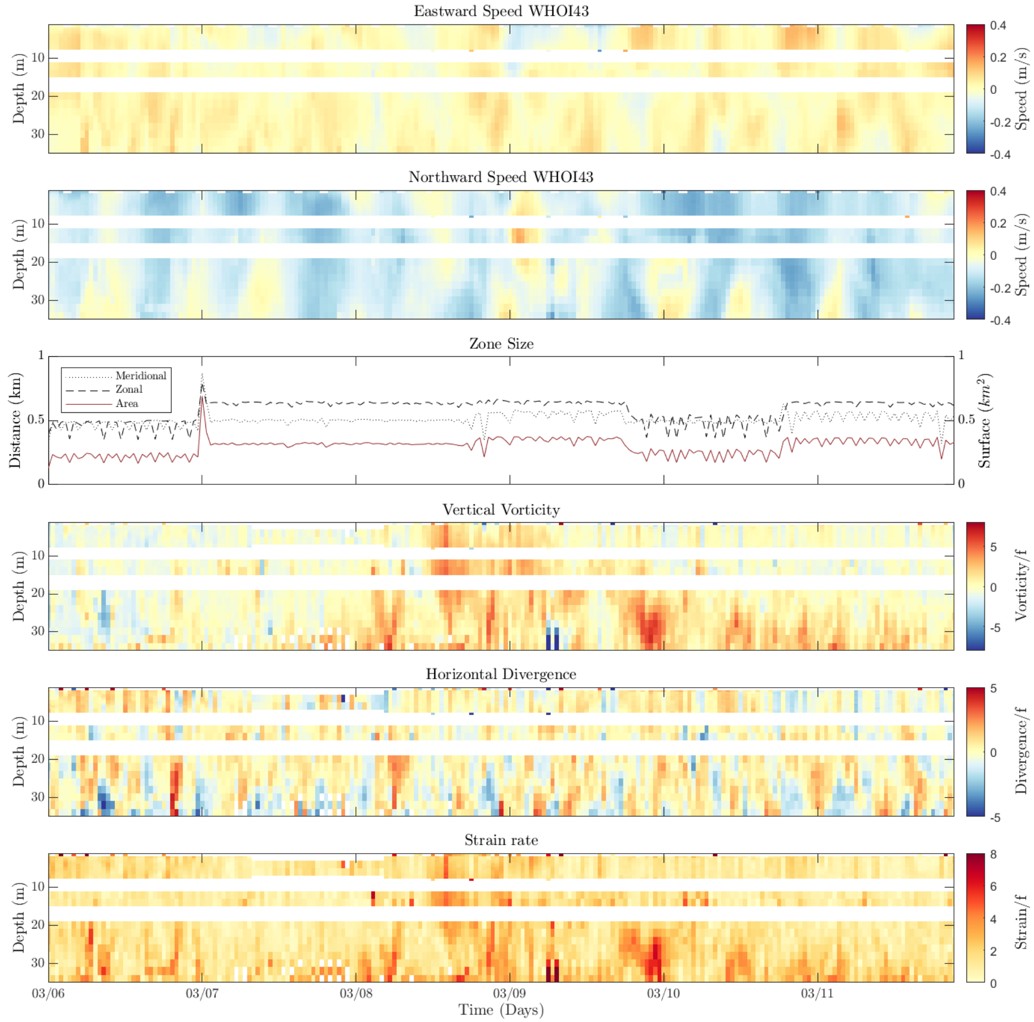
March 4^{th} to 11^{th}, 2021.





Note: Vectorial operators are normalized by f, the Coriolis parameter.

Vorticity, Divergence and Strain

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S-MODE Pilot:
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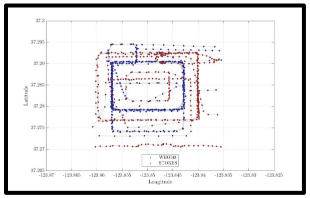

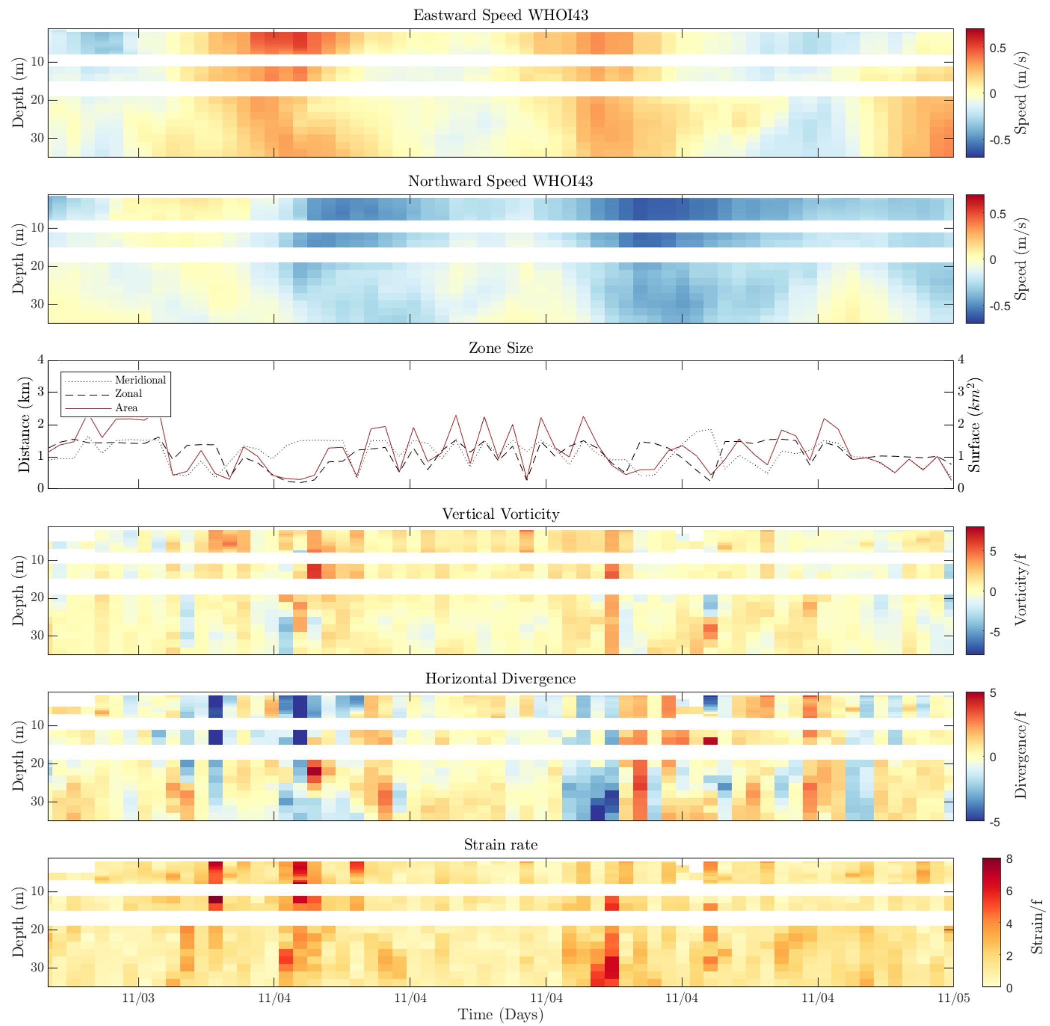

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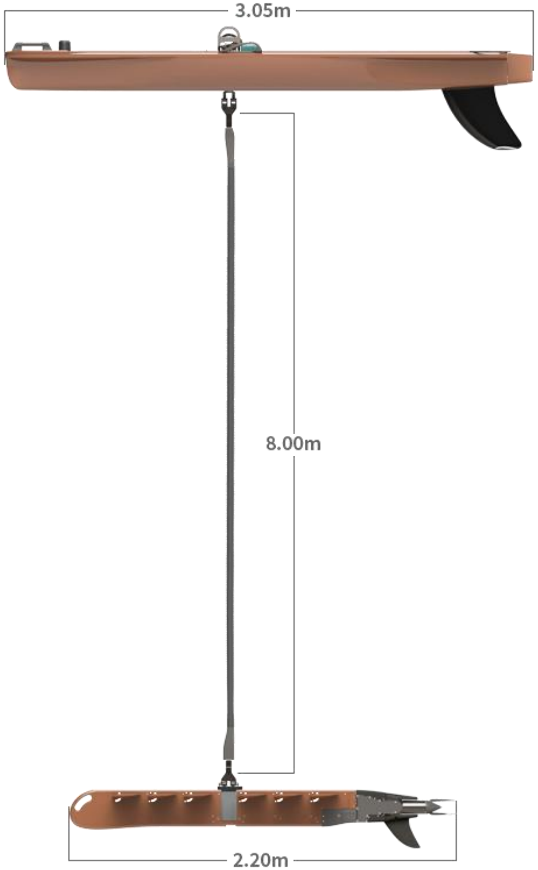
Conclusion



Takeaways:

- After Wave Glider motion correction, we obtain consistent horizontal current measurements over [1;65 m] depth with high resolution near the surface, exhibiting natural spatial and temporal variability.
- Measurements from an array of Wave Gliders enable the calculation of vertical vorticity, horizontal divergence and strain.

Next Steps:

- Integrating a third Wave Glider (PLANCK) in vectorial operator calculations.
- How do wave effects influence the measurement?

Conclusion

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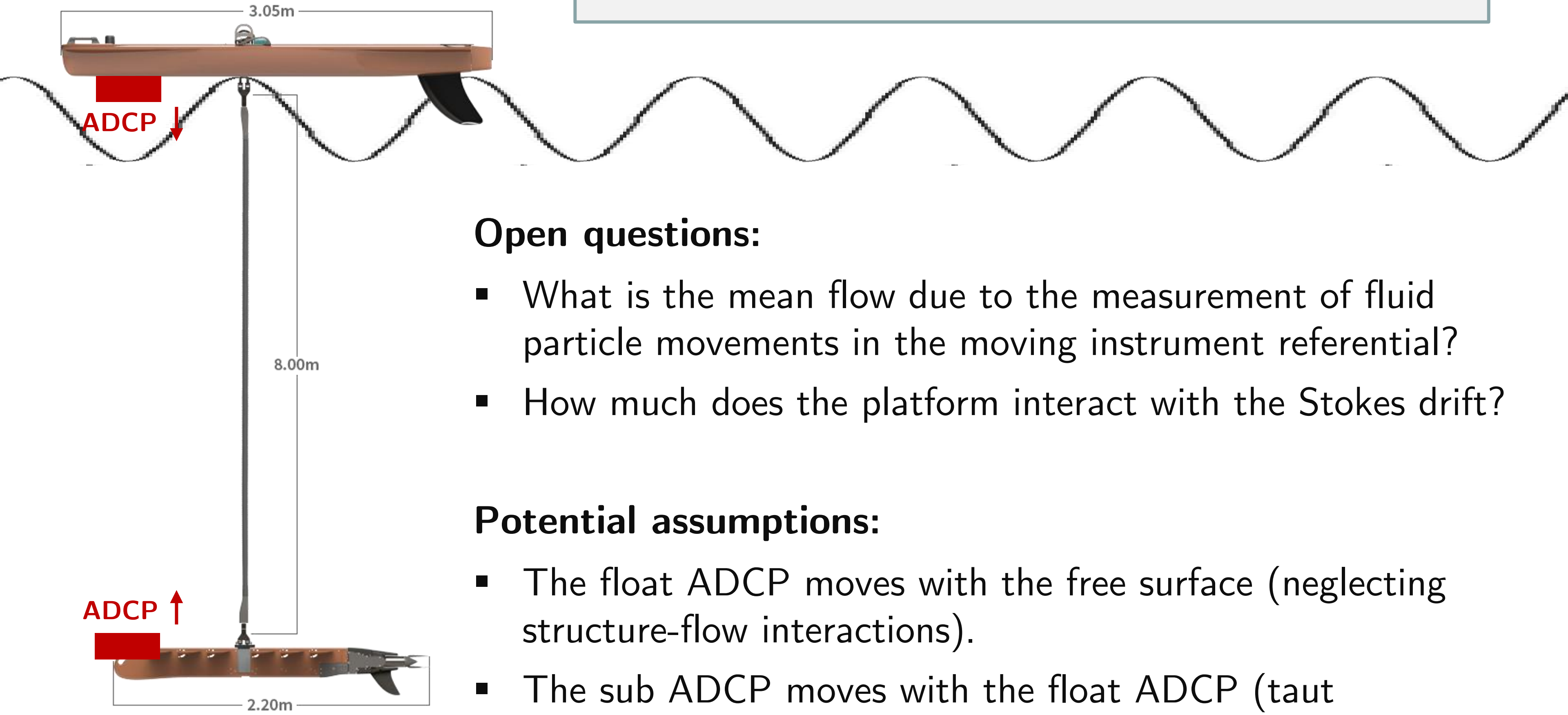

- How do wave effects influence the measurement?

Open questions:

- What is the mean flow due to the measurement of fluid particle movements in the moving instrument referential?
- How much does the platform interact with the Stokes drift?

Potential assumptions:

- The float ADCP moves with the free surface (neglecting structure-flow interactions).
- The sub ADCP moves with the float ADCP (taut umbilical).