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An Optimization-Based Path Planner for Underwater Gliders

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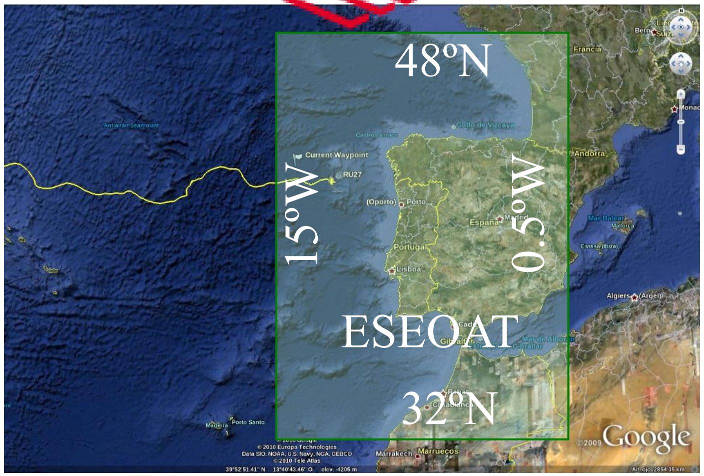
Glider Path Planning

- Find advantageous routes to reach a waypoint
  - Time
  - Energy → Autonomy
- Ocean Currents
  - Strong (>0.5m/s)
  - Eddies
  - Temporal variability
  - ROM: ESEOO Project
    - 1/20º
    - 2D+1h or 3D+day mean

Puertos del Estado



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Problem definition

- Path planning with temporal horizon
  - Minimize the remaining distance to the target
  - Use of ROM's maps with forecast ocean currents
  - Time-varying scenario
  - Computational cost limitations to surface period of glider
- Path planning to reach a waypoint
  - Try to minimize the time to reach the target
  - If long trajectories → Historic ocean currents maps
  - Quasi-stationary scenario

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Non-comprehensive List of Navigation Problems

- Optimal Departure-time
  - Deployment
- Track Evolving features
  - HABs
- Multiple Vehicle Coordination
  - Formation
  - Navigation w/ constraints
- Hold Track
  - Data assimilation
  - Follow line or curve trajectory
- Gathering
  - Recovery

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Introduction
Direct to goal
RRT
A*
Constant-Time Surfacing A*

OTHER PATH PLANNING ALGORITHMS

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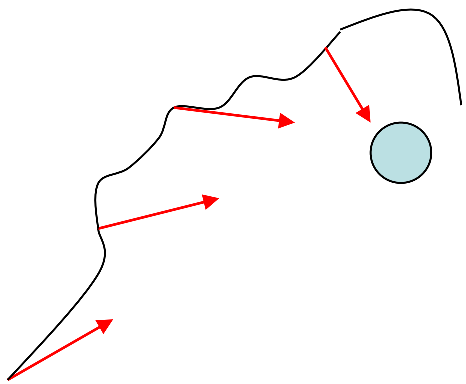
Direct to goal

- Trivial solution
- At each surfacing the next bearing is computed as the direction of the goal point.
- Limitations:
  - Drift significantly in presence of strong currents



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RRT (Rapidly-exploring Random Tree)

- Random generation of test cases.
- Build up an exploring tree with nodes that tend to cover the search space
- Tree is generated both from start and from end point
- Limitations:
  - No applicable in time-varying scenario.
  - No guarantee of finding a route and less an optimal trajectory.

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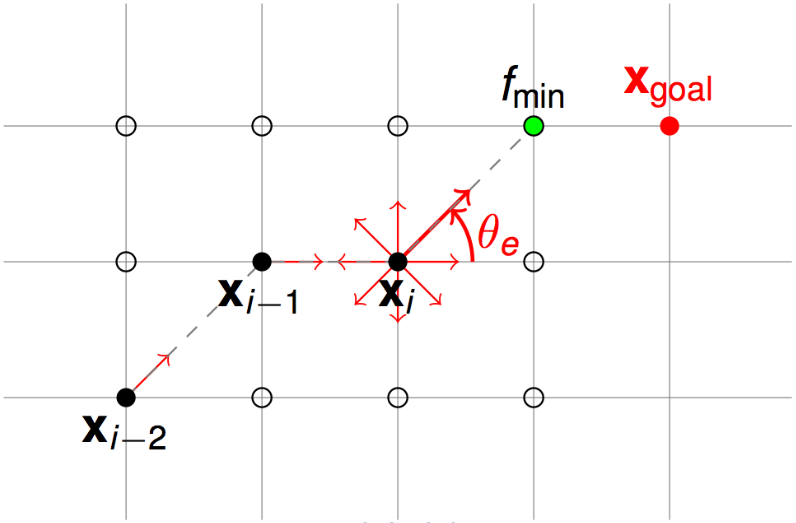
A*

- Adaptation to the glider problem
  - Constrained motion model
- Limitations
  - Uniform grid discretization of the search space
  - Non-constant time stints



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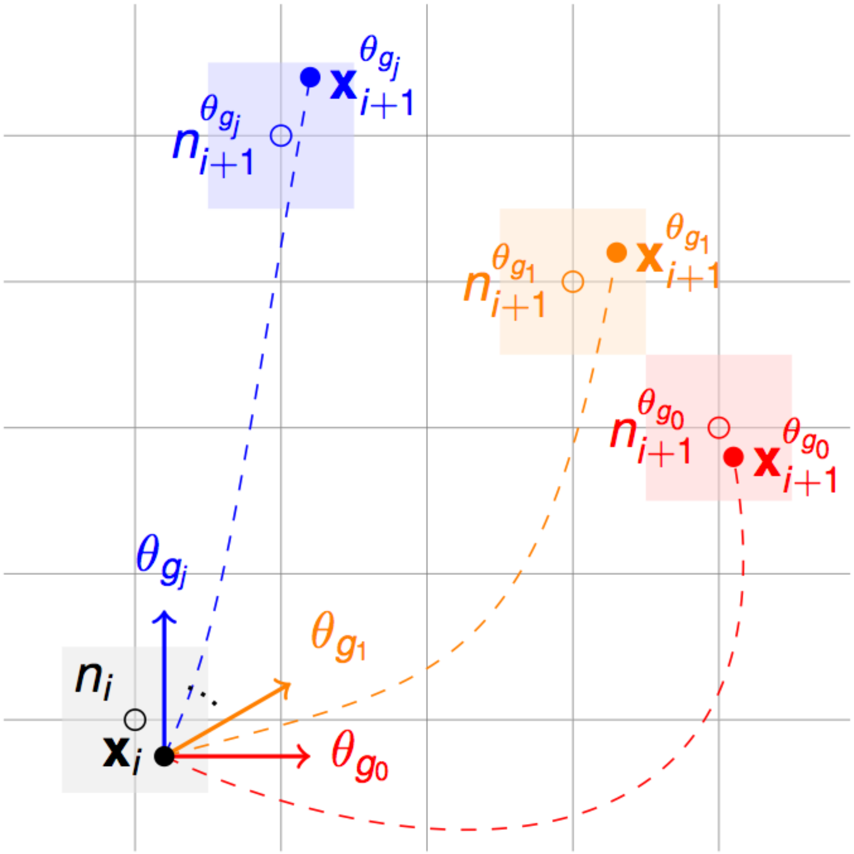
Constant-Time Surfacing A* (CTS-A*)

- Features:
  - Constant-Time Surfacings
  - Bearing set
  - Trajectory integration
  - Continuous locations
- Limitations
  - Bearing discretization
  - High computational cost



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- Path planning with temporal horizon
- Path planning to reach a waypoint

Path planner based on optimization

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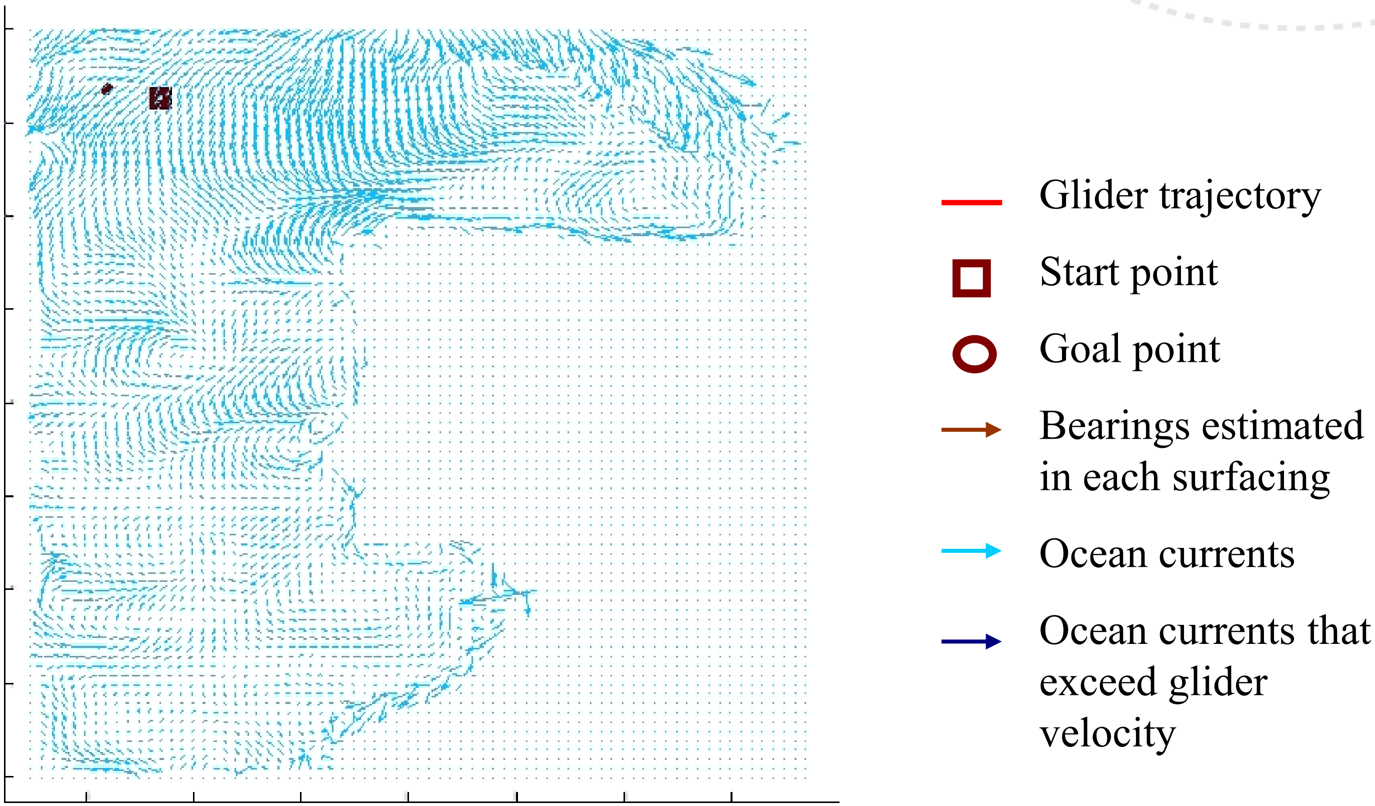
Temporal horizon

- Use of optimization functions
  - Levenberg-Marquardt, SQP, Quasi-Newton …
- Parameters are the bearings of each surfacing
  - The number of parameters is known
- Try to minimize the distance to the goal point
- Initial guess:
  - Start to goal angle
  - Direct to goal results

Optimal trajectory simulation for a 3-days with time-varying currents.



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- Path planning with temporal horizon
- Path planning to reach a waypoint
- Navigation problems

Experimental results

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Temporal horizon
Experiment conditions

- Simulations using Matlab®
- Ocean current maps from the ESEOO model
  - gives outputs for each hour structured in four 24h sets from now-cast to D+3 predictions
- Stint duration: 8 hours
- 25 cases analyzed

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Temporal horizon
Comparative tests

- Measures:
  - **Path quality**: remaing distance from the last surfacing to the goal point
  - **Computational cost:** Using Intel® Core™ 2 Quad processor running at 2.5 Ghz.
- Simulation of glider behavior
  - Combining the commanded bearing with the current model data and the nominal glider velocity
- Methods setup
  - A* and CTS-A* grid size → 1/20º
  - CTS-A* → divisions of 20º in the bearings rose

Temporal horizon

Mean of remaining distance to reach the target

Method	Distance (kms.)
Optim	50.6
CTS-A*	55.8
A*	62.7
Direct to goal	65.4

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Temporal horizon
Mean of computational time

Method	Time (seconds)
Optim	8.1
CTS-A*	38.4
A*	342.4
Direct to goal	<0.1

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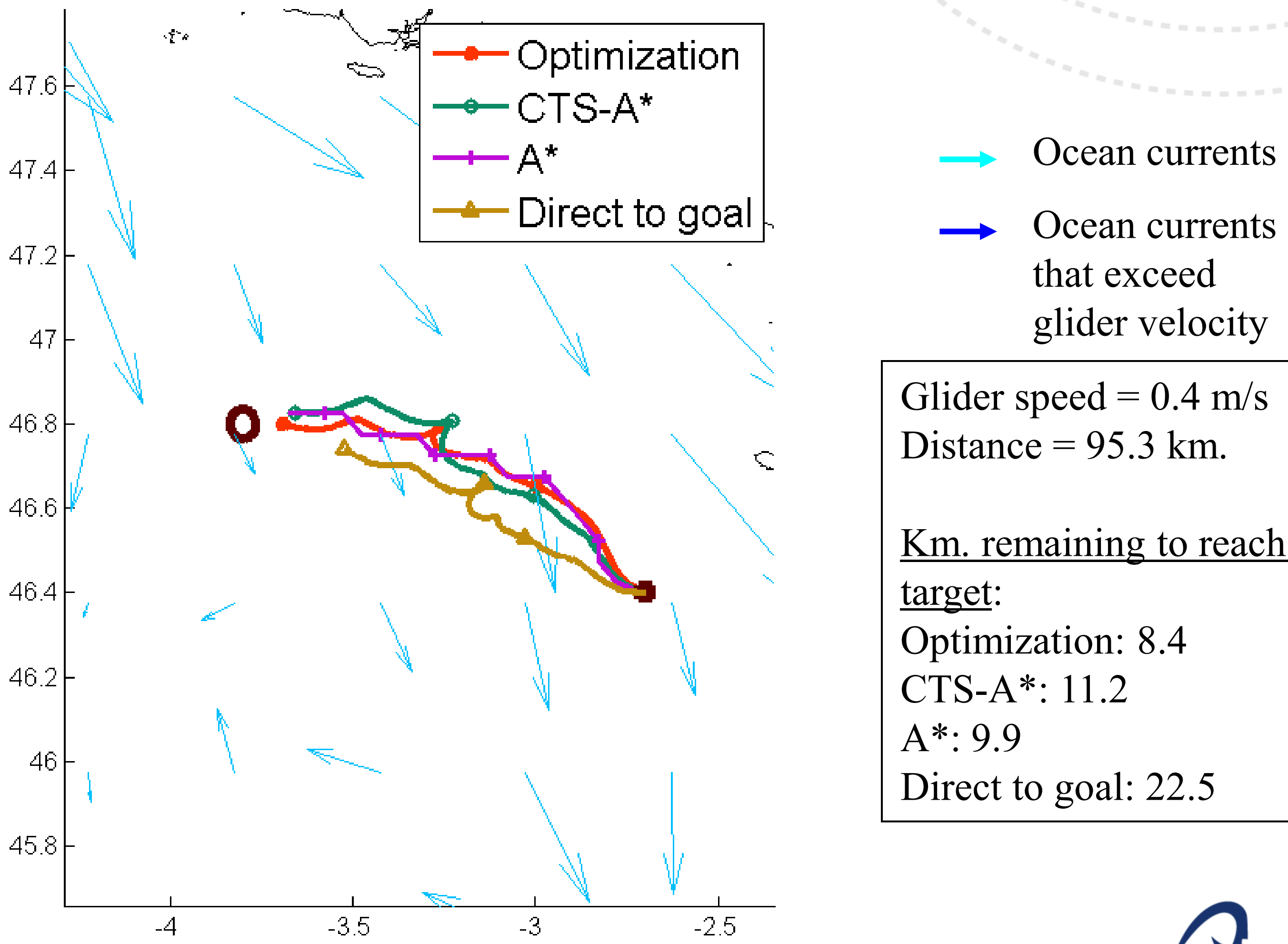
Temporal horizon
Comparative of trajectories



Glider speed = 0.4 m/s
Distance = 95.3 km.

Km. remaining to reach the target:
Optimization: 8.4
CTS-A*: 11.2
A*: 9.9
Direct to goal: 22.5

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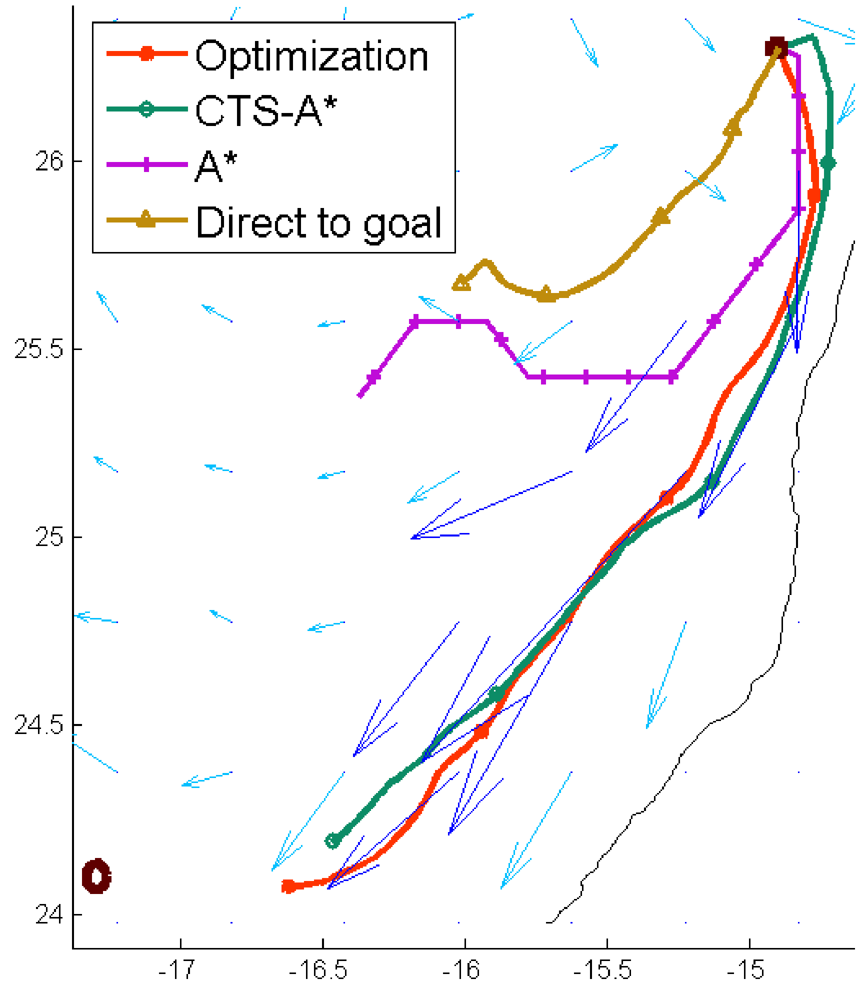
Temporal horizon
Comparative of trajectories



Ocean currents

Ocean currents that exceed glider velocity

Glider speed = 0.4 m/s
Distance = 344.6 km.
Simulation: 4 days

<u>Km. remaining to reach the target</u>:
Optimization: 68.9
CTS-A*: 85.1
A*: 169.4
Direct to goal: 217.6

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To reach the waypoint
Experiment conditions

- Simulations using Matlab®
- Ocean current maps from the ESEOO model
  - static map
- Stint duration: 8 hours
- 20 cases analyzed

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To reach the waypoint

Mean of number of days to reach the goal

Methods	Mean of all cases	Mean of selected cases
Direct to goal	No arrival in the 35% of cases	18.0
RRT	No arrival in the 5% of cases	17.7
A*	18.9	17.1
CTS-A*	18.7	16.9
Optimization	18.4	16.7

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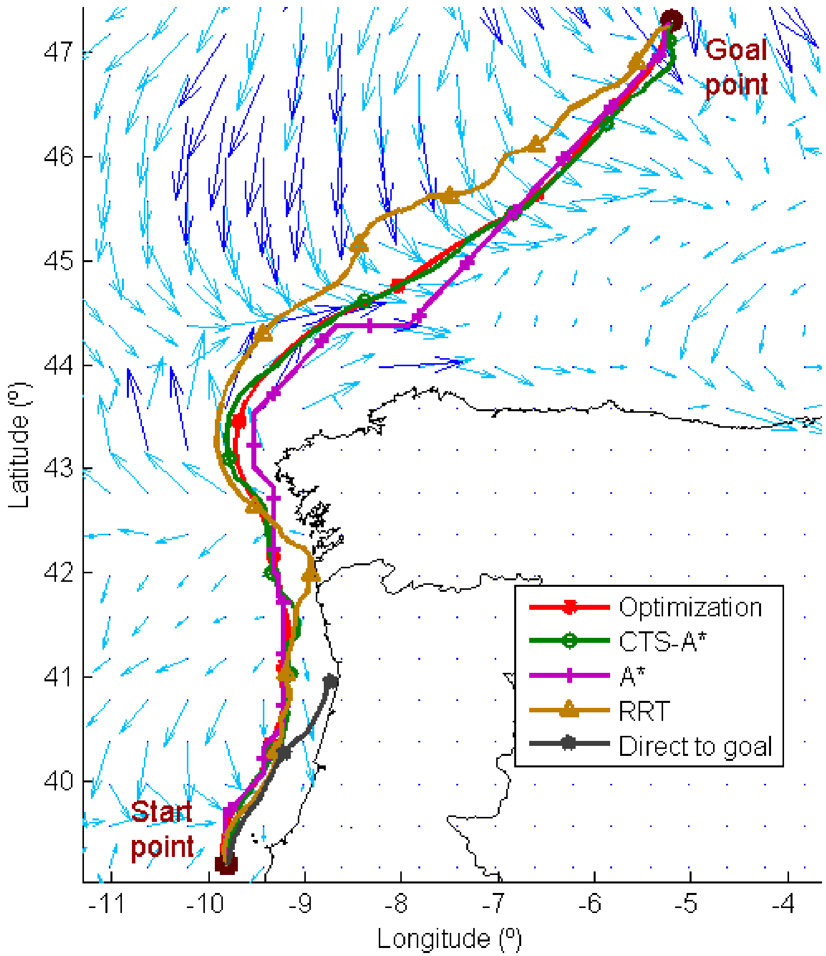
To reach the waypoint
Comparative of trajectories



Ocean currents

Ocean currents that exceed glider velocity

Glider speed = 0.4 m/s.
Distance = 974 km.

Num. days of paths:
Optimization: 26.3
CTS-A*: 27.2
A*: 27.3
RRT: 31.3
Direct to goal: No arrival

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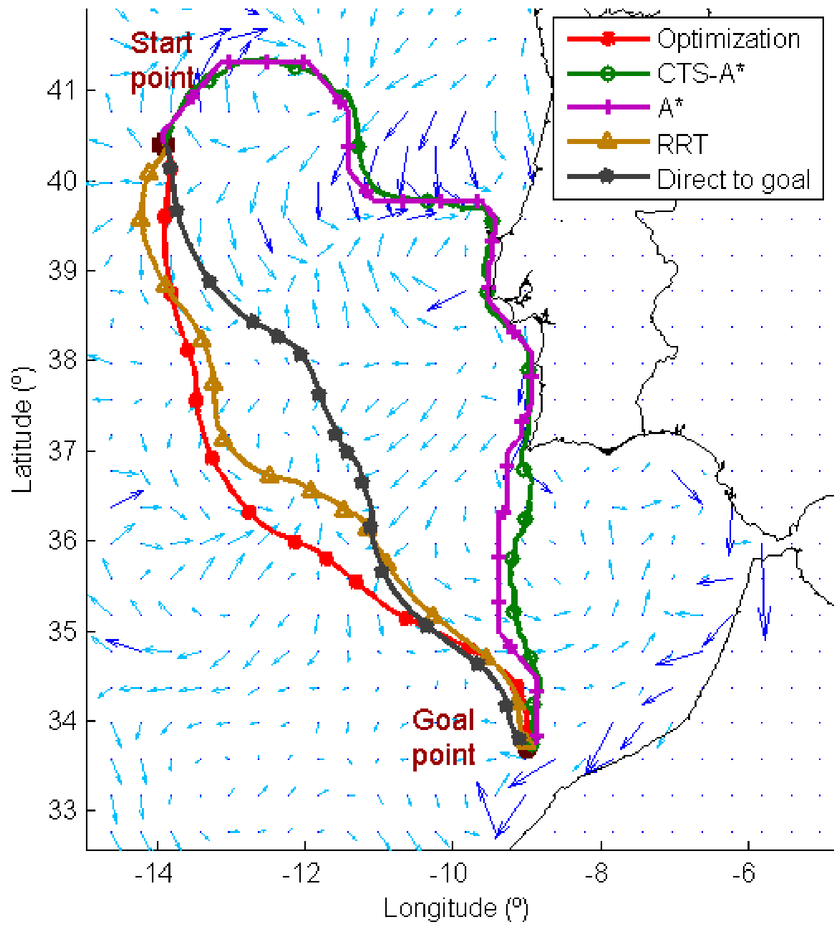
To reach the waypoint
Comparative of trajectories



Ocean currents

Ocean currents that exceed glider velocity

Glider speed = 0.2 m/s.
Distance = 861.9 km.

Num. days of paths:
Optimization: 47.4
CTS-A*: 50.0
A*: 49.6
RRT: 49.7
Direct to goal: 53.8

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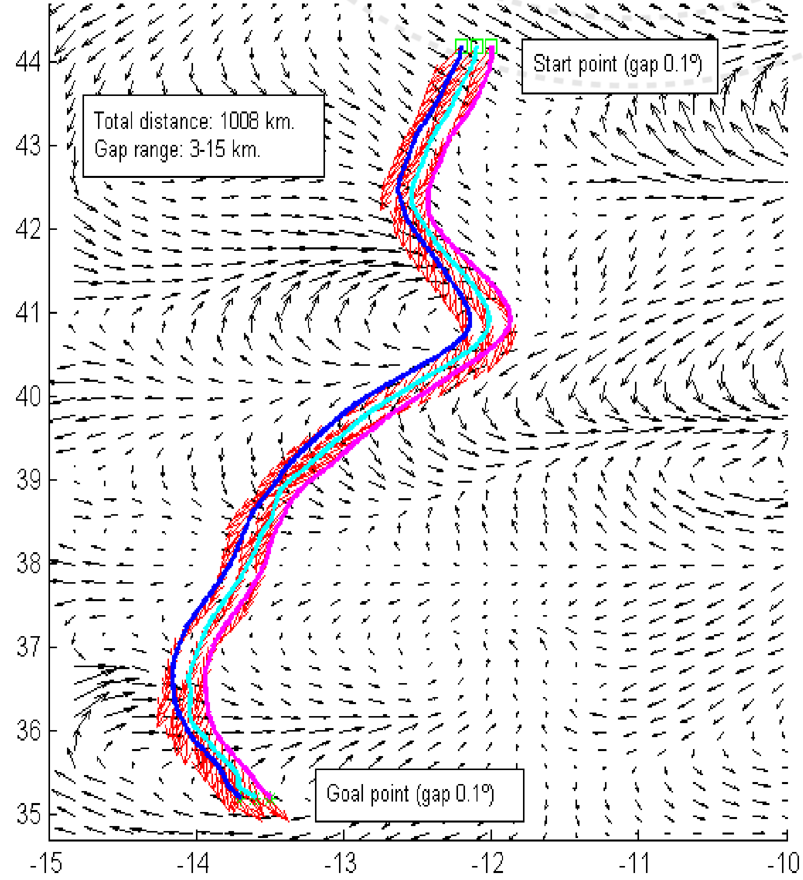
Navigation Problems

- Optimal Departure-time
- Track Evolving features
- Multiple Vehicle Coordination
- Hold Track
- Gathering



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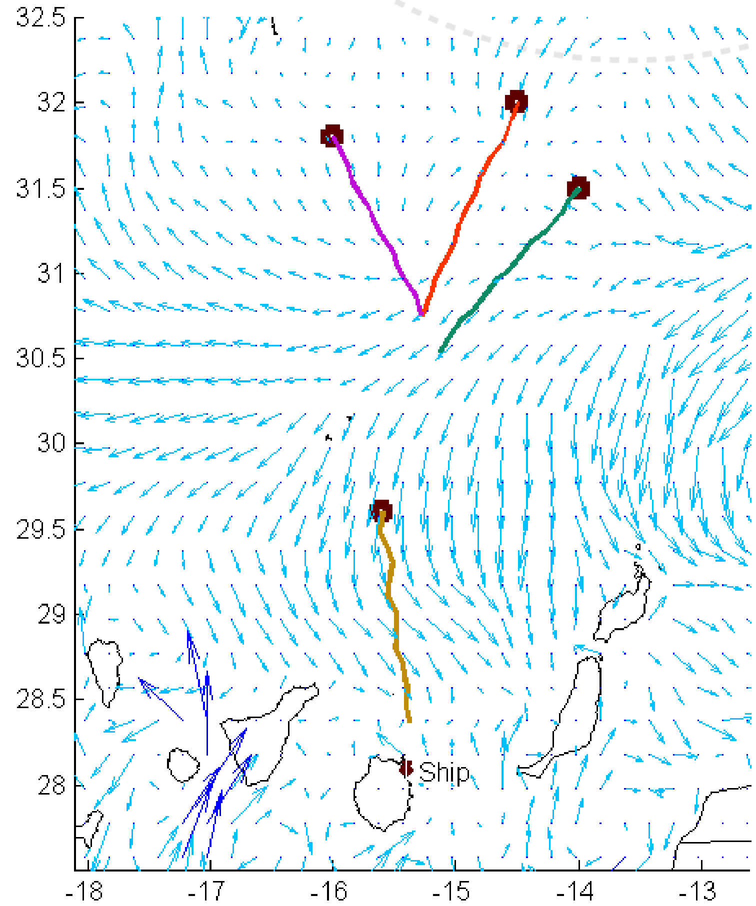

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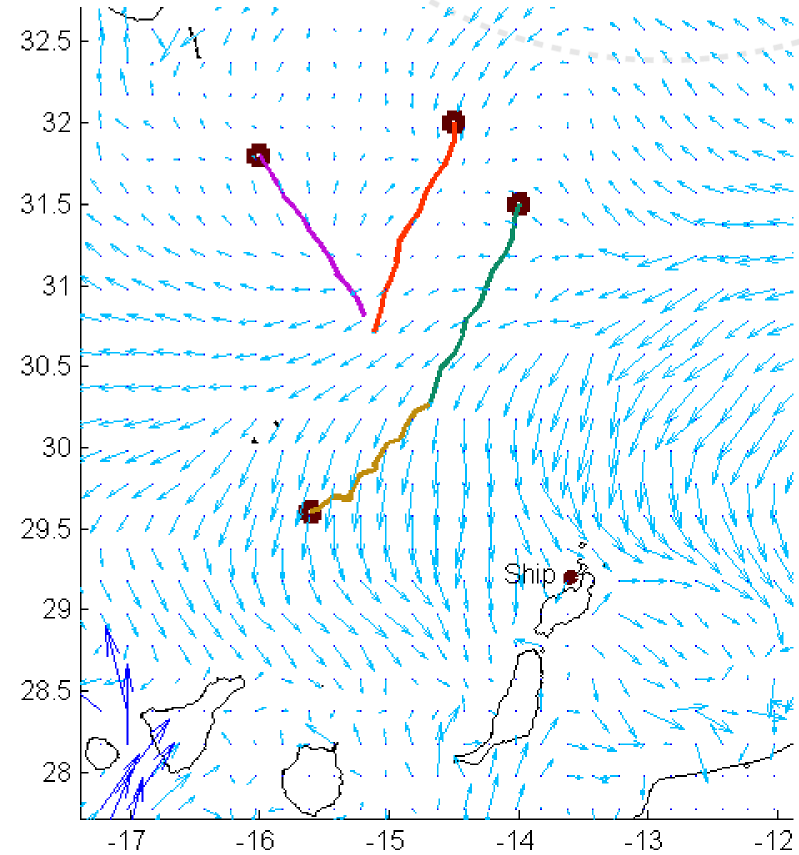

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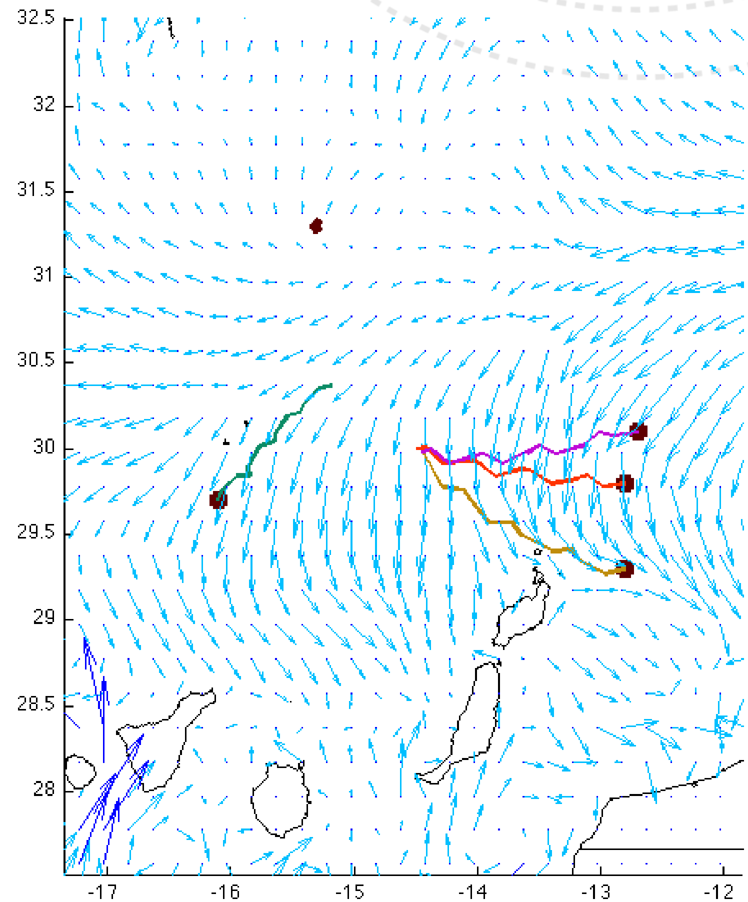

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Conclusions

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Conclusions

- Novel path planning algorithm for gliders based on optimization
  - Reflects accurately the vehicle operation pattern
  - Offers promising results on realistic simulations
  - Allows re-planning in real conditions
  - Adaptable to plan in different practical situations:
    - Cover a set of waypoints (predefined trajectory)
    - Chase mobile objects
    - Coordinate movements of a fleet
- Comparison with other methods
  - Gives better performance (quality path and computational cost) than other approaches

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Future works

- Incorporate 3D current data
  - 3D Glider motion model
- Adaptation of this method to coastal scenarios where obstacles are found.
- Validate the robustness of the method
  - Glider missions

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Thank you for your attention!

Questions, please?

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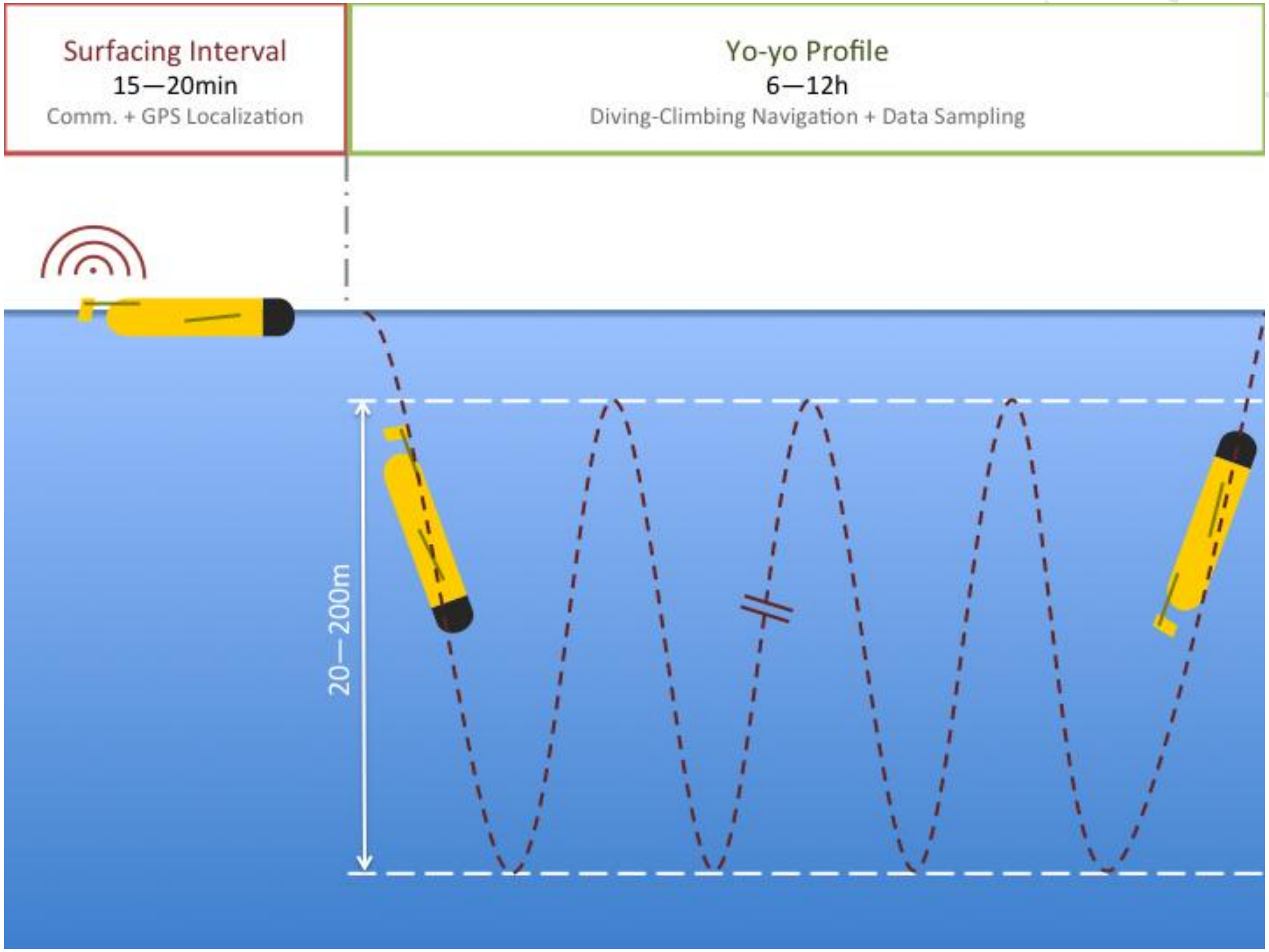
Underwater gliders



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To reach the waypoint

- Problem: The number of stints is unknown
- Algorithm: pathplanner(p_{ini}, p_{end}, M, G, d_{th})
  1. p = p_{ini} → Initialized to start point
  2. B = 0
  3. d = distance(p; p_{end}) → Distance remaining to target
  4. while d > d_{th} do
  5. n = numbearings(p; p_{end}; M; G) → Bearings to goal
  6. Bn = inibearings(p; p_{end}; n) → Init. of new bearings
  7. B0 = [B; Bn] → combine bearings
  8. [B; p] = optimize(B0; p_{ini} ; p_{end};M; G)
  9. d = distance(p; p_{end})
  10. end while
  11. return B

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Gliders path planning

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Glider: Low surge speed (~0.4 m/s)

↓

High influence of ocean currents

↓

Path planning is necessary

↓

Use of Regional Oceanic Models (ROM's)

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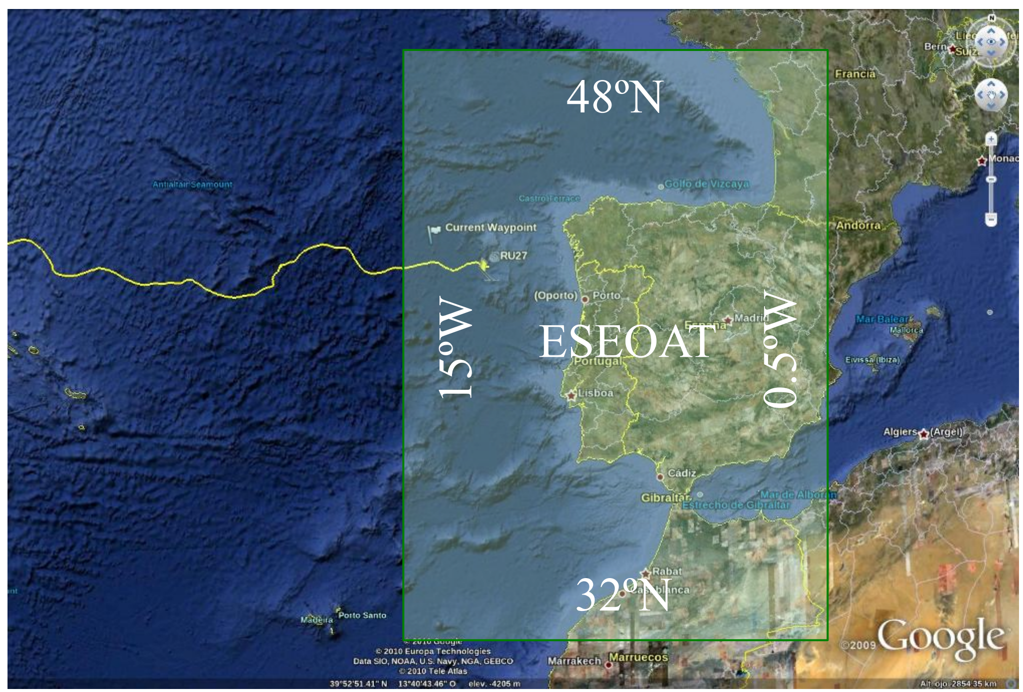
Ocean Currents

- ESEOO [Sotillo, 2007]: POLCOMS model
- Buoys network, fresh water (river) discharges, …
- Output
  - 2D + 1hour or 3D + day means



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Gliders

- Autonomous Underwater Vehicle (AUV)
- Large Autonomy
  - Saw tooth pattern (dive, climb)
  - Surfacing
    - Communicate data
    - Receive bearing (next waypoint)
  - Low speed

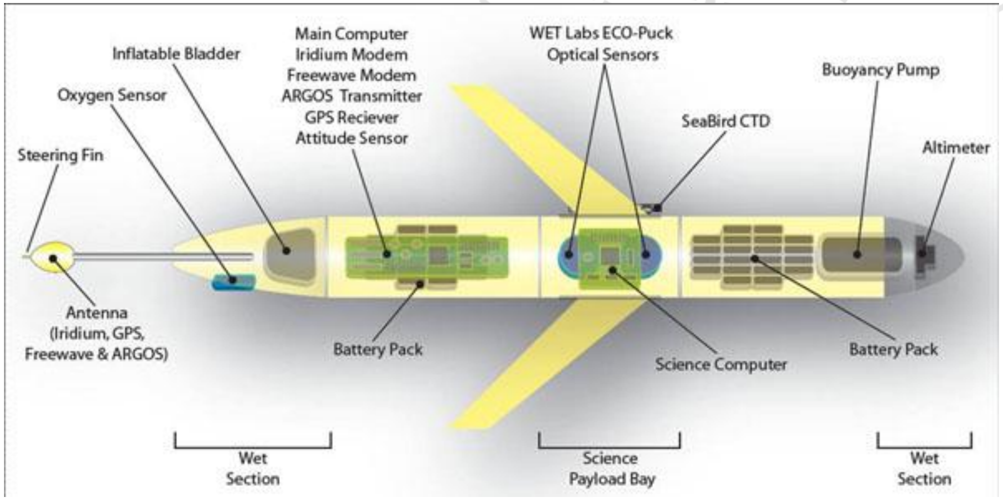

Figure courtesy of Integrated Marine Observing System (IMOS)

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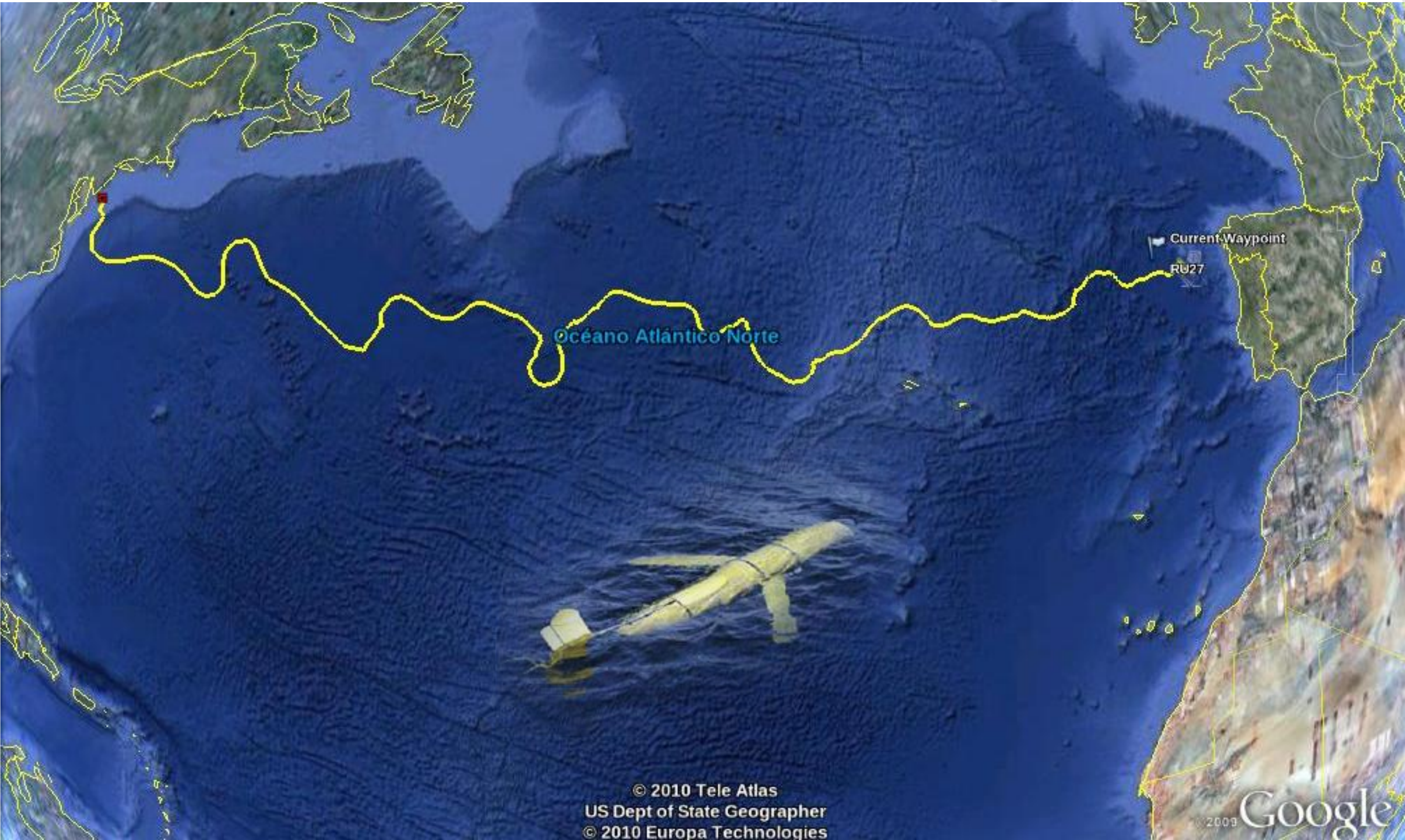
RU27 trans-Atlantic mission



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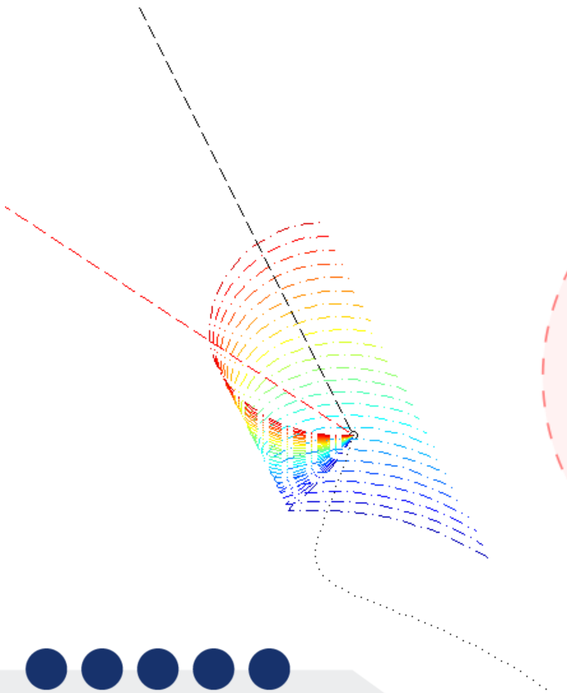
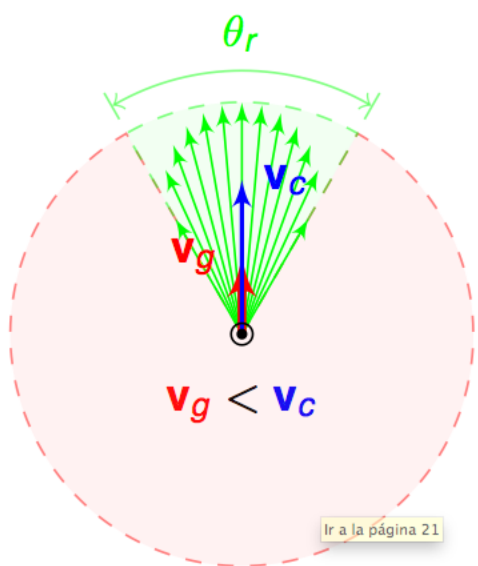
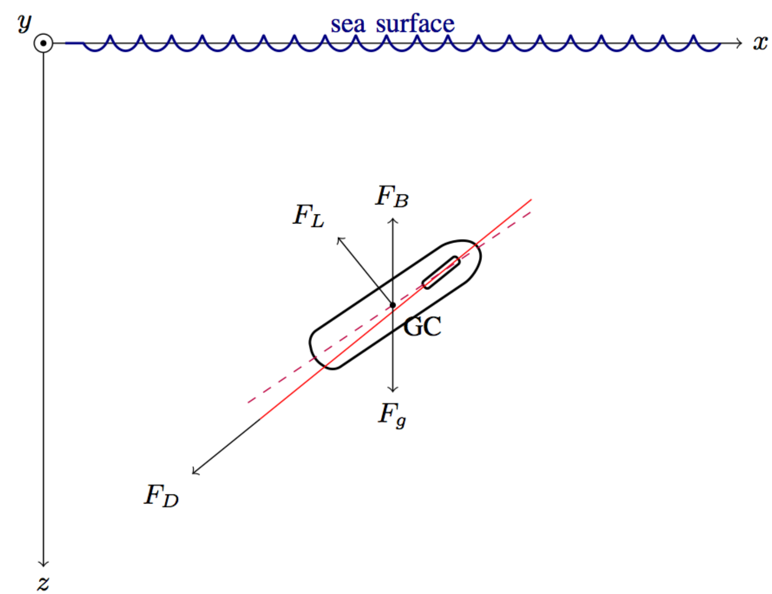
Kinematic Motion Models

- Vector composition + Trajectory integration
- Constrained motion model (feasible headings)
- Force balance (3D bouyancy model)







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