

# Collaborative Research: CPS: Medium: Enabling Autonomous, Persistent, and Adaptive Mobile Observational Networks Through Energy-Aware Dynamic Coverage

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<https://corelab.engin.umich.edu/research/renewably-powered-robotic-systems/>, <https://websites.umich.edu/~dpanagou/>, <https://oomg.meas.ncsu.edu>

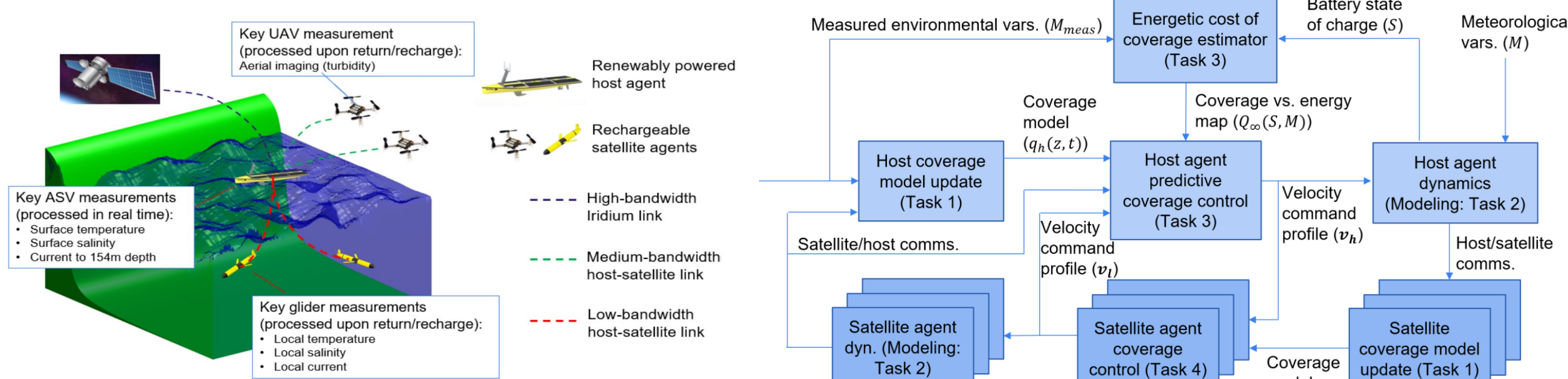
## CPS challenge and solution approach:

**Goal:** Create a ***persistent***, ***adaptive***, and ***autonomous*** mission-planning framework that trades off ***information (cyber)*** and ***energy (physical)***.

### Key solution components:

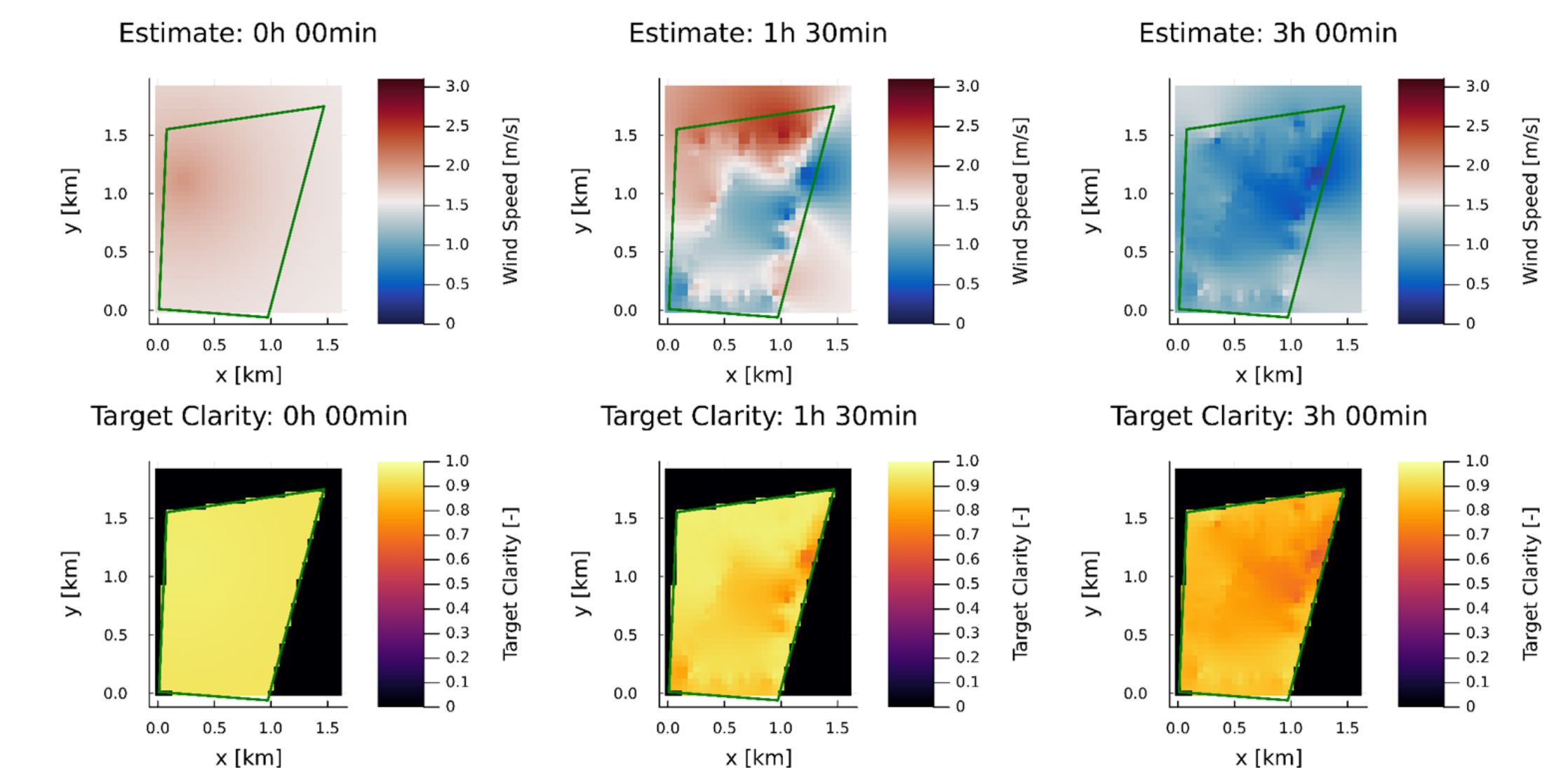
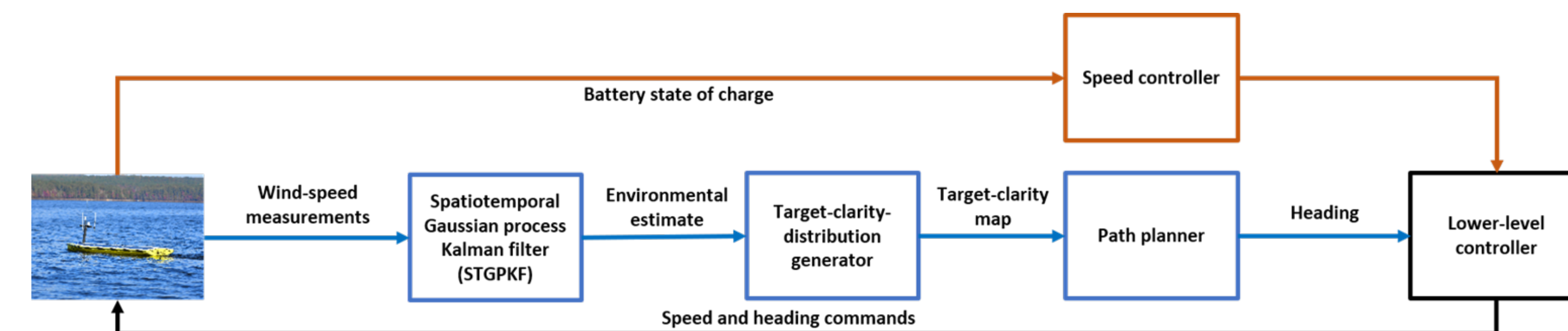
- Predictive, persistent path and velocity control with infinite-horizon ***information value of energy*** terminal reward
- Energy-aware coverage for maximally informative observation and safe rendezvous with host agent/charging station

**Target application:** Persistent surface, aerial, and underwater oceanographic observation in the U.S. Gulf Stream and Outer Banks



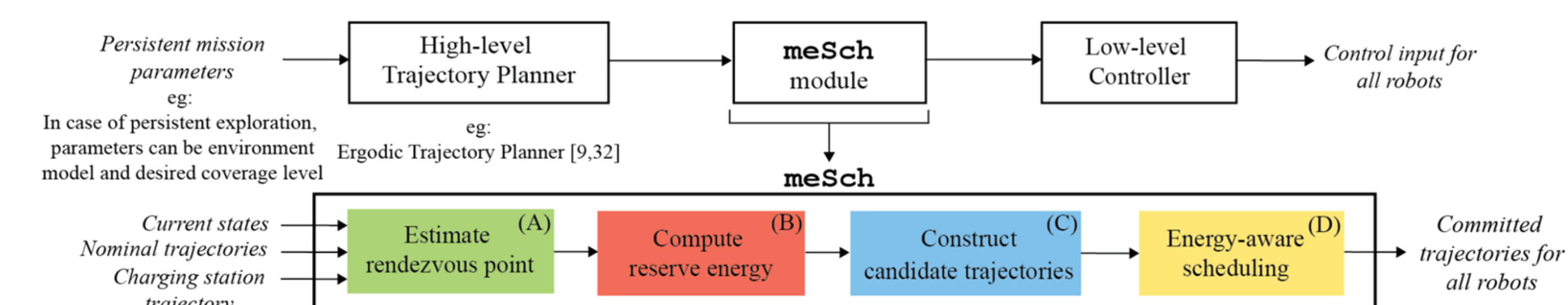
## Research progress – exploration of a spatiotemporal environment using a renewably powered host agent [1]:

- Goal:** Persistently characterize wind speed biasing toward values near a target wind speed.
- Approach:** Clarity (bounded between [0,1]) models quality of information about a quantity of interest (e.g., wind speed) considering information decay. This forms the backbone of the proposed algorithm (presented right).
- Experimental testing at Jordan Lake, NC:** The proposed algorithm was tested at Jordan Lake, NC using the autonomous surface vessel (ASV).



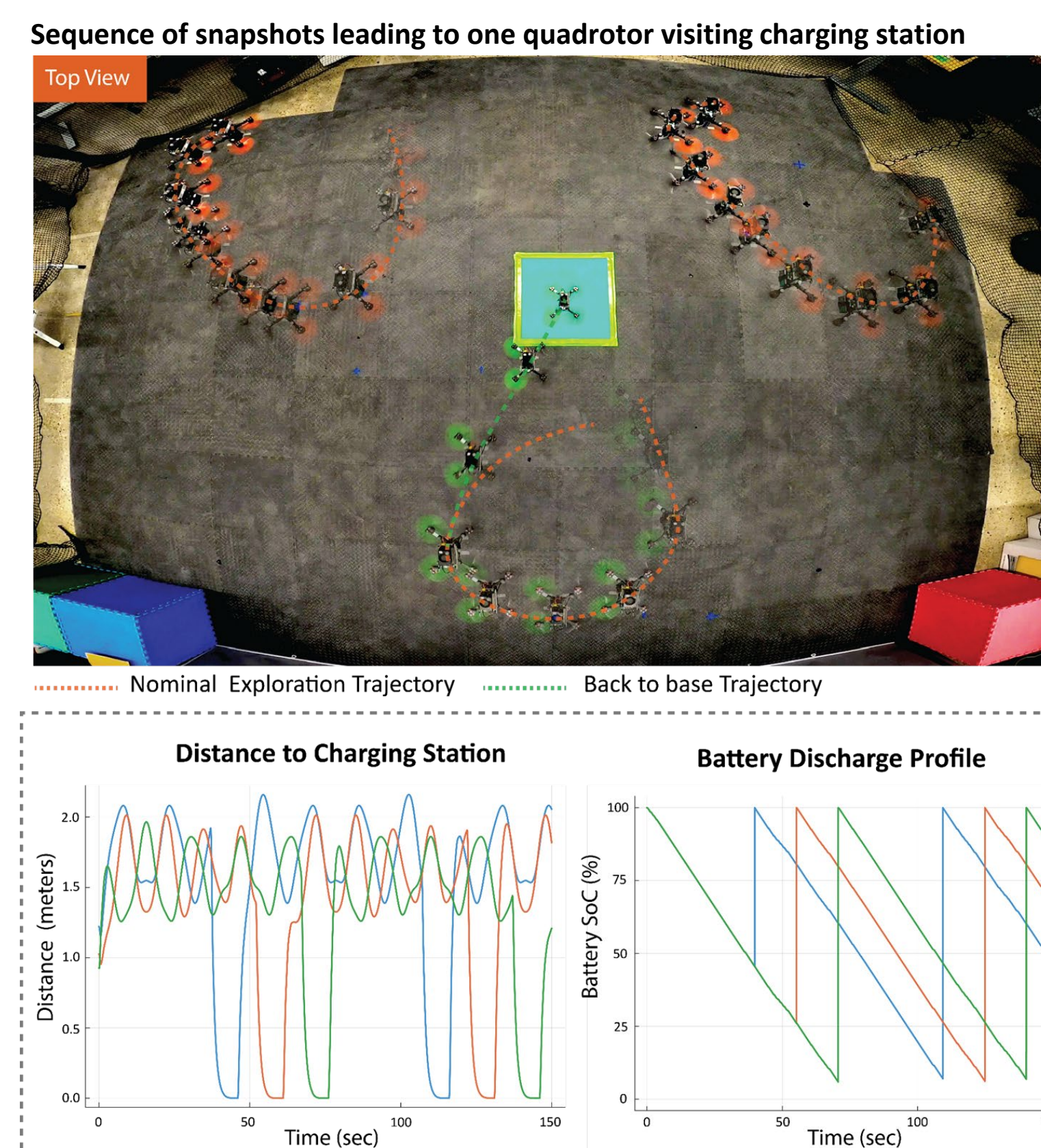
Snapshot of estimates and target-clarity maps from experimental testing

## Research progress – energy-aware coordination of satellite agents



### meSch (multi-agent energy-aware scheduling for task persistence) [4]

- Objective:** Develop an algorithm to track the nominal informative trajectories while ensuring robots never run out of energy and guaranteeing exclusive visits (one at a time) to the possibly mobile charging station.
- Approach:** Iteratively generate candidate trajectories and check two conditions:
  - Ensure non-overlapping charging station visits with minimal gaps.
  - Confirm robots have enough energy to continue.
- Contributions:**
  - Handles robots with both uniform and varying discharge rates.
  - Enables scalability with  $O(N \log N)$  implementation complexity.
  - Supports online replanning and nonlinear dynamics for adaptive missions.



## Broader impacts & ongoing/future work:

### Impact on other application domains:

- The Eclares [5] and meSch [4] frameworks can be applied to long-horizon, adaptive search-and-rescue operations.
- Quantifying the energy/information tradeoff benefits smart agriculture and transportation networks.

### Societal impacts:

- Large deviations in the Gulf Stream, documented with sparse observations, signal potential shifts in atmospheric/oceanic forcing and are crucial for assessing ocean energy-harvesting potential.

### Broader Impacts:

- Kaleb Ben Naveed, Outreach Ambassador for Michigan Robotics, partnered with Carnegie Mellon University's Robotics Institute to develop a free robotics education website for high school students.
- Kavin Govindarajan has been working with InspireNC and FIRST Robotics Competition Team 6908 Infuzed to teach high school students robotics, with a focus on autonomous controls.

### Ongoing/future work:

- Characterizing information value of energy
- Information-and-energy optimal rendezvous planning of host and satellite agents
- Ocean-resource characterization experiments at Outer Banks, NC



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