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An updated system for guidance of heterogeneous platforms used for multiple gliders in a real-time experiment

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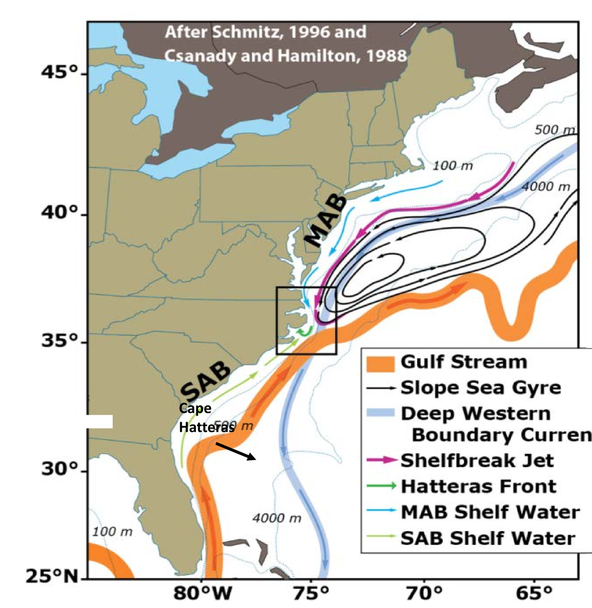
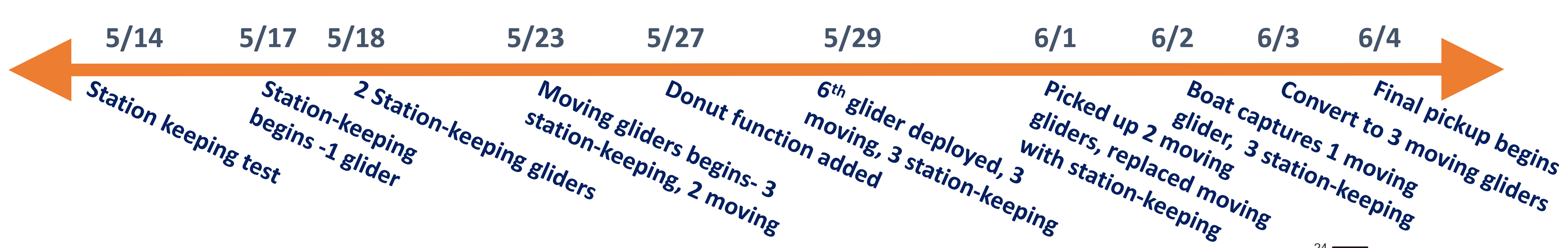
ABSTRACT

The Guidance of Heterogeneous Observation Systems (GHOST) is a tool designed to sample ocean model outputs to determine a suite of possible path options for unmanned platforms. The system is built around a Runge-Kutta method to determine all possible paths, followed by a cost function calculation, an enforcement of safe operating area, and an analysis to determine a top 10% level of cost function and to rank the paths that qualify. A field experiment took place from 16 May until 5 June 2017 aboard the R/V Savannah operating out of the Duke University Marine Laboratory (DUML) in Beaufort, NC. Gliders were deployed in alternating groups with missions defined by one of two possible categories: a station-keeping array and a moving array. Unlike previous versions of the software, which monitored platforms individually, these gliders were placed in groups of 2-5 gliders with the same tasks. Daily runs of the GHOST software were performed for each mission category and for two different 1 km orientations of the Navy Coastal Ocean Model (NCOM). By limiting the number of trial solutions and by sorting through the best results, a quick turnaround was made possible for glider operators to determine waypoints in order to remain in desired areas or to move in paths that sampled areas of highest thermohaline variability. Limiting risk by restricting solutions to defined areas with statistically less likely occurrences of high ocean currents was an important consideration in this study area that was located just inshore of the Gulf Stream.

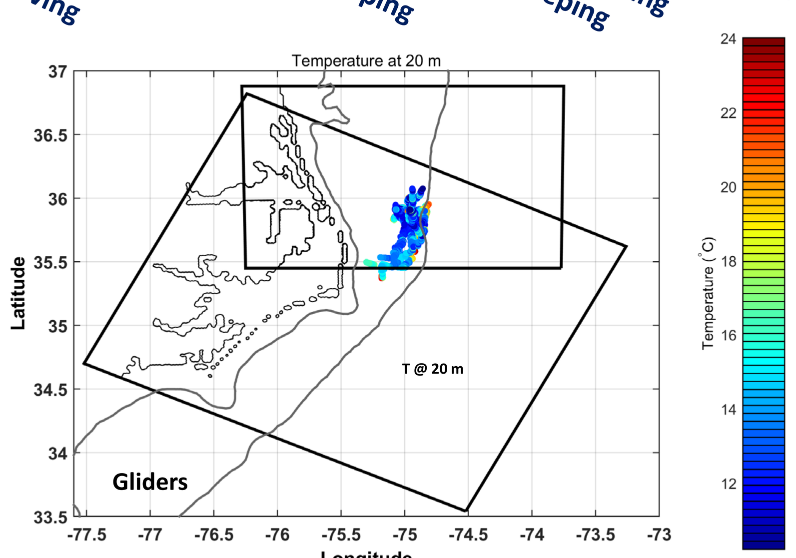
SGT17/PEACH EXPERIMENT

- PEACH: Processes driving Exchange At Cape Hatteras
- NSF funded collaborative project focused on identifying the processes that control the exchange of waters between MAB and SAB shelves and the open ocean.
- NRL teamed up with PEACH to optimize resource use.



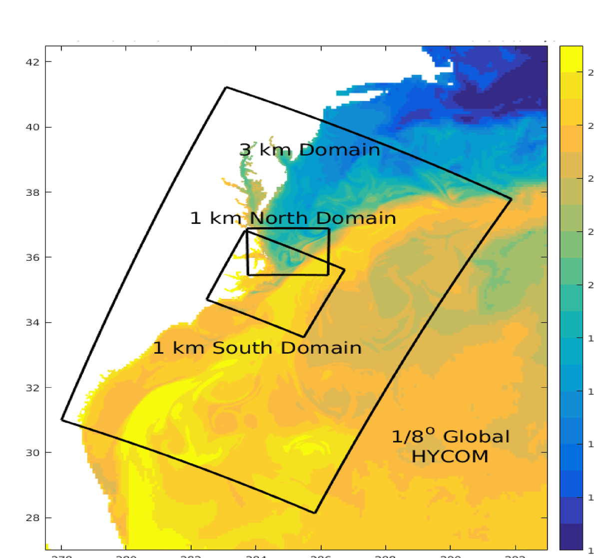


- Smart Glider Teams 2017 (SGT17)
  R/V Savannah cruise May 16- June 5 out of Beaufort, NC.
- Glider operations:
  - 19 days of gliders in the water – 12 days with 5 or 6 gliders working together
  - Station-keeping glider team and a moving glider team
  - > 13,000 glider profiles transmitted in real-time



Nested Model for Experimental Use

- Two 1 km overlapping local area NCOM models run in real-time at 3h intervals with 96 hr. forecasts.
- 1 km models nested in NCOM 3 km domain and in 1/8° Global HYCOM domain.
- Only sub-surface data assimilated during experiment was acquired glider data.
- Caveat: used conventional 3D-Var assimilation -- not effective at assimilating glider data (e.g. 1-2 glider profiles per day)



GHOST COST FUNCTION

The reward function (RF) is based on two types of terms:

- Temporal variability of temperature (T) and salinity (S) at a point
- Spatial (horizontal) variability of T and S at a point

It is computed once a day in the model domain over the forecast period (96 hours) at 0, 25 and 100 m depths.

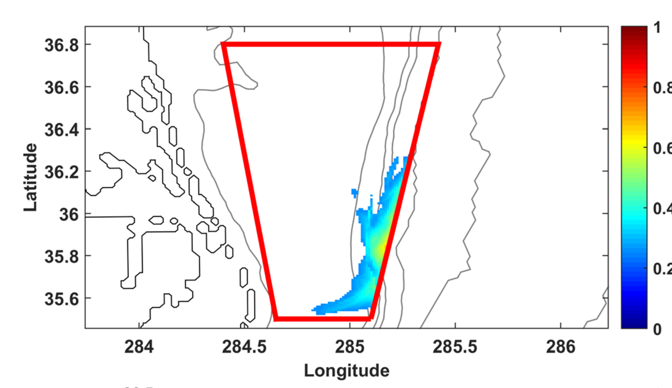
The time invariant reward contribution term (R_c) for T at depth z is:

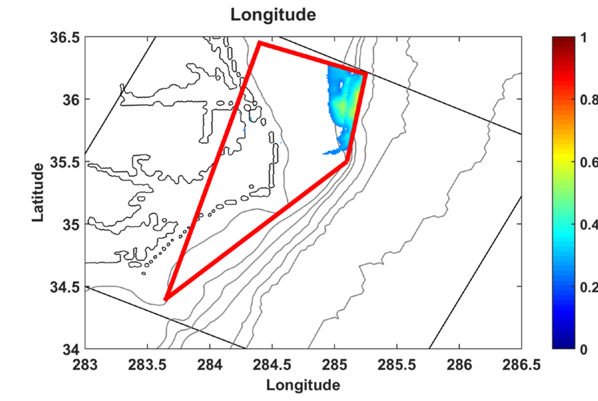
$$R_c\,(T,z) \;=\; a_T{}^{\sigma}(z)\;\sigma_T\,(x,y,z)\;+\;a_T{}^{|\nabla T|}(z)\;\left|\nabla T\right|(x,y,z)$$

This rewards glider paths with high gradients in time and space

The full RF is given by:

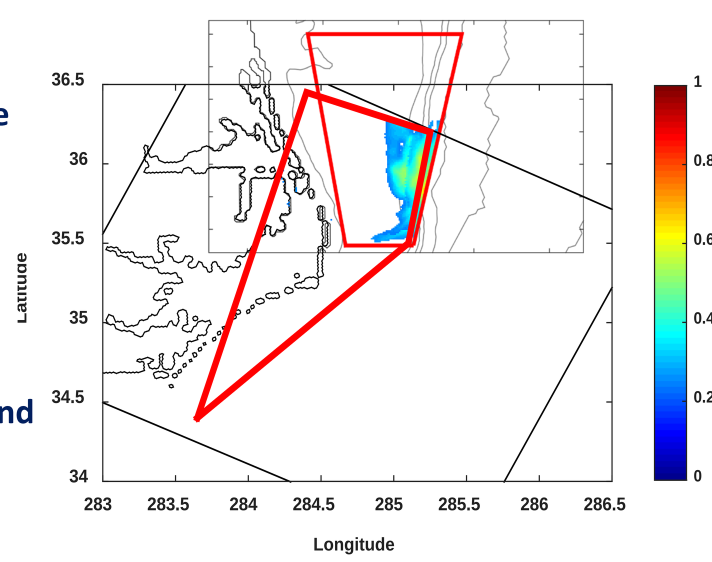
Cost(x,y)=*Rc*(T,0)+*Rc*(T,25)+*Rc*(T,100)+*Rc*(S,0)+*Rc*(S,25)+*Rc*(S,100)



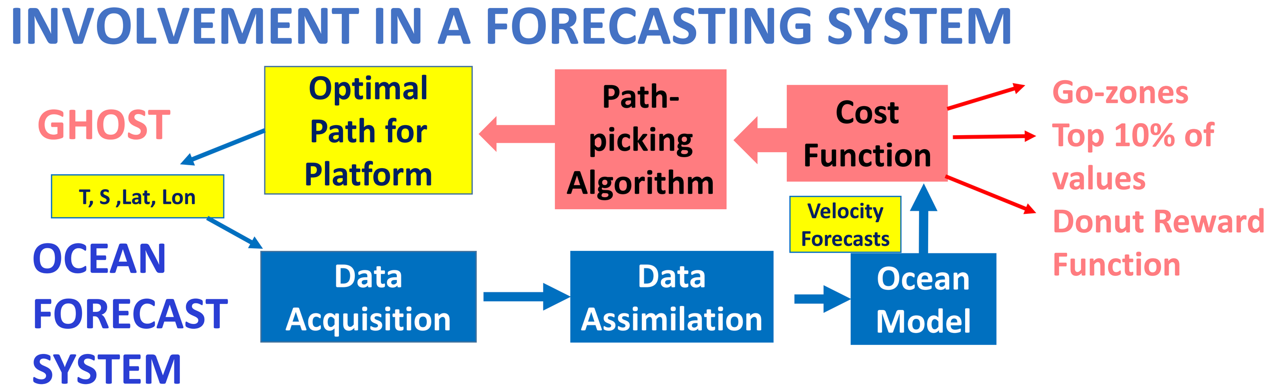


In the next-generation GHOST only the top 10% of values within the glider go-zones are considered in the cost function.

In SGT17/PEACH the maximum RF values occurred overlapping regions of the north and south local model domains.

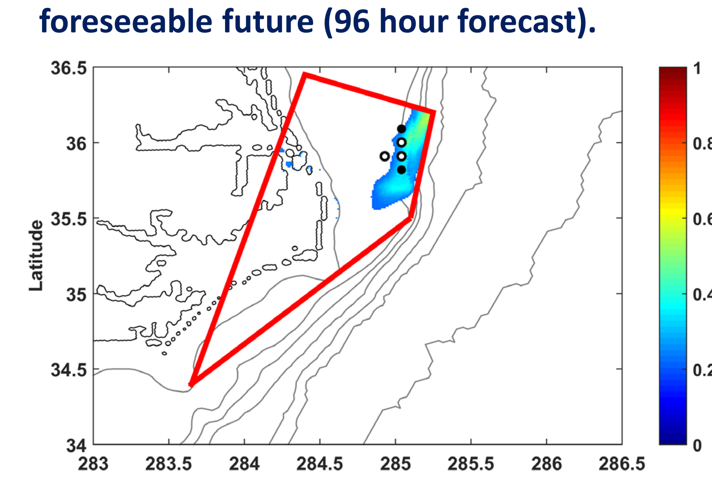


INVOLVEMENT IN A FORECASTING SYSTEM



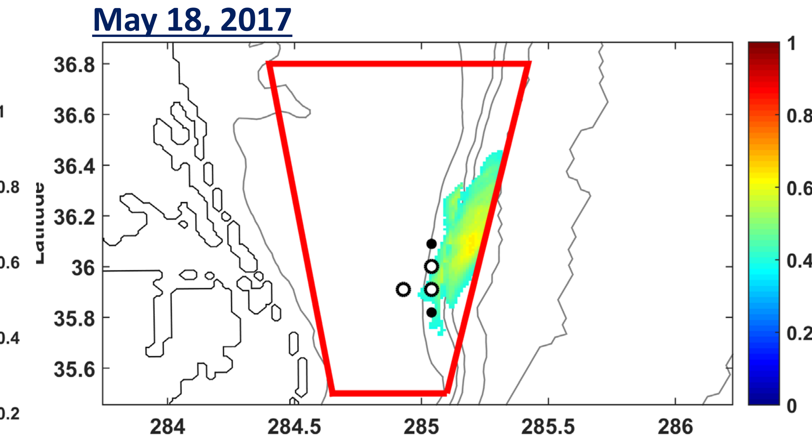
STATION-KEEPING GLIDERS

Goal: Find location(s) with highest RF value and with weak enough currents (< 25 cm/s) that an "L" shaped team of gliders (with 10 km spacing) are able to station-keep for the foreseeable future (96 hour forecast).



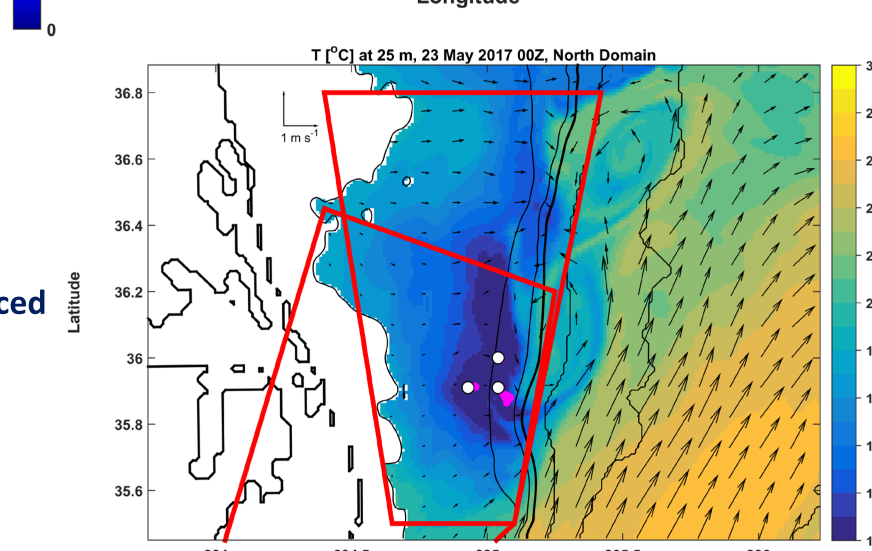
The initial chosen station-keeping team for SGT17/PEACH is shown outlined in white.

May 18, 2017



May 23, 2017

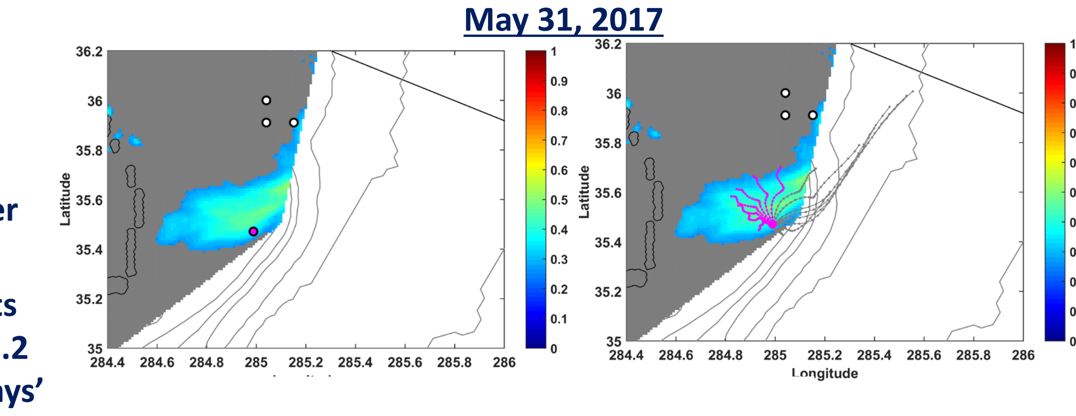
Highest RF and "L" shaped 10 km spaced station-keeping team made a nice sampling pattern keying into a cold dome at 25 m predicted by NCOM.

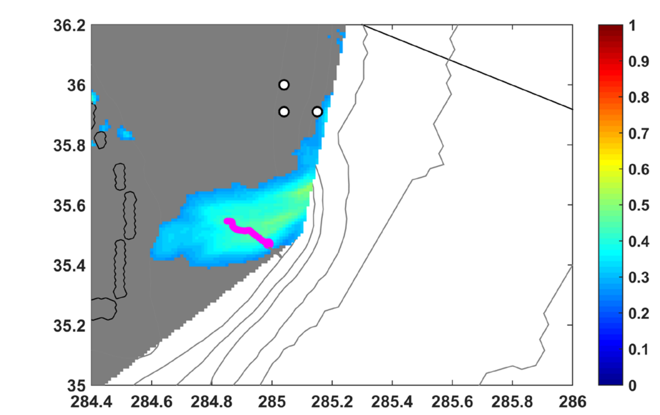


PATH-PICKING ALGORITHM

- Use path-picking algorithm to provide realistic moving team glider paths to pilots (one waypoint per glider per 24 hr. period).
- Begin with 16 waypoints (22.5° apart) each at 43.2 km (approximately 2 days' distance of glider movement) from present glider location.
- Compute ALL paths for one day at hourly intervals based on 96 hr. NCOM velocity forecasts.
- Eliminate paths that cross no-go zones and compute integrated RF along path for remaining paths.

May 31, 2017

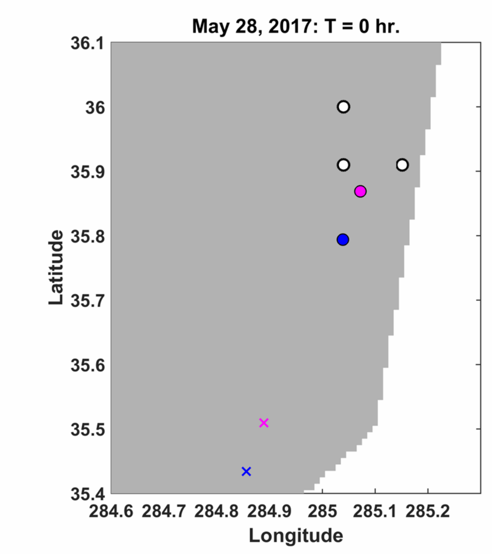




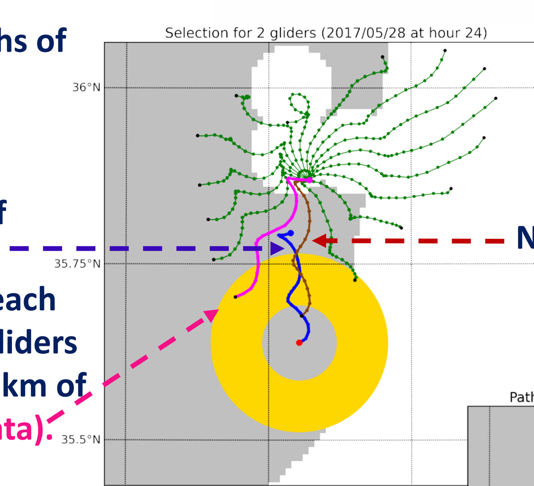
The winning path is the one with the highest integrated cost function!

MOVING GLIDERS

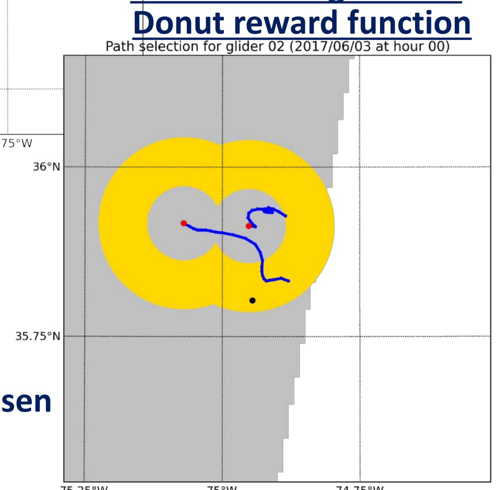
- 3 station-keeping gliders
- 2 moving gliders: blue & magenta
- Implemented path-picking algorithm, however results of independent winning paths result in intertwining of paths and thus poor team behavior.
- Model rejects data that is close together, which leads to poor use of data for analysis and inferior data assimilation impact.



- The donut reward function optimizes paths of glider teams by maintaining appropriate spacing between team members.
- The team member with the highest independently computed integrated RF of winning path receives the donut (blue).
- The algorithm chooses the best path for each dependent team member by rewarding glider paths that stay within 14 km, but no less that 6 km of their teammates' predicted paths (magenta).



June 3, 2017
South model guidance
Donut reward function

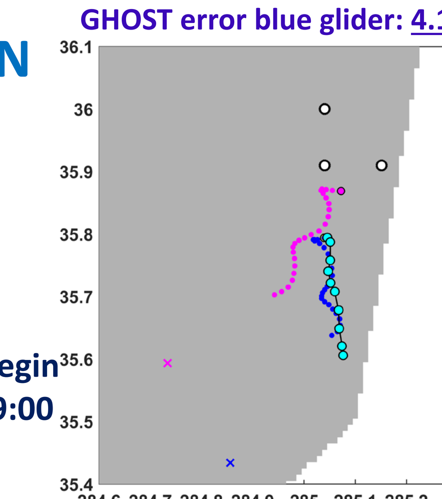


- 3 moving gliders and no station-keeping gliders
- The team member with the highest independently computed integrated RF of winning path receives the first donut
- Follow iterative process to assign a second donut to the team member with highest dependent integrated RF path
- The optimal path for the third dependent team member is chosen by rewarding paths that fall within any donut
- Solution not guaranteed to be global optimal solution

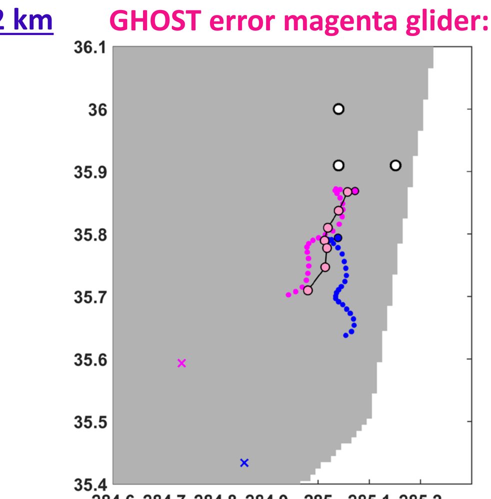
SYSTEM EVALUATION

- 3 station-keeping gliders
- 2 moving gliders: blue & magenta
- Daily GHOST predictions begin at 18:00 UTC and end at 19:00 UTC the next day.

GHOST error blue glider: 4.12 km



GHOST error magenta glider: 3.51 km



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