GENIoS for marine autonomy

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Manual piloting

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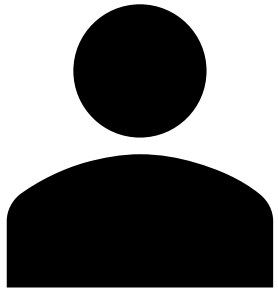

Human operator

.ma file

surfacing pos

Manual piloting

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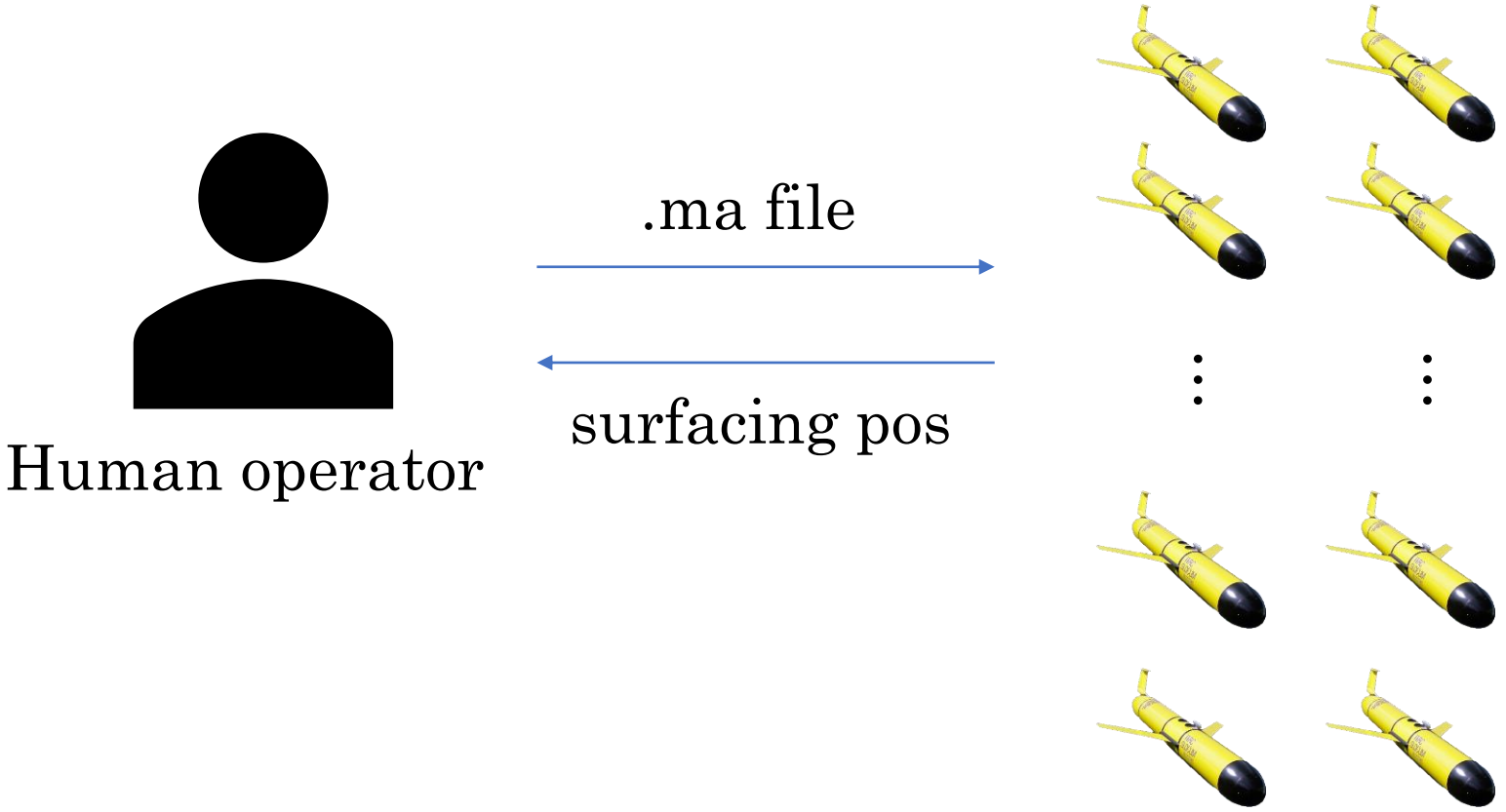
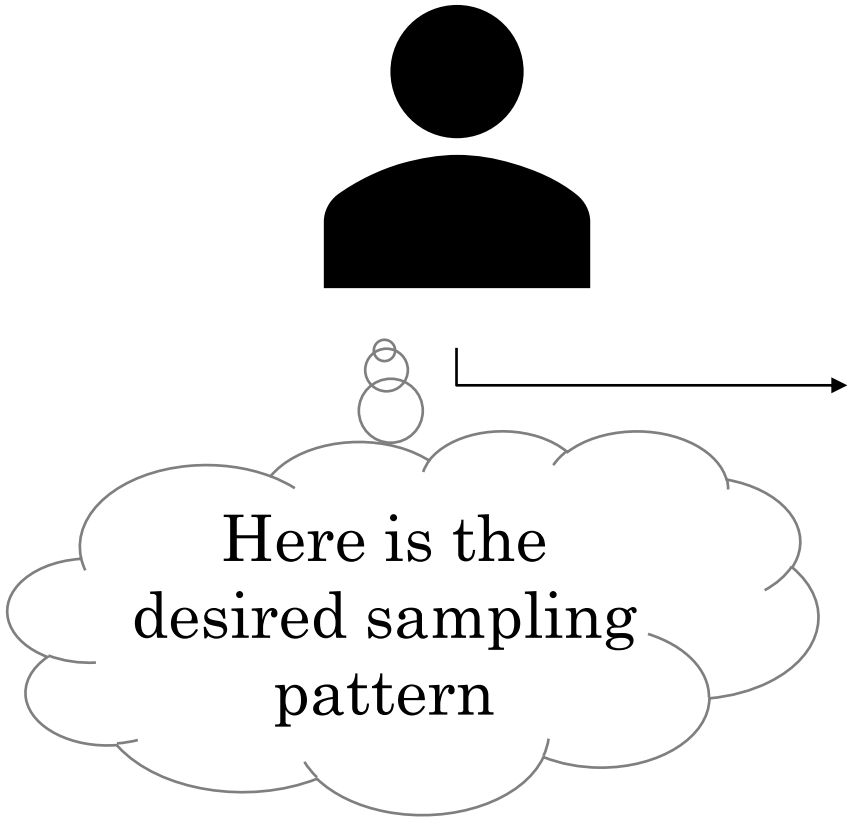
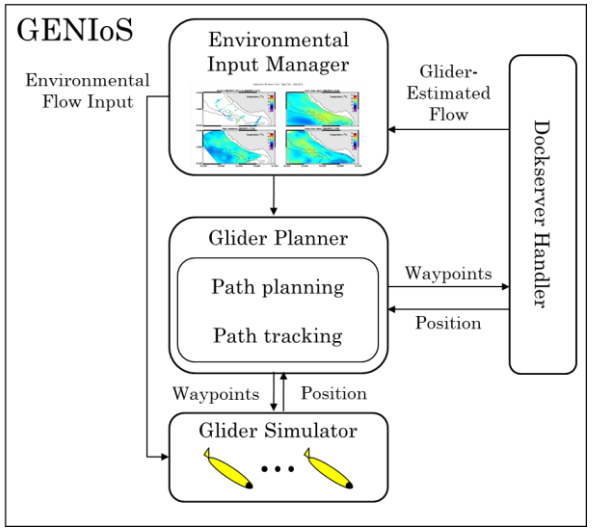


GENIoS function

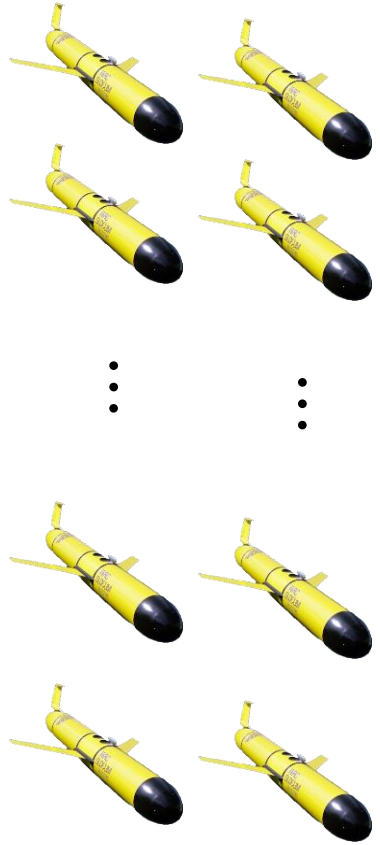




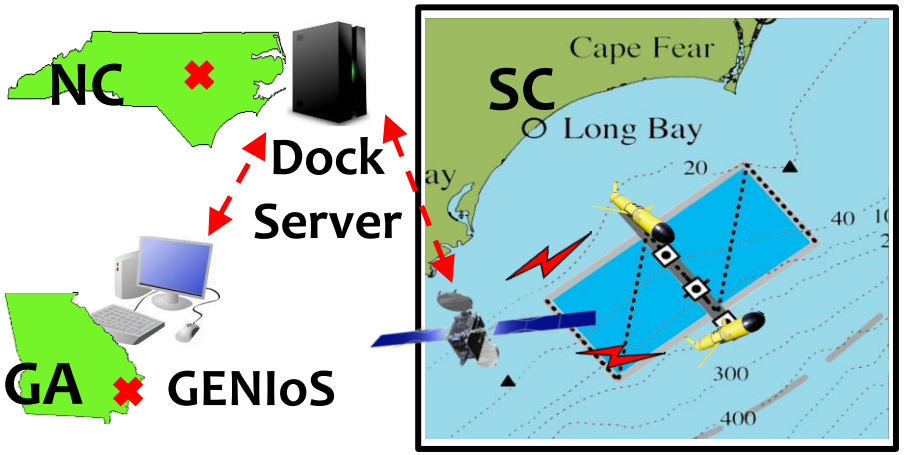
GENIoS

.ma file

surfacing pos

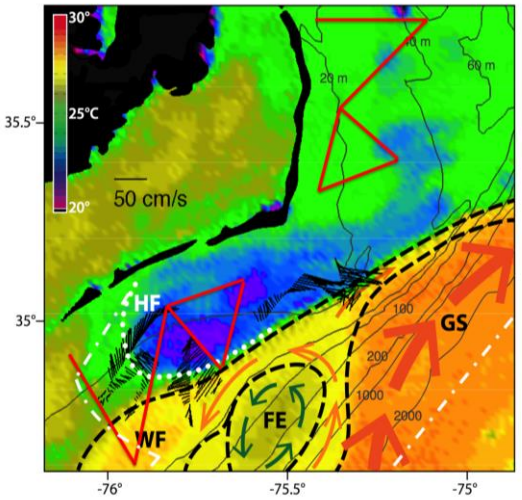


GENIoS supported deployments



LB2012, LB2013 deployment in Long Bay

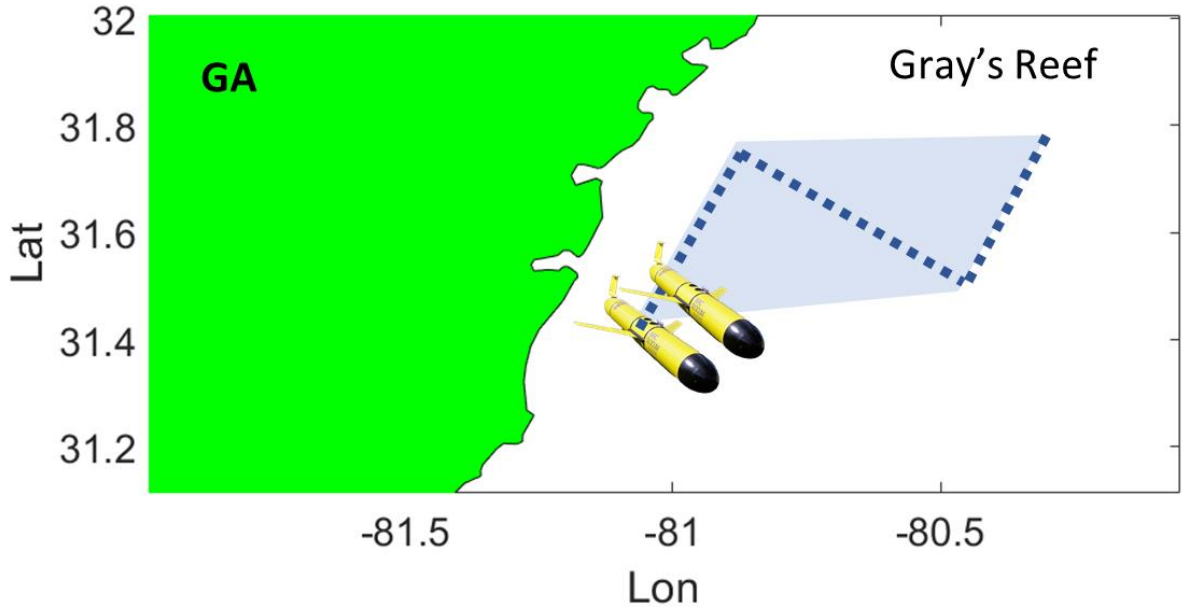
- Ramses: station keeping
- Pelagia: on-shore and off-shore transect following



CH2017 deployment in Cape Hatteras

- Ramses: transect following
- Uses path planning algorithm to handle spatial variability of the flow field

GENIoS supported deployments



GR2019 deployment in Gray's Reef

- Angus: on-shore and off-shore transect following
- Franklin: on-shore and off-shore transect following
- ~ 3 days of GENIoS piloting (stopped due to Franklin anomaly)

GENIoS real-time visualization

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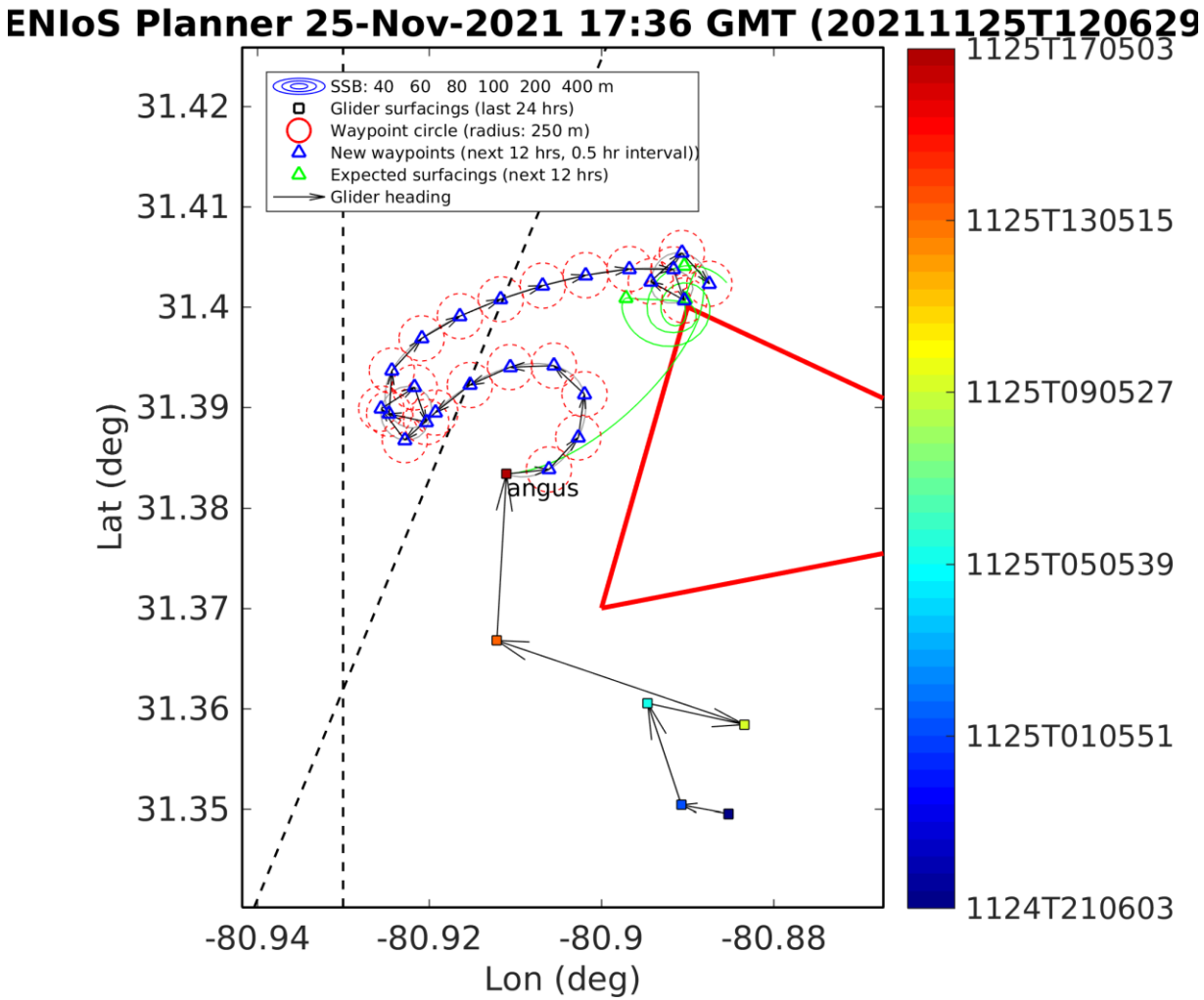

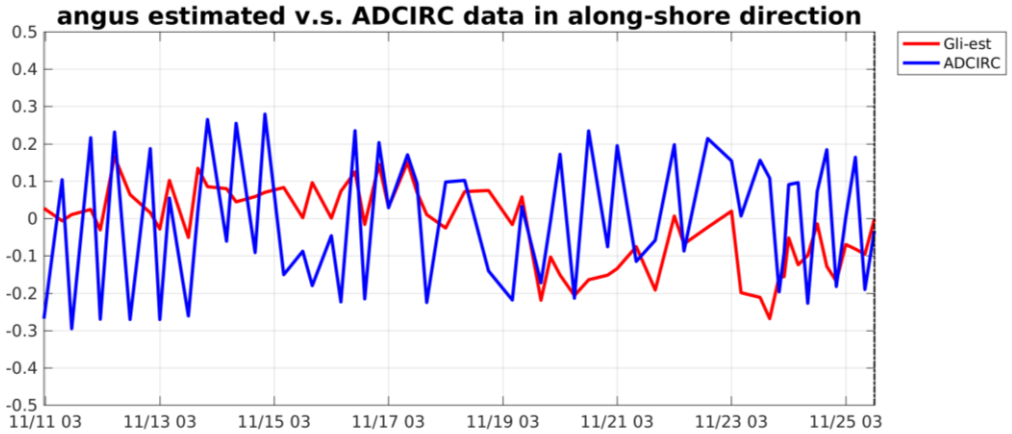

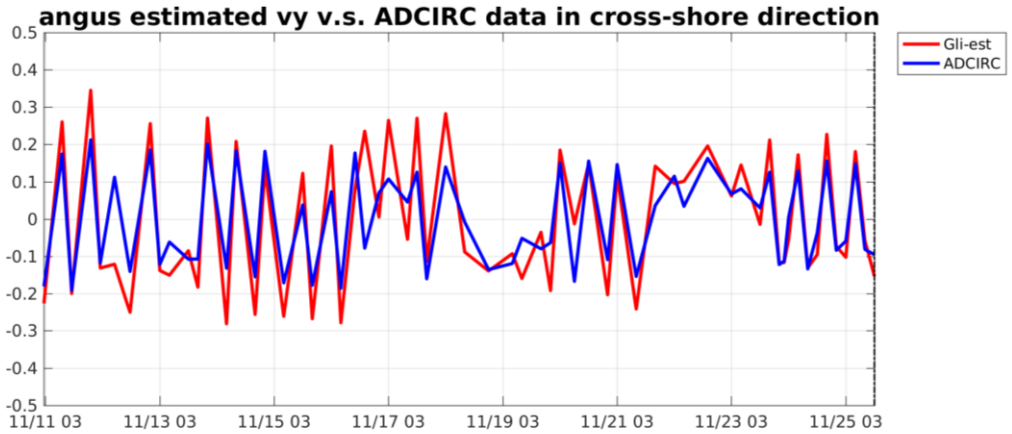

SKIO dockserver: /home/localuser/realtime/genios/angus/frames/

GENIoS in Angus deployment

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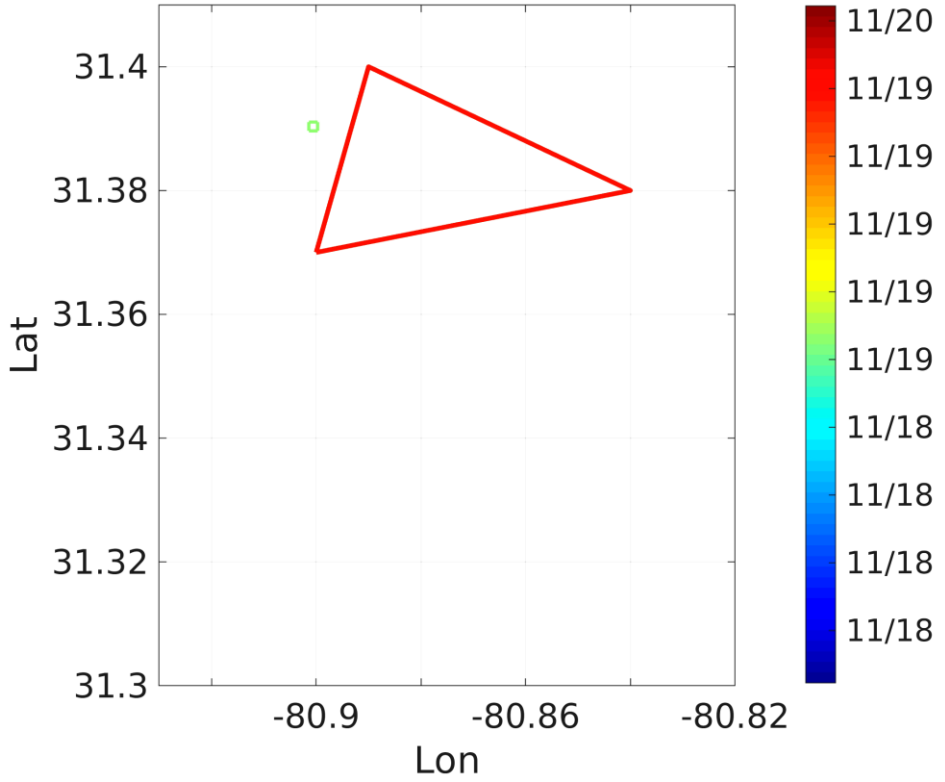
GENIoS piloting:
Nov. 11 – Nov. 25, 2021, 1 week

- ✓ Successful waypoint generation & transmission for all surfacings
- ✓ Sampling near region of interest
- ✓ Reduced waiting time for GENIoS waypoint generation (< 1.5 min)
- ❑ Slow progress towards target



Glider-Environment Network Information System

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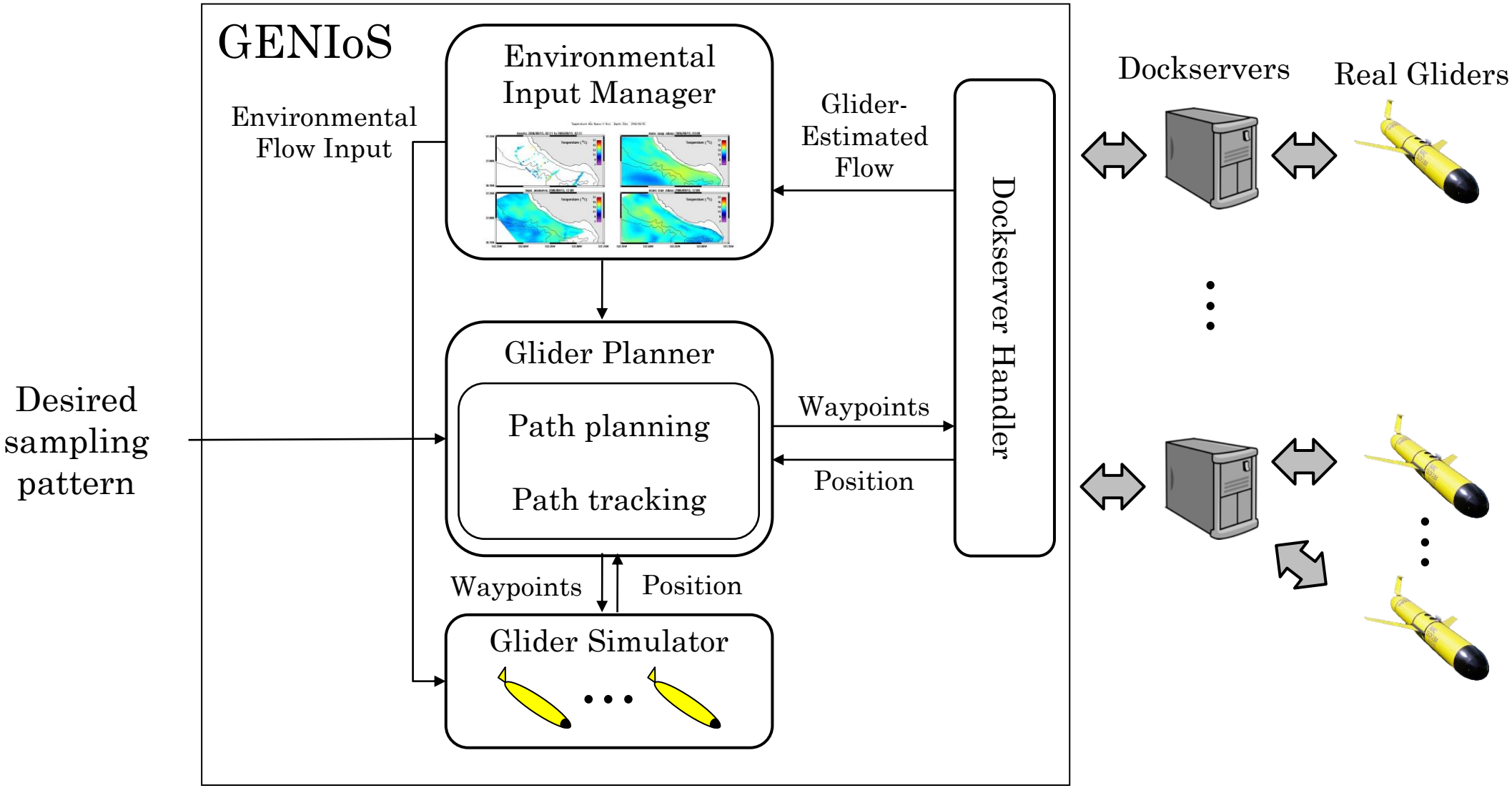
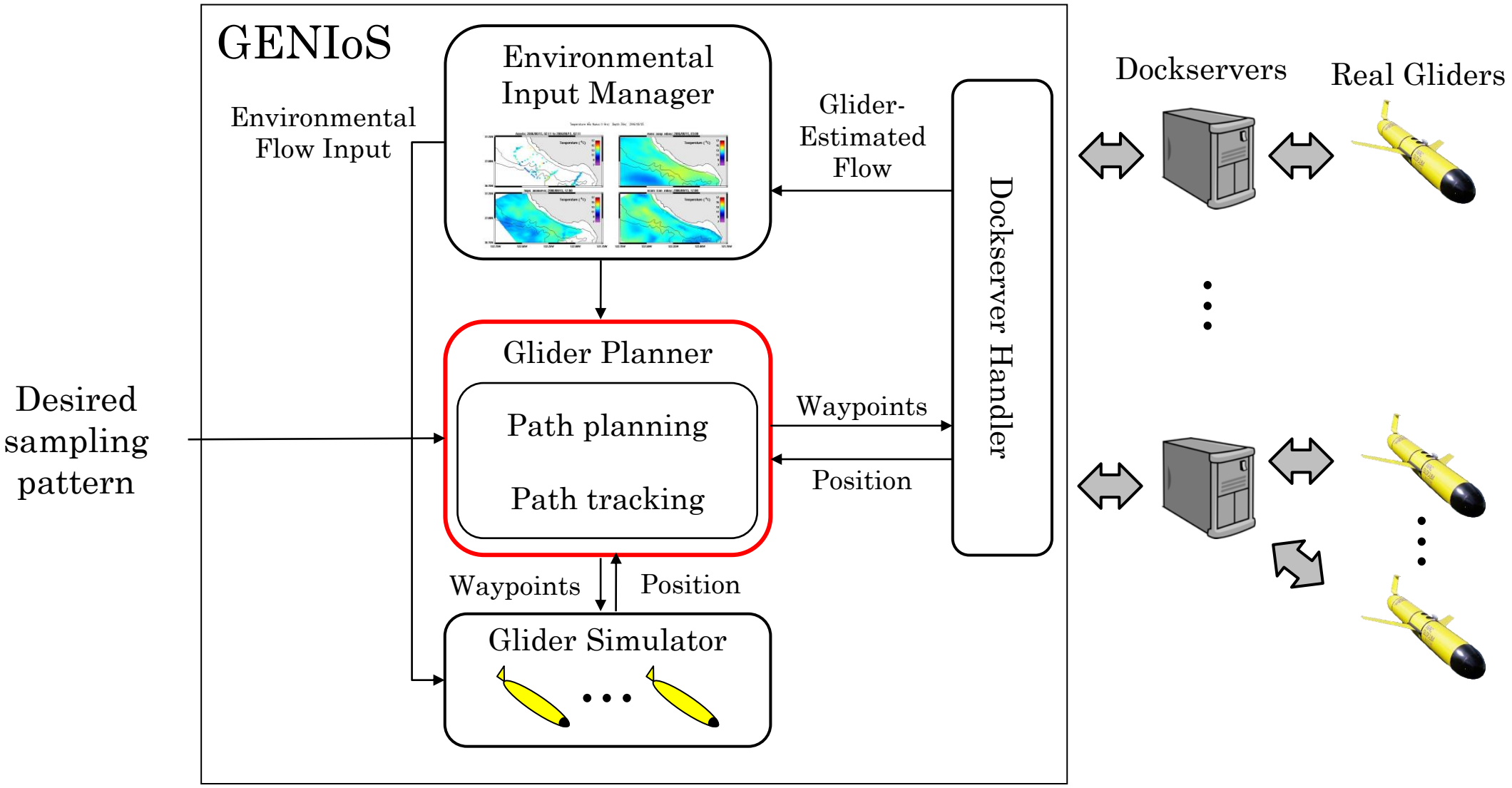


Glider-Environment Network Information System



Built-in glider navigation

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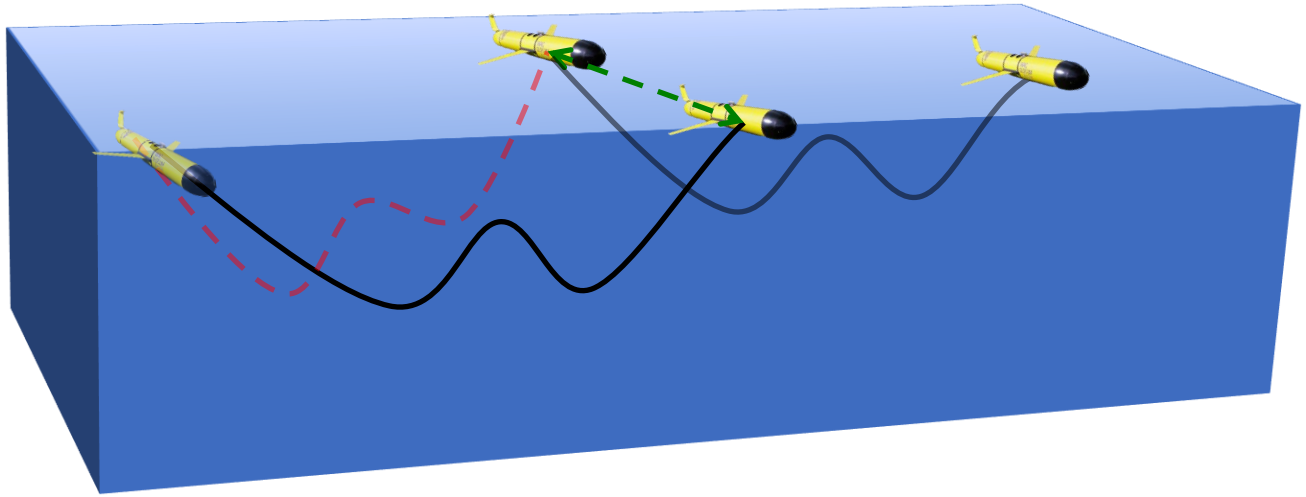
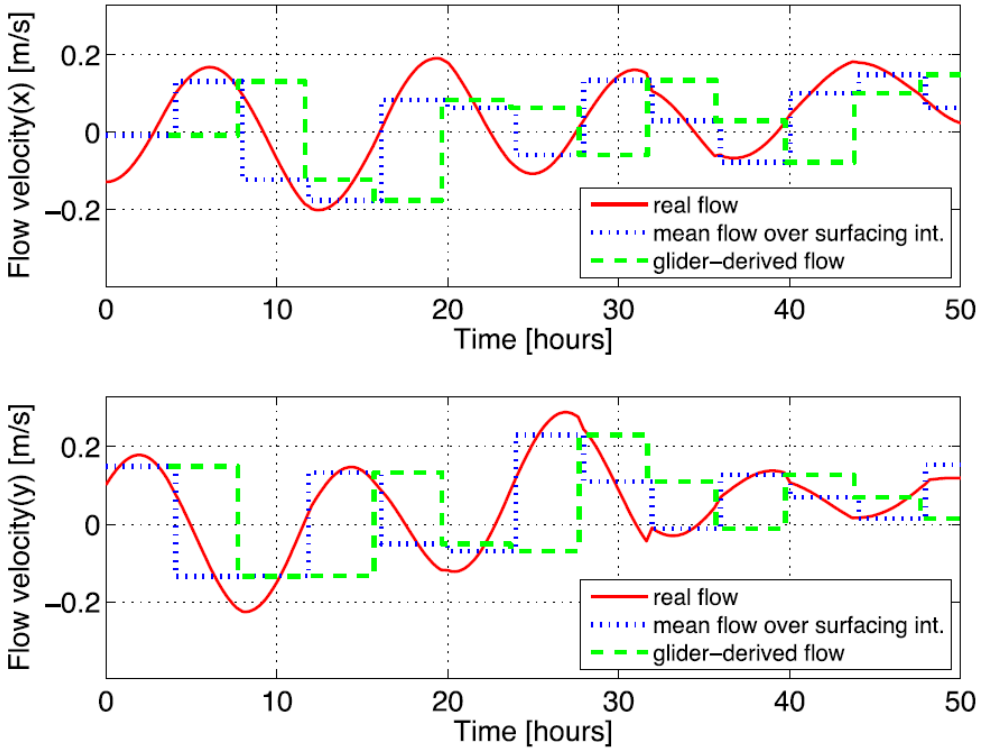
Dead-reckoned Error

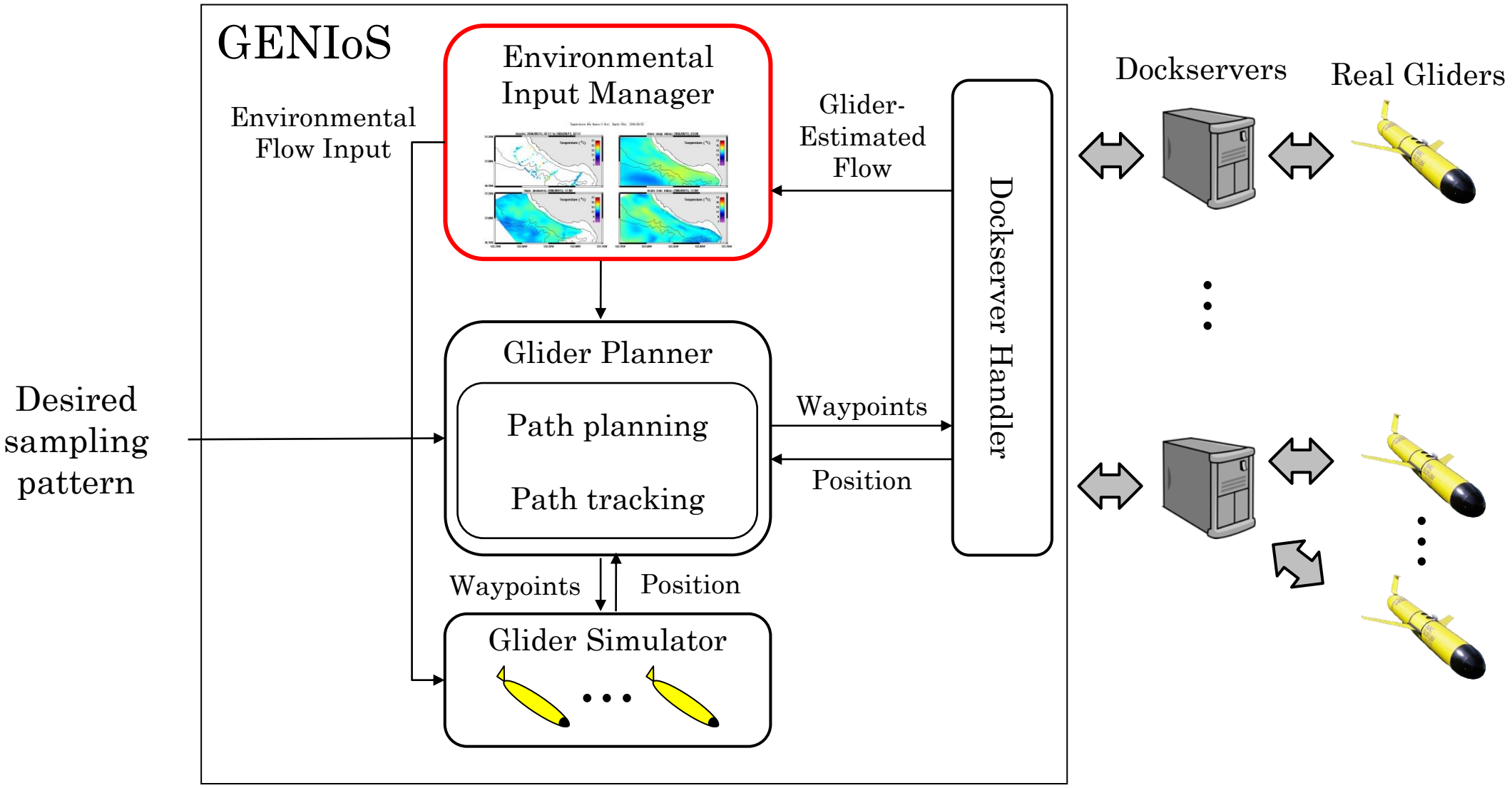




- Compared with built-in navigation scheme, GENIoS planner gives better navigation performance

Chang, D., Zhang, F., & Edwards, C. R. (2015). Real-time guidance of underwater gliders assisted by predictive ocean models. *Journal of Atmospheric and Oceanic Technology*, *32*(3), 562-578.

Glider-Environment Network Information System



Environmental input manager

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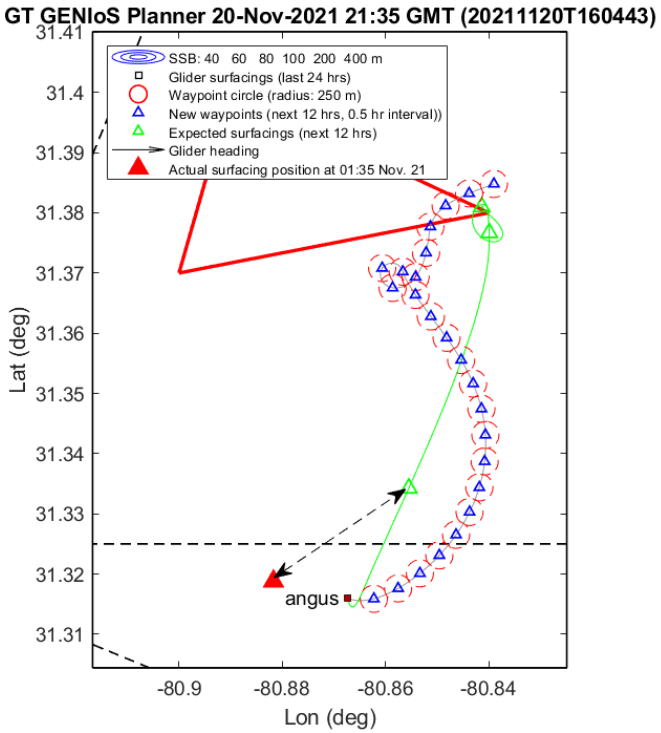
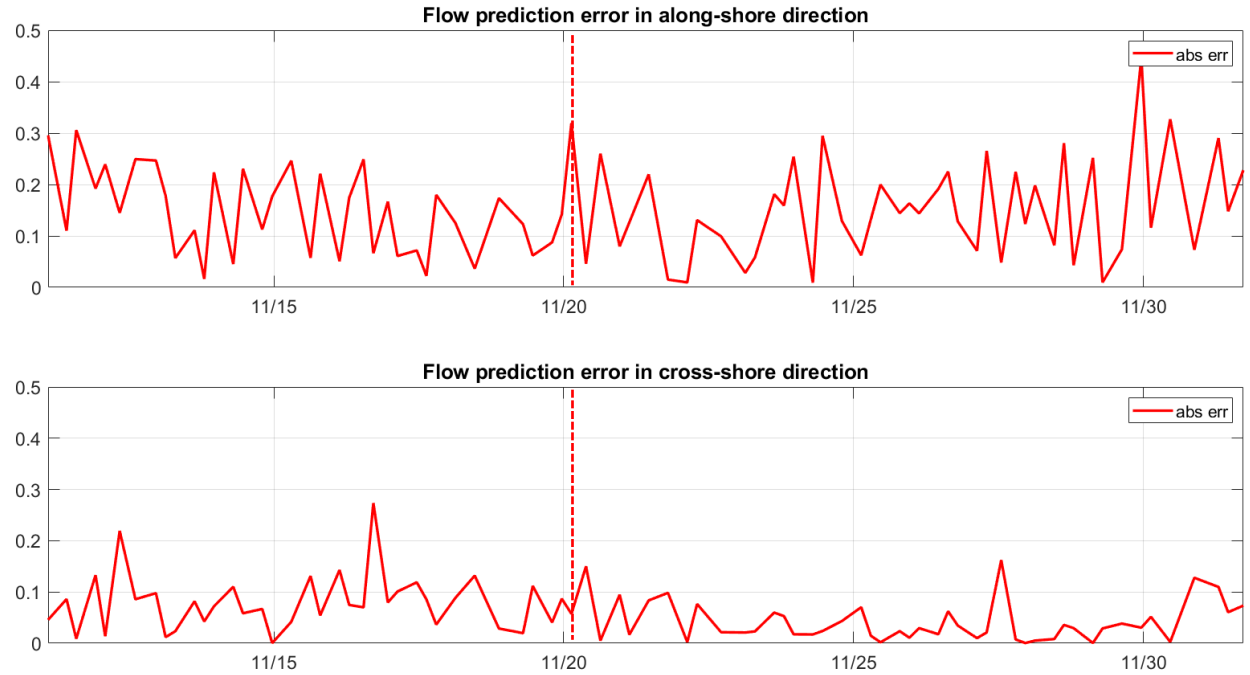
Goal: output a flow model that matches with the actual depth-averaged flow speed that the glider will experience in the planning horizon

Why important: flow prediction error makes the glider unable to reach the target





Advanced Circulation (ADCIRC) ocean model

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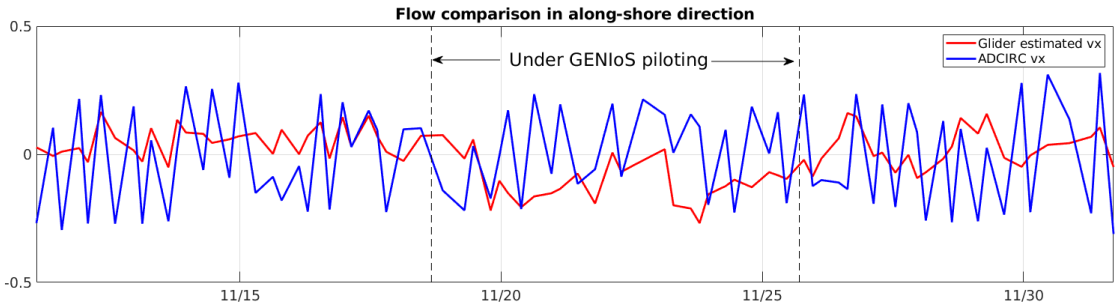

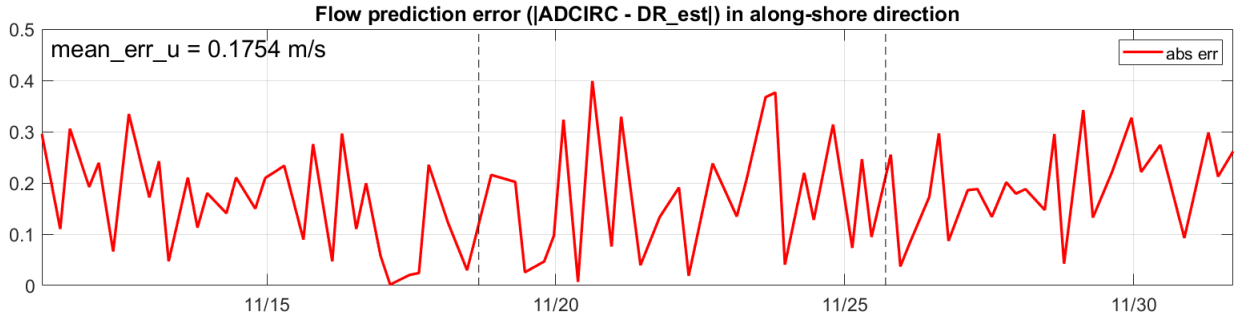

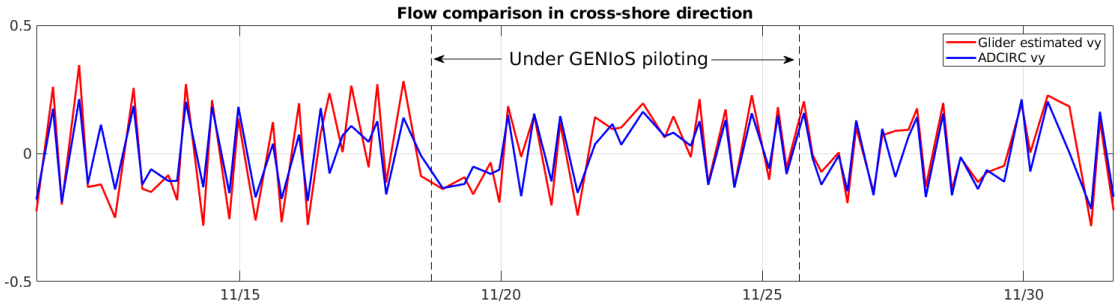

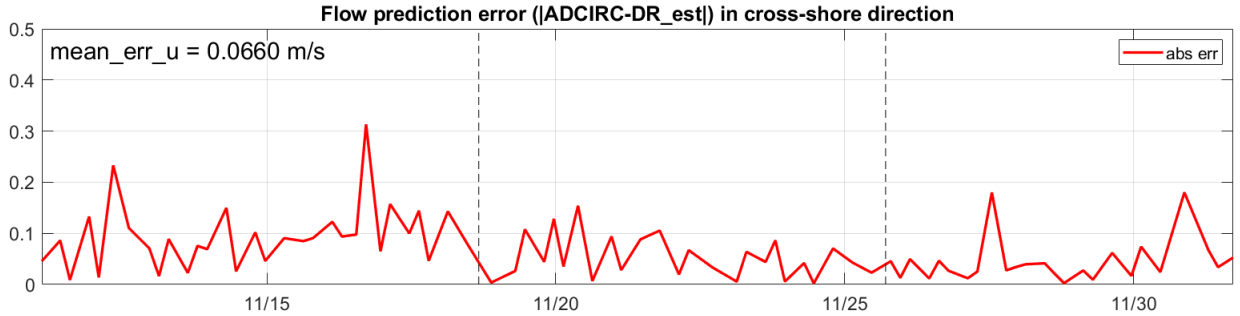

ADCIRC matches with glider DR flow estimation well in cross-shore direction, but there is larger difference in along-shore direction

GliADCIRC feedback model

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Key idea:

flow speed prediction = **low-freq. flow** + **high-freq. flow**

The low freq. component in de-tided DR est.

ADCIRC modeled tidal flow component

GliADCIRC feedback model

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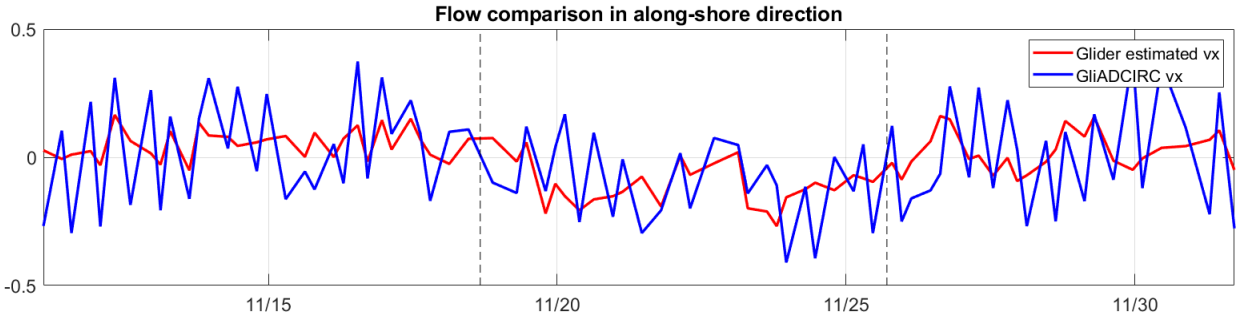
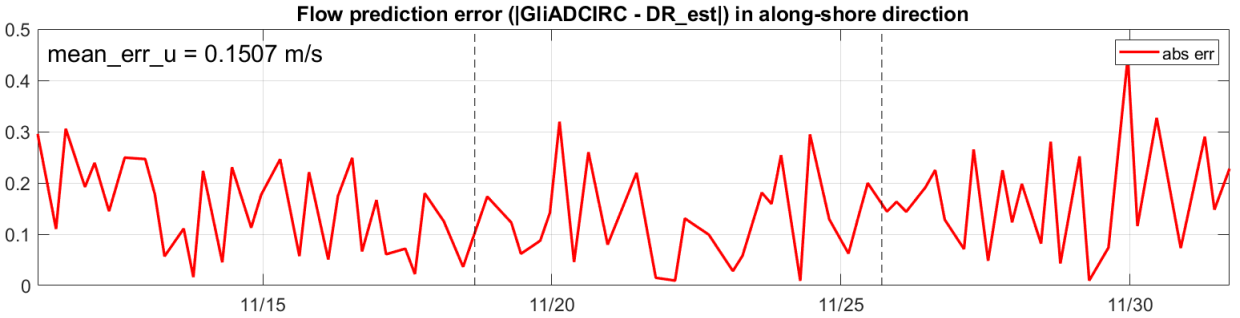
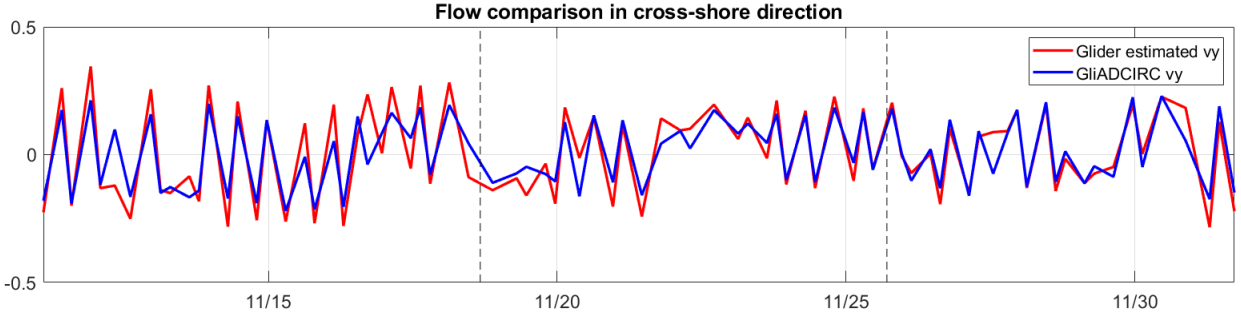
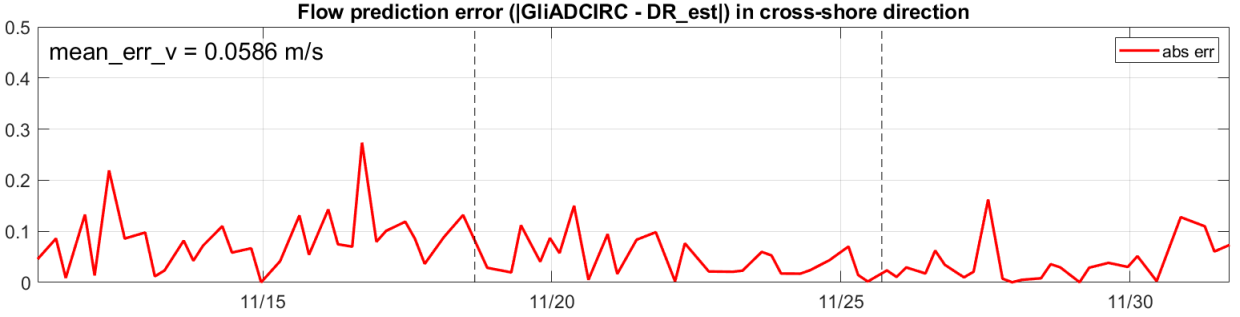


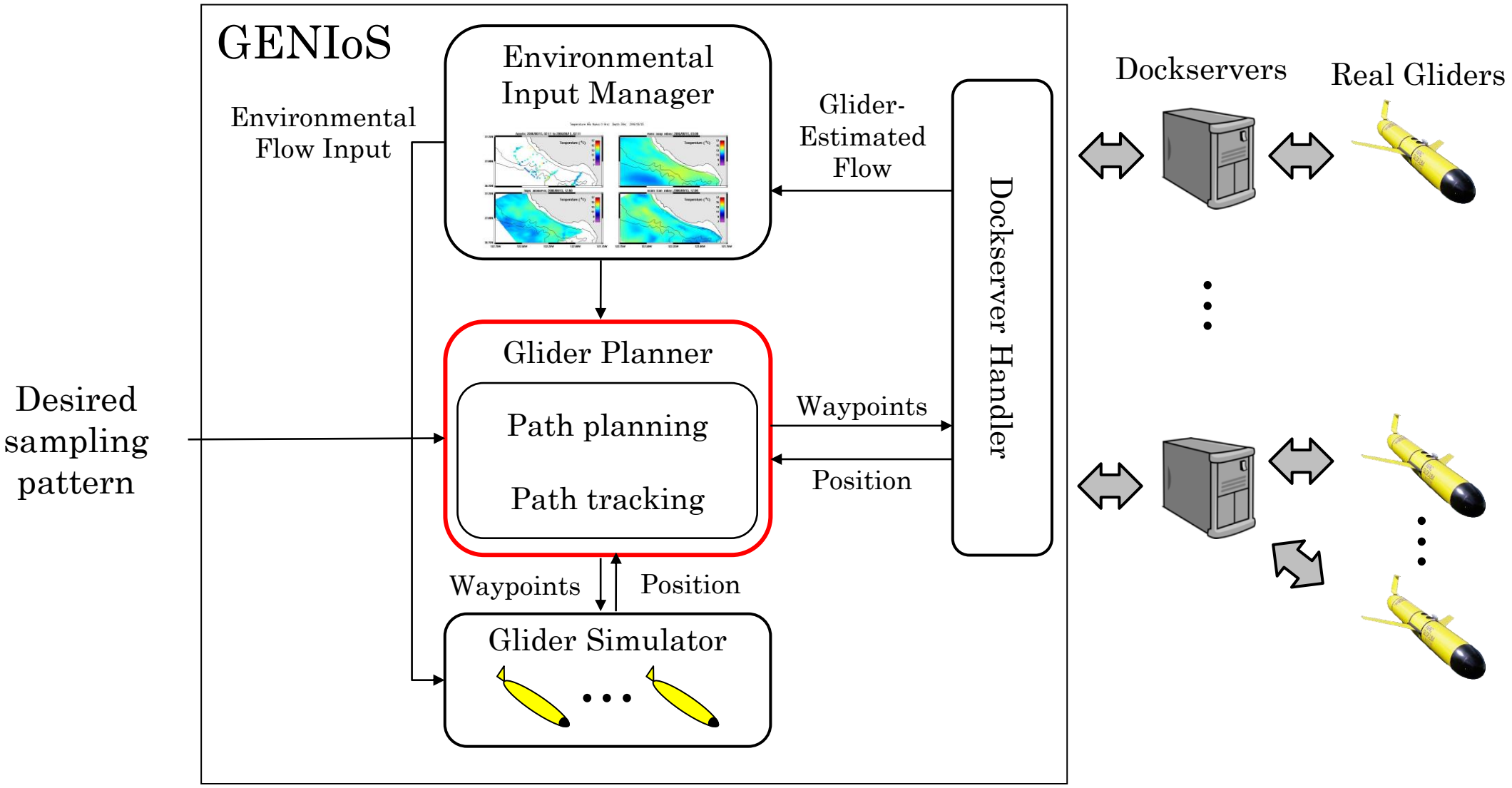






14% decrease in along-shore direction flow prediction error
11% decrease in cross-shore direction flow prediction error

Glider-Environment Network Information System



Comparison between GENIoS control and human piloting

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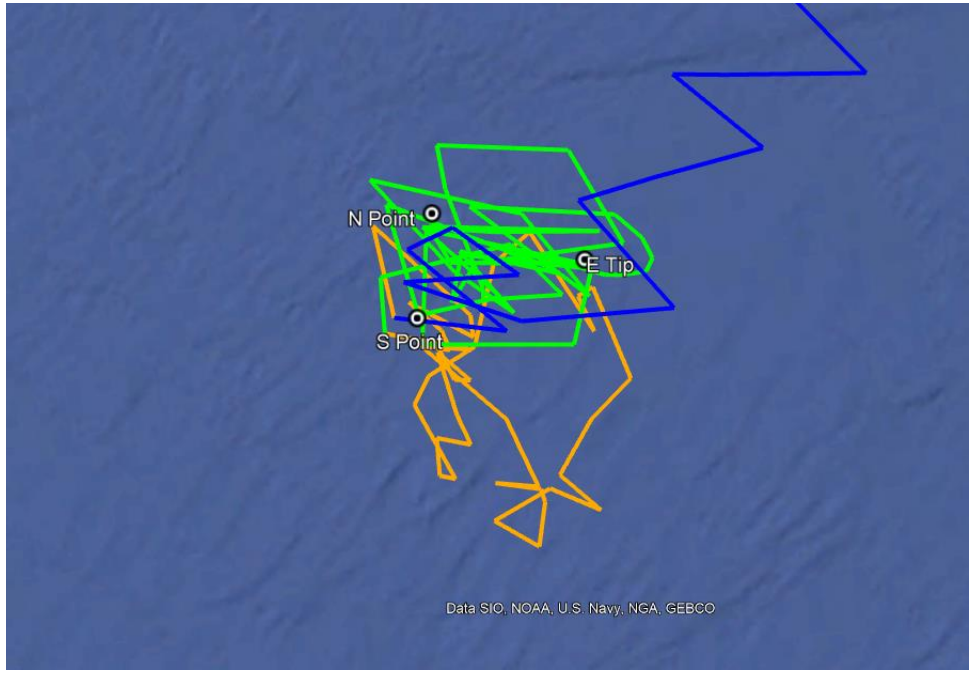

Possible reasons for GENIoS taking longer time to drive Angus back:

- Full moon. Tidal flow is stronger
- Ballast change on Nov. 16 and Nov. 24
- **Difference in the piloting strategy**

Path tracking controller: flow canceling strategy

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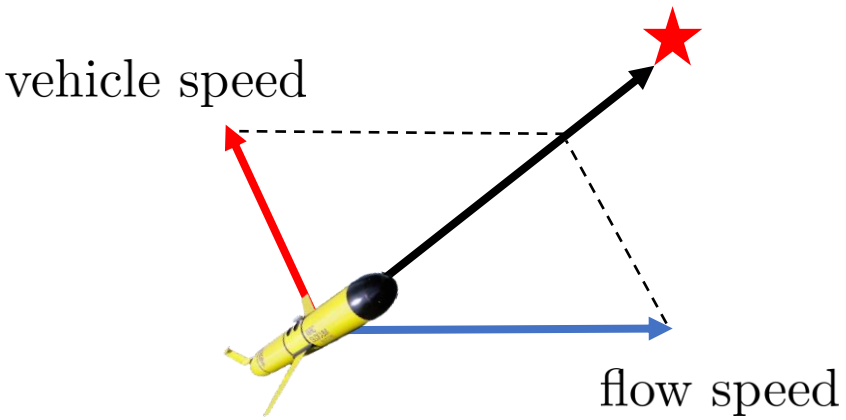
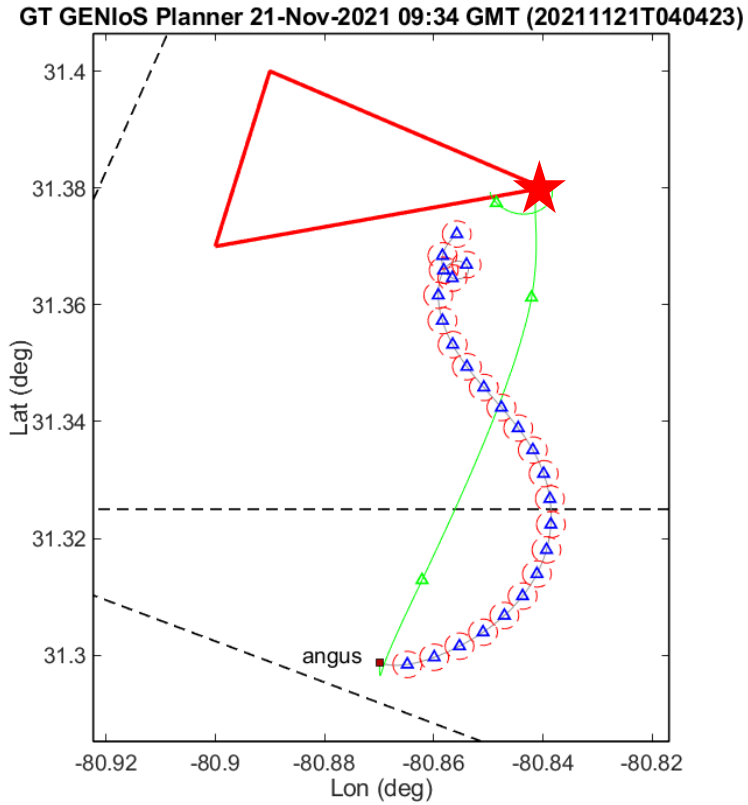
At each timestep, the flow canceling strategy drives the glider towards target position in a straight line

Vehicle model: $\dot{x} = f(x,t) + V \begin{bmatrix} \cos\psi \\ \sin\psi \end{bmatrix}$





Comparison between GENIoS control and human piloting

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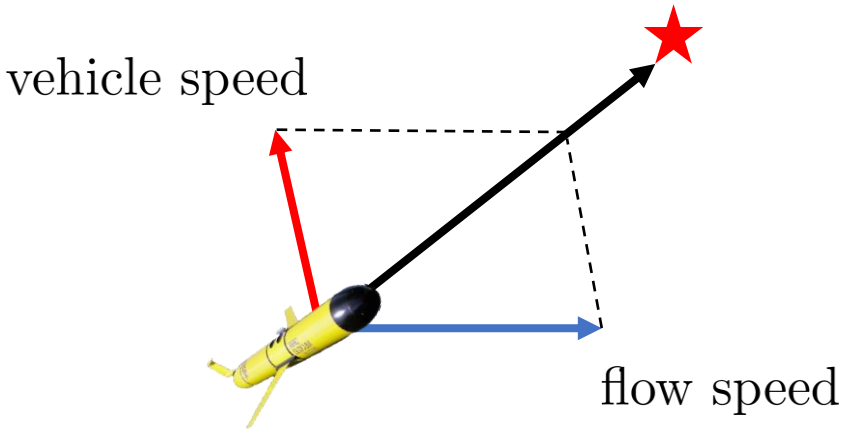
Flow canceling strategy



- Less along-track progress
- More “controlled” motion in cross-track direction

Comparison between GENIoS control and human piloting

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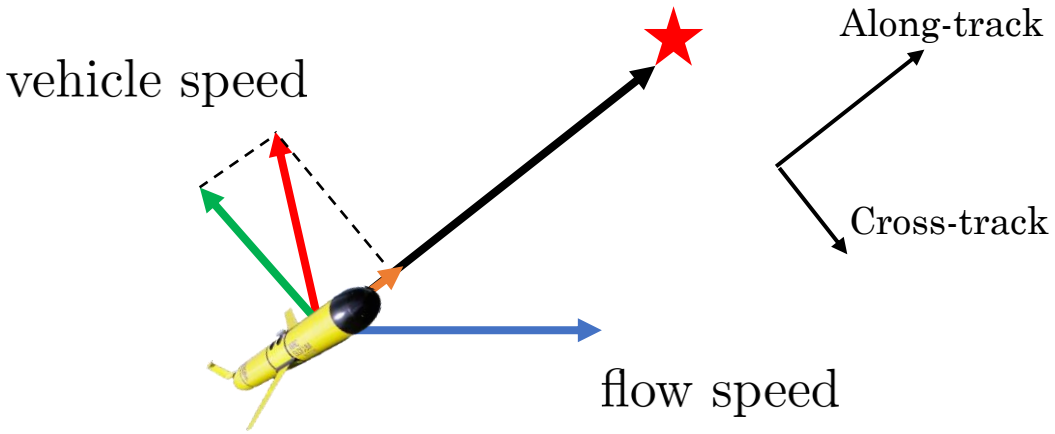
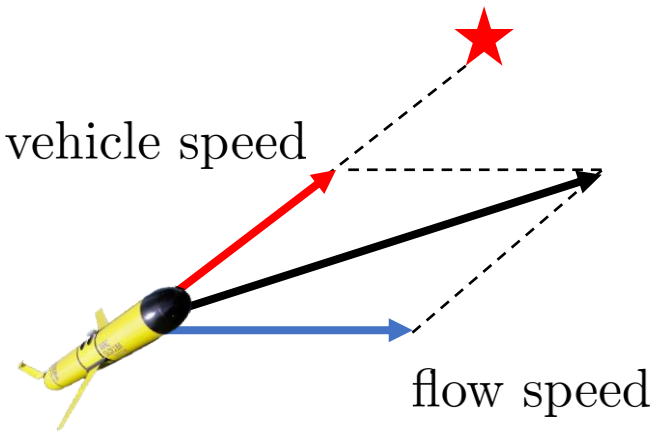
Flow canceling strategy



- Less along-track progress
- More “controlled” motion in cross-track direction

Human piloting strategy



- Larger along-track progress
- Less “controlled” motion in cross-track direction

Comparison between GENIoS control and human piloting

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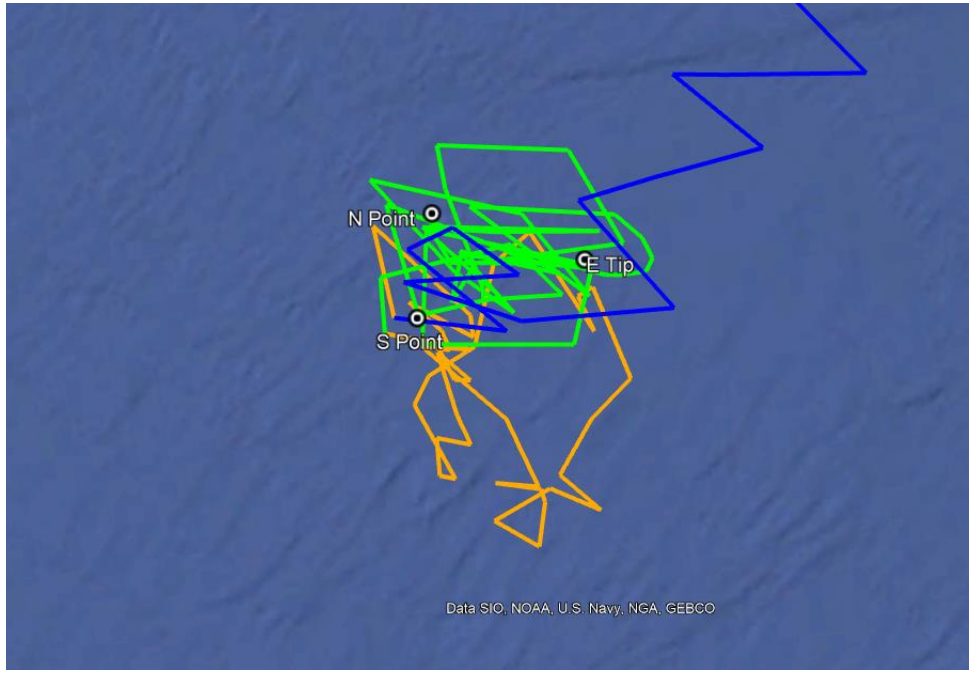

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Other functionality of GENIoS

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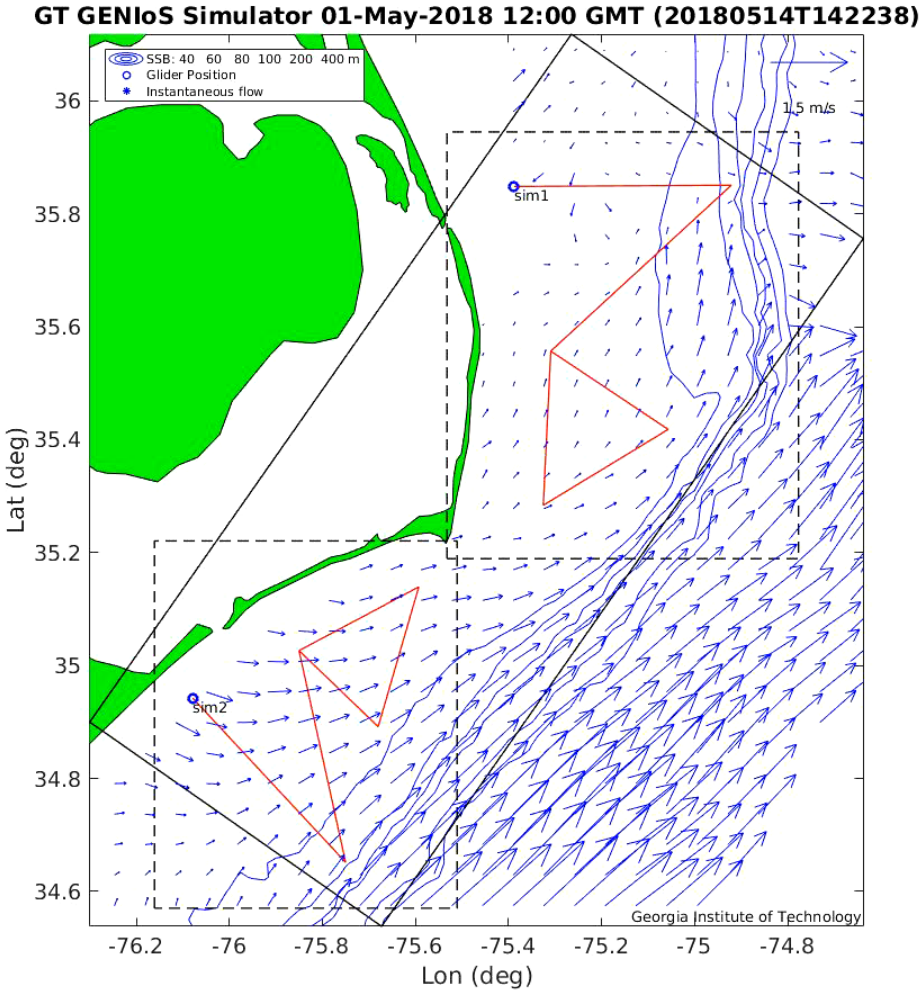
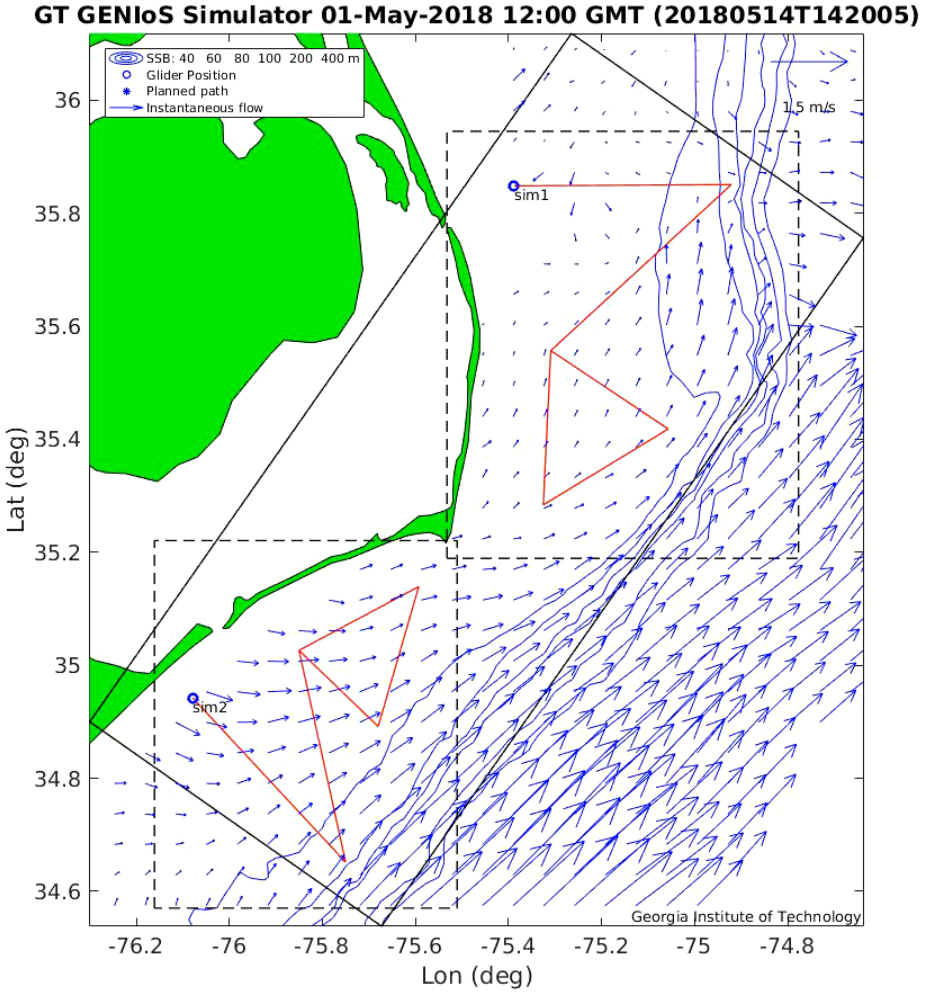
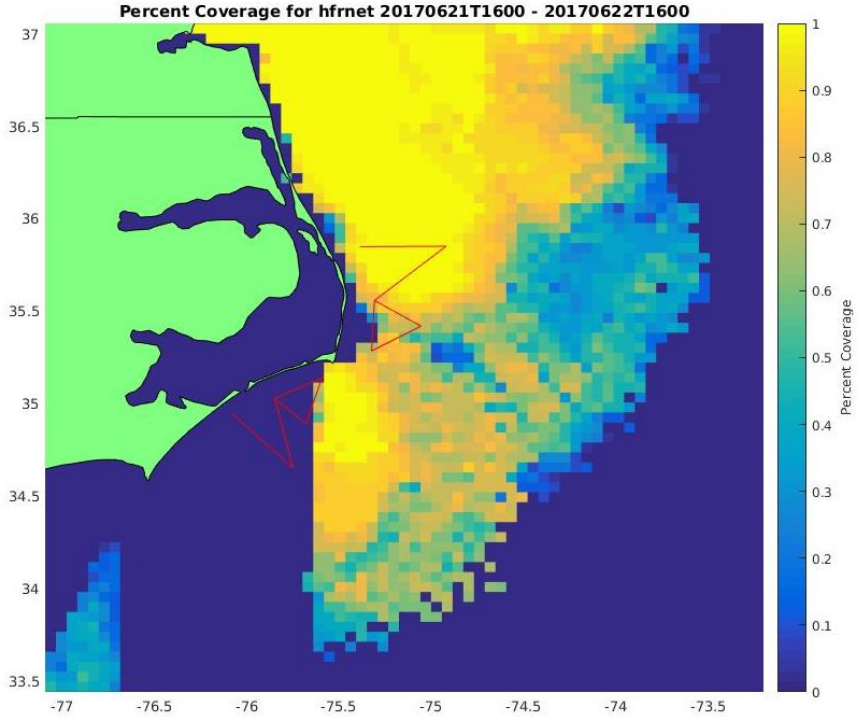


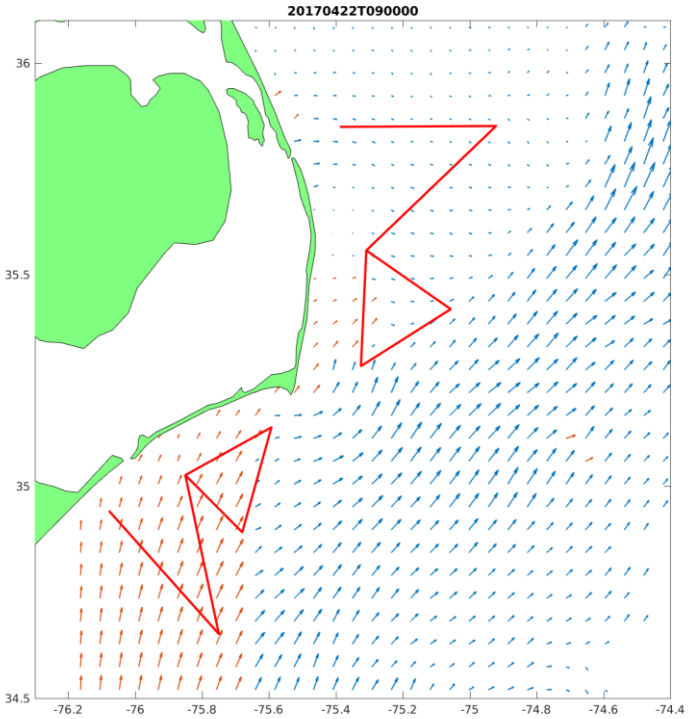
In-parallel simulation, hindcast analysis

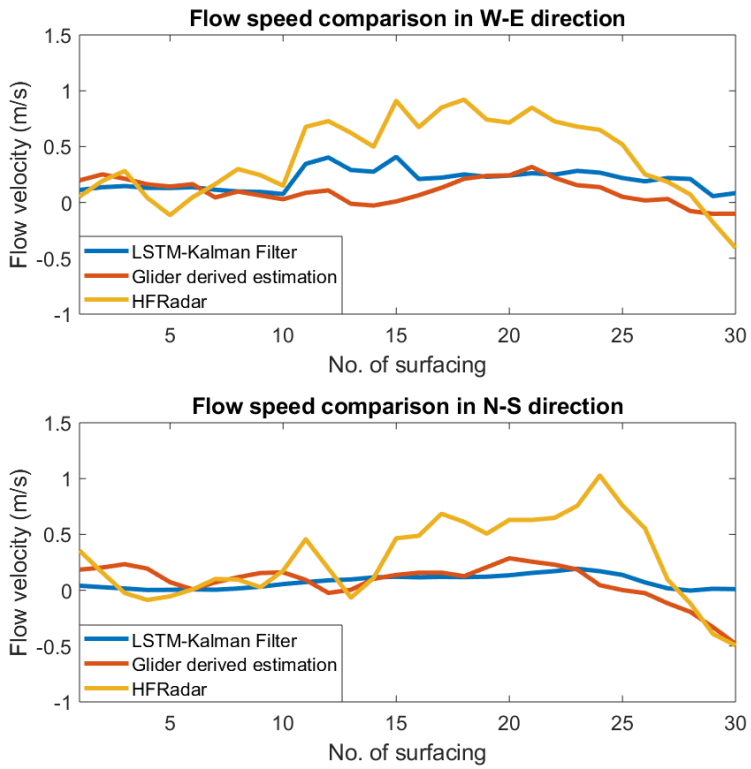


Path planner: handles flow field spatial variability

Other functionality of GENIoS







Environment input manager: read-in and data assimilation of HF radar, NCOM, and ADCIRC data

Anomaly detection

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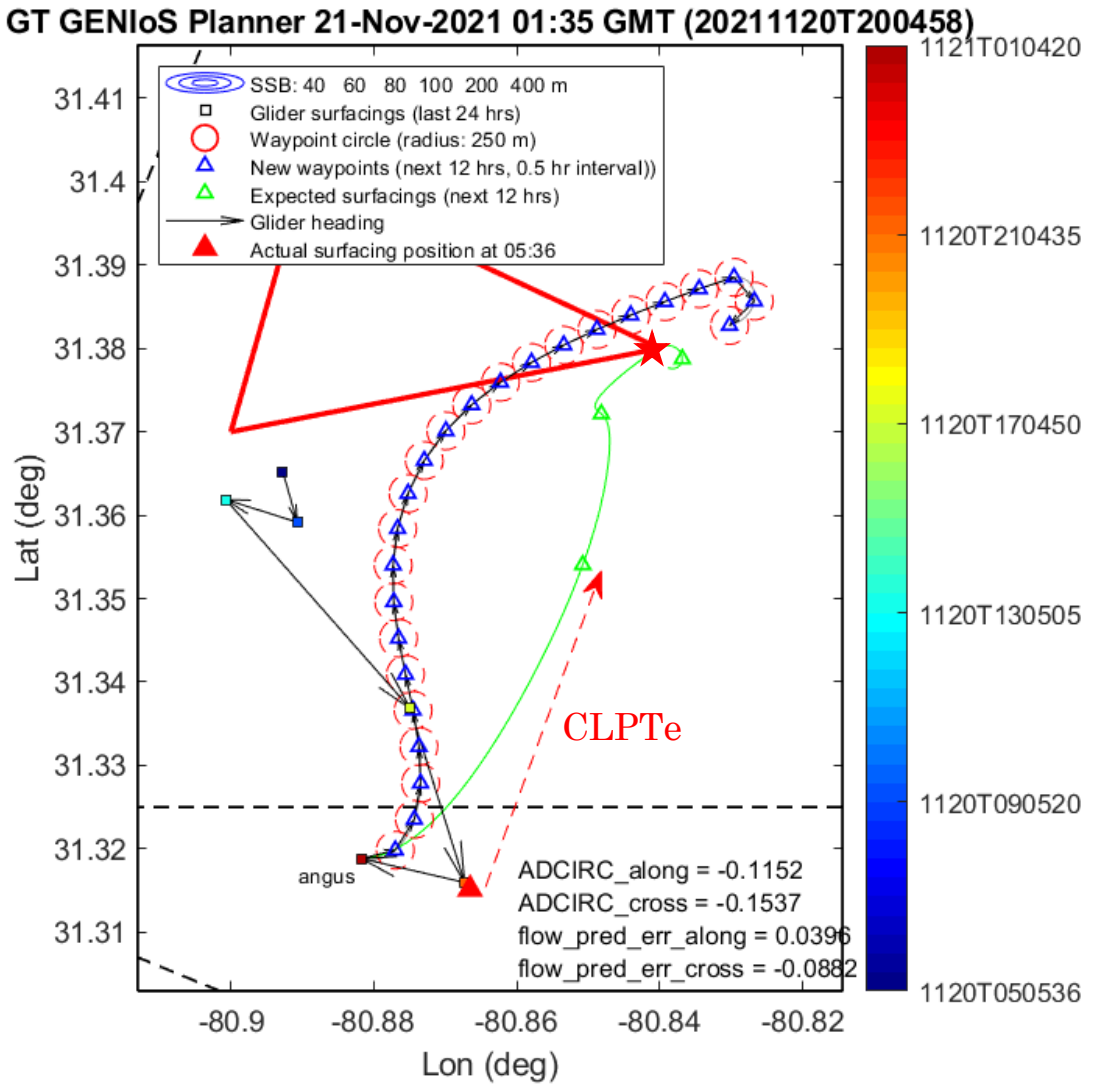
Observation:

- The flow prediction error is small (~0.09 m/s), but the CLPT error is large (~5km)

- If the vehicle is in normal mode, the forward speed should be able to cancel the flow speed in cross-shore direction to move to the North

Hypothesis:

- Vehicle speed is lower than the expected value (remora attack)



Anomaly detection

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Goal: detect anomaly condition in glider deployments

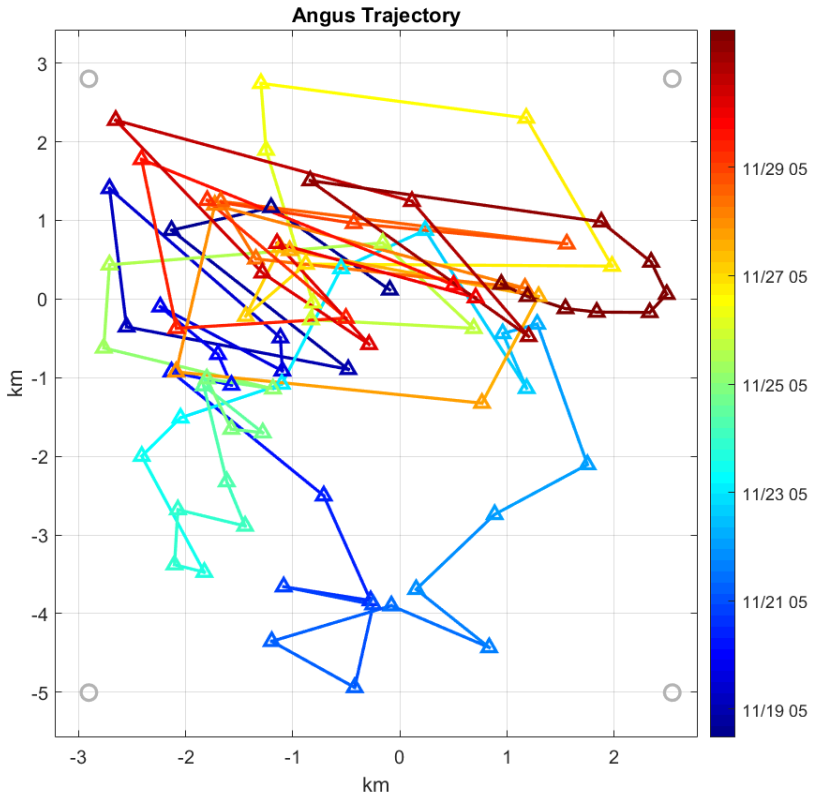
Approach: given the glider trajectory and the heading angle, estimate the flow speed and the vehicle's forward speed

Anomaly condition:

$$\|\text{estimated glider speed - glider reported data}\| \geq \epsilon_V$$

and

$$\|\text{estimated flow speed} - \text{DR estimate}\| \leq \epsilon_f$$



Cho, Sungjin, Fumin Zhang, and Catherine R. Edwards. "Learning and detecting abnormal speed of marine robots." *International Journal of Advanced Robotic Systems* 18, no. 2 (2021): 1729881421999268.

Why estimate the flow & forward speed?

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Glider's horizontal forward speed est.:

Depth rate

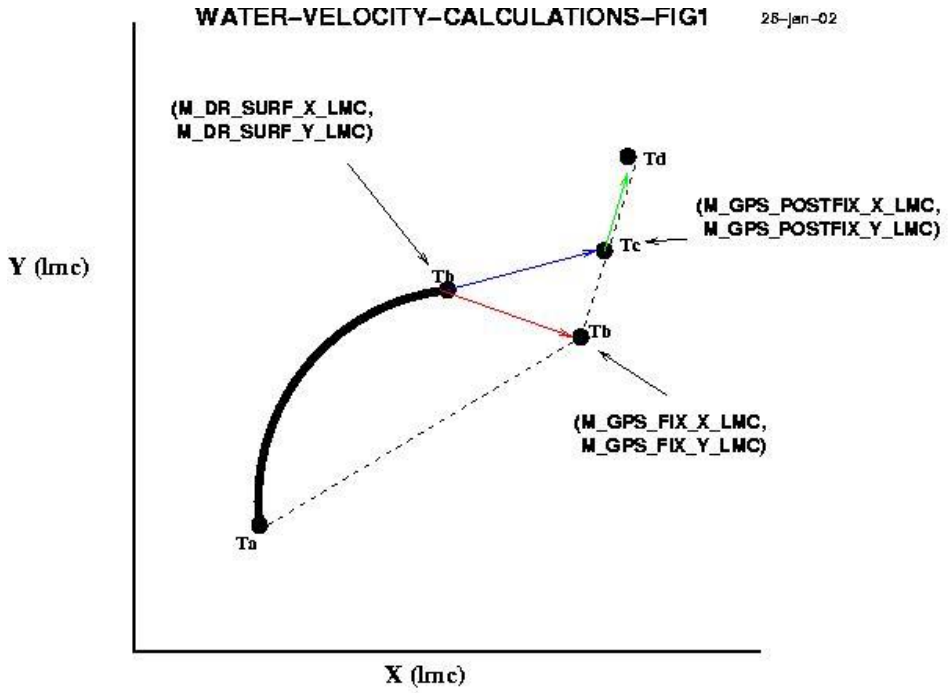
$$U_g = \frac{\omega_g}{\tan(\alpha)}, \text{ if } |\alpha| \geq 11°$$

Measured pitch

$$U_g = \text{avg speed}, \text{ if } |\alpha| < 11°$$

Angle of attack ignored, causing over-estimated horizontal speed

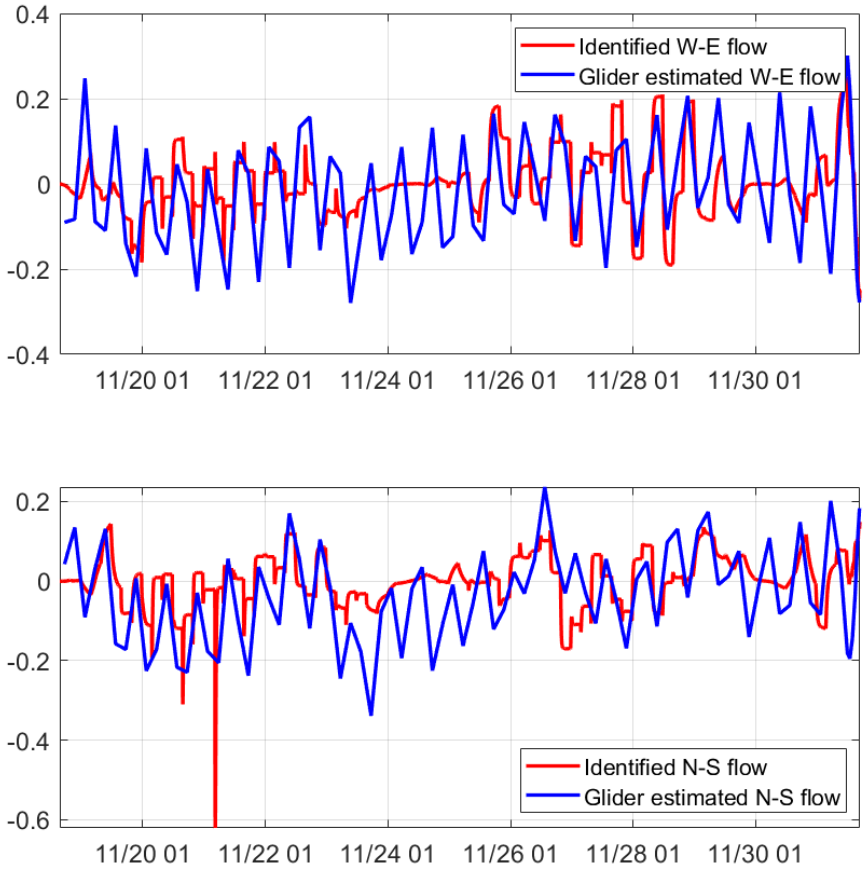
Dead Reckoning flow est.:

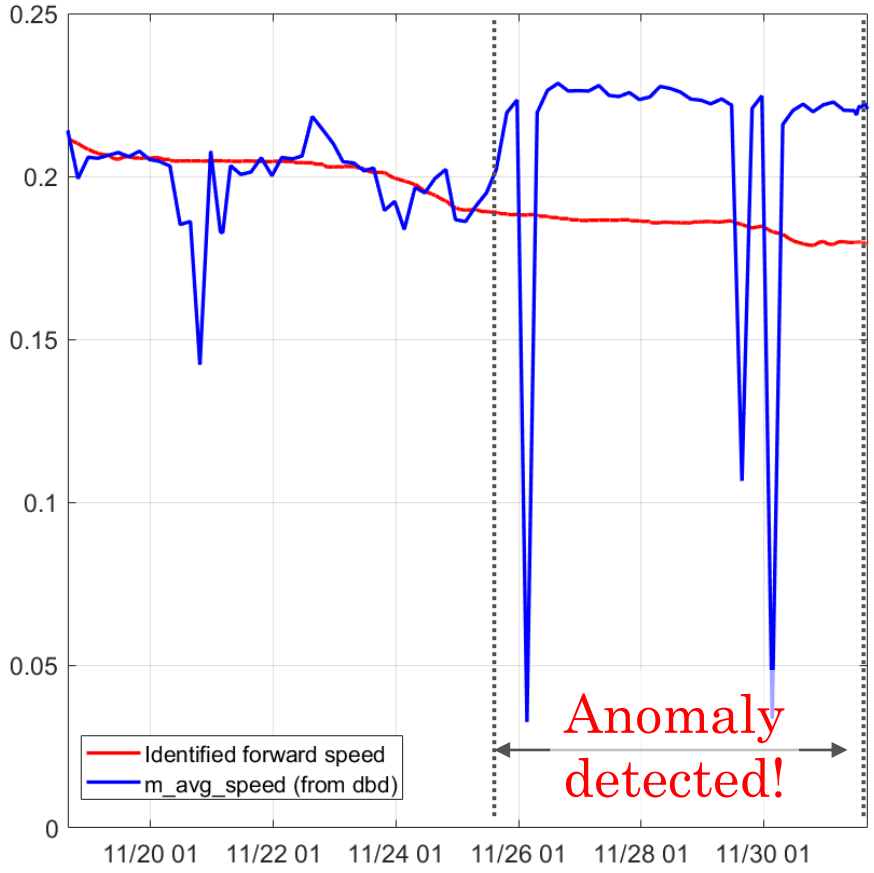


Error in horizontal speed leads to error in DR est.

Merckelbach, L. M., Briggs, R. D., Smeed, D. A., & Griffiths, G. (2008, March). Current measurements from autonomous underwater gliders. In *2008 ieee/oes 9th working conference on current measurement technology* (pp. 61-67). IEEE.

Result





- The identified flow speed captures the tidal flow, which is the major flow component in GR
- The algorithm identifies forward speed dropping around Nov. 25 (-0.02 m/s).

Result

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Stayed on the seafloor (Nov. 25)

gliderstatus – Nov 26th

RangerK 8:15 AM

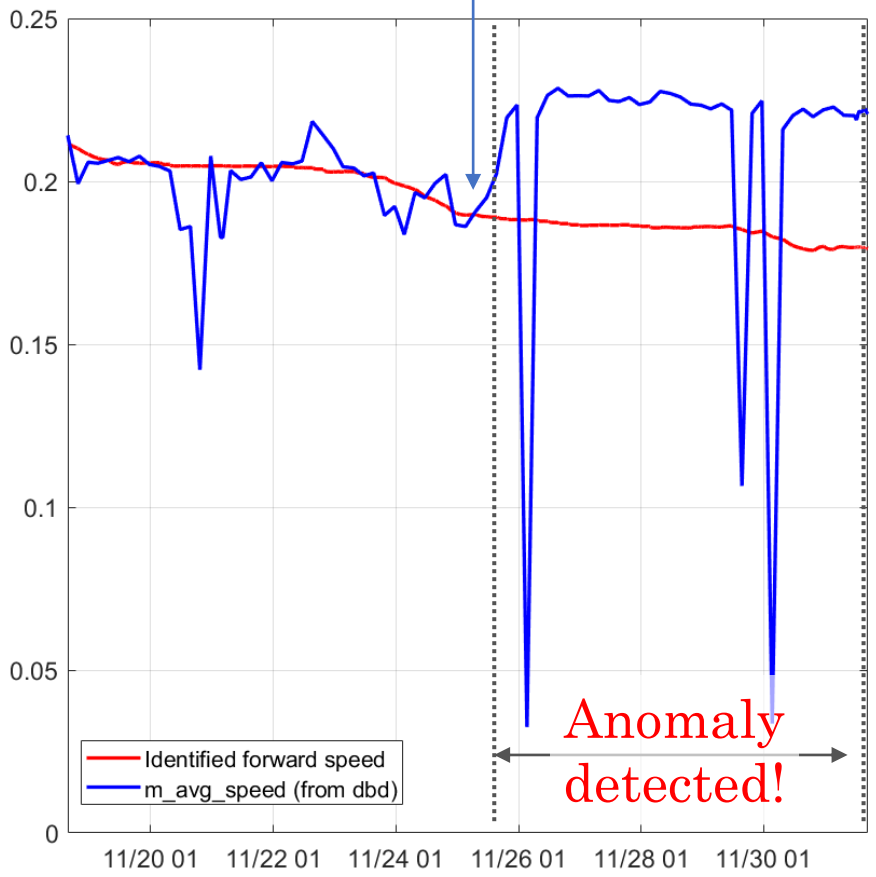
Angus continues to make progress around the triangle of receivers at Grays Reef, although he did spend a few hours on the seafloor yesterday. The use of GENIoS was stopped during the 12pm surfacing on Thursday and we are currently using the 'sbdToDock' script'.

In further attempts to reduce Angus' power consumption, the Fluorometer sampling was stopped during the 8am surfacing (Friday). Currently the only science sensors still collecting data are the CTD and Vemcos [although the Vemcos may get turned off in the next few days to further stretch our remaining power].

Relative charge: 39.31%

Next surfacing: 12:05pm

Remora attack?



- The identified flow speed captures the tidal flow, which is the major flow component in GR
- The algorithm identifies forward speed dropping around Nov. 25 (-0.02 m/s).

Take-away messages & thoughts on future improvements

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- ✓ GENIoS operates reliably, especially in domains where we have accurate flow prediction model

- ✓ The adaptive learning algorithm can identify anomaly condition in glider deployments.
  - More evidence to support the conclusion?

How to have larger along-track progress under GENIoS control?

- Flow canceling strategy + human piloting strategy

Thanks!
Q&A