The Yucatan HF Radar Network: A Multinational Technology Demonstration to Advance Monitoring of Western Boundary Currents

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***Abstract*—The Yucatan High Frequency Radar (HFR) Network is a trilateral collaboration between the U.S., Mexico, and Cuba designed to monitor surface currents in the Yucatan Channel, a critical segment of the Atlantic Ocean conveyor belt. Two long-range CODAR SeaSonde systems were installed on Isla Contoy and at UNAM's Puerto Morelos facility to provide sustained, near-real-time observations of the Yucatan Current, which feeds the Loop Current and impacts hurricane intensification and climate variability. A key innovation is the use of Automatic Identification System (AIS) ship-tracking data to continuously calibrate receiver antenna patterns, eliminating the need for traditional on-water calibration. Hourly surface currents are processed, quality-controlled using QARTOD standards, and publicly distributed via an ERDDAP server. A derived velocity transect product along the strait's axis is used to analyze flow variability and validate ocean models, which often misrepresent the spatial structure observed by HFR. During the 2024 Mini-Adaptive Sampling Test Run (MASTR), real-time radar products supported autonomous vehicle missions and targeted ship sampling. Expansion to Cuba and additional Mexican sites is underway, positioning the network as a foundation for Caribbean-wide HFR coverage under GOOS and TAC-OOFS to improve ocean forecasting and hurricane prediction.**

Keywords— High Frequency Radar (HFR), Yucatan Current, Loop Current, AIS calibration, antenna pattern, surface currents, CODAR SeaSonde, model validation, ocean observing, adaptive sampling, data assimilation, Gulf of Mexico, western boundary current, QARTOD

I. Introduction

Understanding and predicting the Loop Current System in the Gulf of Mexico is a long-standing challenge with important implications for climate and coastal hazards. The Yucatan Current, the fast, northward flow between the Yucatan Peninsula (Mexico) and Cuba, is a principal gateway feeding the Loop Current. After entering the Gulf, this current forms the Loop Current, which can extend and eventually shed large eddies, influencing regional ocean heat distribution and potentially fueling hurricanes. The Yucatan Current is effectively a western boundary current (WBC) chokepoint, as it channels Caribbean inflow through the narrow Yucatan Strait (also called Yucatan Channel). Changes in the strength and structure of this inflow can have downstream effects on the Gulf Stream and the Atlantic Meridional Overturning Circulation. Thus, monitoring the Yucatan Strait is critical for improving models of ocean circulation and hurricane intensity prediction.

Despite its importance, continuous in situ observations of surface currents in the Yucatan Channel have been sparse. Recognizing the need for sustained monitoring, the Understanding Gulf Ocean Systems (UGOS) program of the U.S. National Academies' Gulf Research Program funded a pilot HFR network as part of a larger effort to improve Loop Current forecasting. The Yucatan HFR network is envisioned as a trilateral collaboration among the U.S., Mexico, and Cuba to provide sustained, real-time monitoring of this key current segment [1]. By openly sharing data across borders, the project aims to advance regional oceanographic research and support operational oceanography for all three nations.

The initial HFR deployment was completed in mid-2022 with two long-range CODAR SeaSonde stations on the Mexican coast of the Yucatan Channel. Station UASA (UNAM's Unidad Académica de Sistemas Arrecifales) is located near Puerto Morelos, Quintana Roo, on a developed stretch of coast between Cancun and Playa del Carmen. Station ISCY (Isla Contoy) is sited on a small uninhabited island about 30 km north of Cancun. Both radars operate at approximately 5 MHz (long-range mode), providing a nominal range of up to ~100 km and a spatial resolution of 5–6 km. Each installation was equipped with a self-contained power supply and communication system appropriate to its setting. ISCY is off-grid in a protected natural area (powered by solar panels and with satellite uplink for data), whereas UASA has grid power and internet but contends with greater radio-frequency noise due to nearby infrastructure [2]. This dual-site configuration allowed testing the HFR system performance under both ideal and challenging conditions.

By early 2023, the Yucatan HFR network began sustained data collection. Data from the two radars are processed in near-real time and made publicly available via an interactive web portal and an ERDDAP data server [2]. The open-data approach ensures that researchers and operational centers in any country can access the information. Immediate applications of these observations include enhanced forecasting of Loop Current extension or retraction events and associated eddy-shedding cycles, as well as improved coupled ocean-atmosphere models for hurricane prediction. As an example, forecasters can use HFR-derived surface currents to validate and adjust ocean model outputs that feed hurricane intensity models, since accurate ocean currents help determine ocean heat content and upper-layer thickness.

II. Methods

A. Radar System and Installation

Each HFR station is a CODAR SeaSonde long-range (5 MHz) radar, consisting of a transmit antenna, a receive antenna (direction-finding type), and on-site processing hardware. At ISCY (Isla Contoy), the radar is deployed on a remote beach with minimal infrastructure nearby, ideal for clean antenna patterns. At UASA (Puerto Morelos), the radar is mounted at a coastal research facility where buildings, fences, and power lines introduce potential distortions. Both sites were configured with custom power and communications: ISCY uses solar power and satellite telemetry due to the lack of grid and internet, while UASA is connected to mainland power and internet. The two SeaSonde units operate continuously, emitting 5 MHz radio waves that backscatter off ocean surface waves. The backscatter signal contains Doppler-shifted peaks (first-order Bragg peaks) proportional to surface current velocities. Each radar yields radial velocity components (toward or away from the antenna) on an hourly basis over a polar grid. The coverage area of each site extends roughly 90–100 km offshore, overlapping significantly in the Yucatan Channel between about 21°N and 22°N (see Figure 1). Overlap of the two radars is crucial, as it enables the computation of total current vectors by combining radial data from both stations.

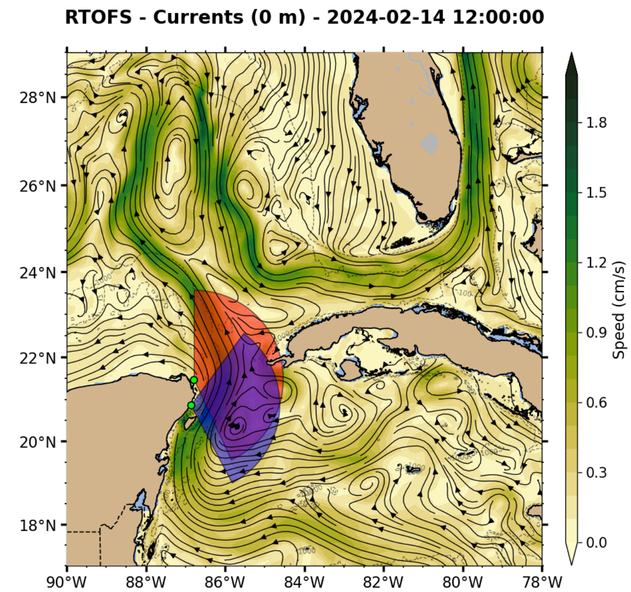

Figure 1: Map of the Yucatan Channel with HFR coverage areas for ISCY (northern site) and UASA (southern site). The red and blue shaded areas indicate the ranges of each radar, with the purple region showing the overlap where total surface currents are measured. Sample surface current vectors (black arrows) from a given hour during the MASTR 2024 campaign are shown.

B. Data Processing and Quality Control

Raw backscatter spectra from each HFR are processed using CODAR SeaSonde algorithms, with significant custom enhancements developed during this project. The signal processing includes identifying the two dominant Bragg peaks even in the presence of a strong, persistent current and mitigating radio frequency interference (RFI). Software upgrades were implemented to better distinguish true ocean echoes from ionospheric interference and to adjust the direction-finding algorithms for the expected single-direction strong flow in this region. After spectral analysis, radial velocities are derived for each range/bearing cell where sea echo is detected. Every radial data point then undergoes automated quality assurance/quality control (QA/QC) checks consistent with the latest QARTOD HFR guidelines [3]. These checks include: (1) Velocity Threshold – rejecting unrealistic speeds, (2) Spatial and Temporal Continuity – flagging outliers that differ greatly from neighbors or prior time steps, (3) Geometric Dilution of Precision (GDOP) – assessing whether radials from two sites intersect at sufficiently orthogonal angles, and (4) Ionospheric Interference – filtering out anomalous signals of vertical origin. Each radial is flagged as pass/fail for every test [4]. Operators and users can choose to use only radials that pass all QARTOD tests, which is the default for generating standard products. The fully quality-controlled radial data from each station are archived and made available for potential data assimilation into models beyond the overlap region (since radials cover a larger area than the combined totals).

C. Total Vector Mapping and Derived Products

Once calibrated radial currents from both sites are available, they are combined to produce total surface current vectors on a predefined grid covering the overlap region. Initial real-time processing employed two methods for vector generation: standard unweighted least squares (UWLS) and an optimal interpolation (OI) scheme. OI provided spatially interpolated vector fields with associated uncertainty estimates, useful for analysis in the core domain, while UWLS was computationally efficient and frequently used for operational dissemination.

One of the most innovative aspects of the Yucatan HFR network is the method of receive antenna pattern calibration using opportunistic ship signals. Each SeaSonde site is paired with an Automatic Identification System (AIS) receiver, capturing real-time locations of large vessels in the radar domain. Large metal-hulled ships traversing the Yucatan Channel act as moving point targets that reflect the radar signal and produce distinct "spikes" in the SeaSonde Doppler spectrum separate from the ocean Bragg peaks. By correlating these detections with AIS-reported positions, we can calculate the bearing offset between the radar's measured angle and the true ship bearing. The SeaSonde processing software was augmented to continuously adjust the receive antenna's pattern (the complex gain as a function of direction) by minimizing the bearing error across many ship detections. This approach effectively crowdsources the calibration to all AIS-tracked ships in the area, eliminating the need for dedicated calibration voyages which are logistically difficult in this region [5].

The calibration procedure is as follows:

- Collect a large sample of ship passages with known positions from AIS and simultaneous radar detections.
- Compute initial bearing discrepancies for each detection by comparing the radar's bearing estimate to the AIS coordinate-derived bearing.
- Use a least-squares optimization to adjust the receive antenna pattern (complex gain of the two orthogonal antenna loops) to minimize the overall error between measured and true bearings.
- Update the antenna pattern file and apply it in subsequent radial processing and repeat the process periodically.

Using one month of data (Feb 1–Mar 1, 2023) at the pristine ISCY site, we obtained 46,856 paired ship-radar detections to derive an initial antenna pattern. The recalibrated pattern significantly reduced bearing errors (root-mean-square error under 3°) and proved to be stable: when re-checked multiple times over the following year, essentially no degradation was observed. This stability is expected in an environment with no nearby scatterers or changes. At the UASA site, surrounded by buildings and infrastructure, we anticipated more variability. Indeed, we recalculated the pattern at regular intervals, especially during intensive operations. During the MASTR 2024 campaign (Jan 15–May 15, 2024), over 277,000 paired detections were accumulated for UASA. Comparing calibration solutions from the first month versus the last month of this period showed little change, indicating that even in a complex setting the antenna pattern did not drift significantly over a few months. For operational simplicity, we used the full multi-month dataset to generate a robust antenna pattern for UASA. Continuous monitoring with AIS data will allow us to detect any future changes (for instance, due to new construction or storm impacts) and recalibrate as needed in near-real time. The resulting patterns from both sites are shown in Figure 2, with AIS-tracked ship locations overlaid on the radar bearing diagrams. These patterns demonstrate both the effectiveness and stability of this calibration approach.

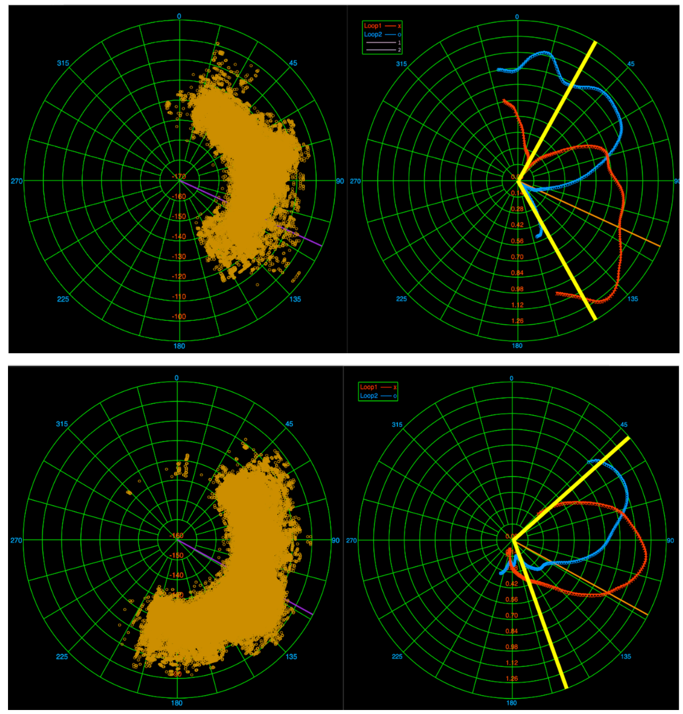

Figure 2: AIS-derived ship tracks used to calibrate receive antenna patterns at ISCY (top) and UASA (bottom). Resulting Loop 1 and Loop 2 patterns are adjusted to minimize bearing error. Patterns remained stable over months, indicating high calibration fidelity.

To further improve data quality and product reliability, we conducted a comprehensive end-to-end reanalysis using CODAR's Release 23 processing suite. This refined reanalysis effort included enhancements at the spectral, radial, and vector levels to maximize data integrity, minimize noise, and optimize current field accuracy for both scientific interpretation and data assimilation.

Spectral Level Improvements: We applied advanced ionospheric interference filters to reduce long-range spectral noise and utilized new Release 23 settings to better detect bimodal Bragg spectral peaks. Each radar's spectral line configuration was manually verified to ensure accurate detection, and all receiver antenna setups were reviewed across the full dataset for quality. An example of these enhanced spectral diagnostics, including filtered ionospheric interference and Bragg peaks across antenna channels, is shown in Figure 3.

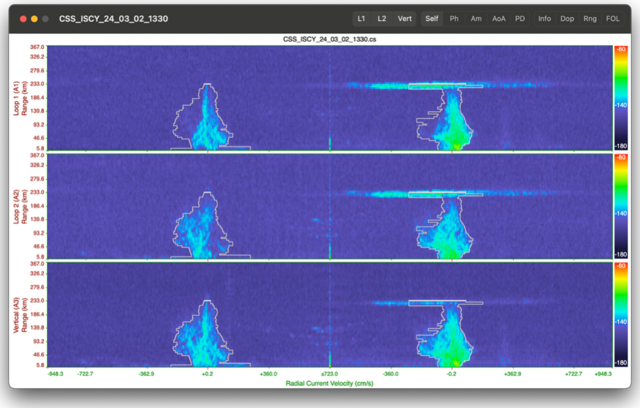

Figure 3: Spectral Doppler returns from Loop1, Loop2, and Vertical antennas show first-order Bragg peaks and ionospheric interference. New CODAR software allowed for improved filtering of spectral noise and better resolution of split peaks in strong boundary current regimes.

Radial Level Processing:

- *Antenna Pattern Optimization:* As detailed above, we used AIS-derived antenna patterns and selected the most stable multi-month solution for each site.
- *Bearing Angle Selection:* Through MUSIC parameter sensitivity testing, we found that single-angle solutions produced more realistic and physically consistent current fields for this strong boundary current regime.
- *Look Angle Segmentation:* We shifted look angle boundaries 15° seaward to more accurately reflect the observable ocean sector and removed outermost radial bins prone to spurious returns.
- *Quality Control Enhancements:* We applied all IOOS QARTOD radial-level QC flags and excluded radials beyond the HFR field of view to eliminate unreliable data.

Total Vector Processing: To combine radial currents into total vector fields, we refined the search radius for pairing observations, adjusting it to 9 km to align with our 6-km output grid spacing and prevent vectors from appearing beyond the realistic footprint. We compared the UWLS and OI vector combination methods in depth. OI yielded higher-fidelity results in the domain center, especially where radial crossing angles were optimal. However, UWLS demonstrated superior performance along the field edges and was ultimately preferred for generating assimilation-ready products. Figure 4 illustrates the total vector field calculated from ISCY and UASA radials with flagged values removed.

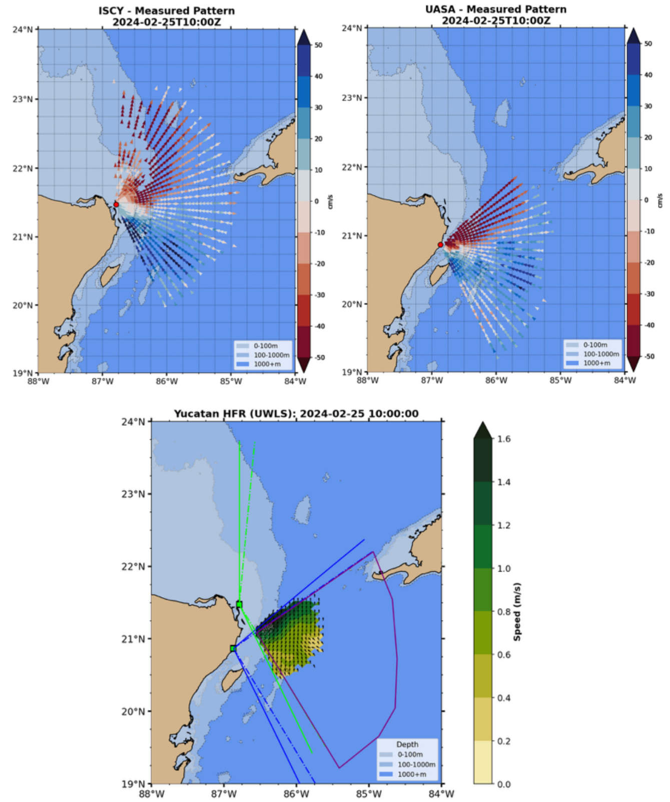

Figure 4: Sample radial velocity maps and combined total vector field. Top Left: Radial component toward (blue) and away from (red) the northern site (ISCY). Top Right: Radial components toward/away from the southern site (UASA). Bottom: Merged total surface current vectors obtained via optimal interpolation; color shading indicates total velocity.

All HFR-derived products are updated hourly on a web-based dashboard for easy viewing, and data files (netCDF) are continuously uploaded to an ERDDAP server. Among the suite of products, a particularly useful one for scientists and modelers is the cross-strait velocity transect. This is a plot of the along-channel (northward) and cross-channel (east-west) surface current components along the red line shown in Figure 5, as a function of distance across the channel and time.

Figure 5 presents a composite Hovmöller visualization:

- The top panel shows the *downstream (northward)* component of the surface current velocity, overlaid with wind direction, HFR-derived transport, and channel bathymetry. This panel highlights the variability of the core inflow location and strength, with persistent dips near 50–60 km from shore aligned with Banco Arrowsmith.
- The bottom panel depicts the *cross-stream (east-west)* velocity component. Periodic westward flow dominates, punctuated by short-lived eastward events associated with wind forcing or Loop Current shifts.

This enhanced visualization framework allows assessment of inflow structure, reversals near Cuba, and the influence of bathymetric features on the current core's spatial evolution.

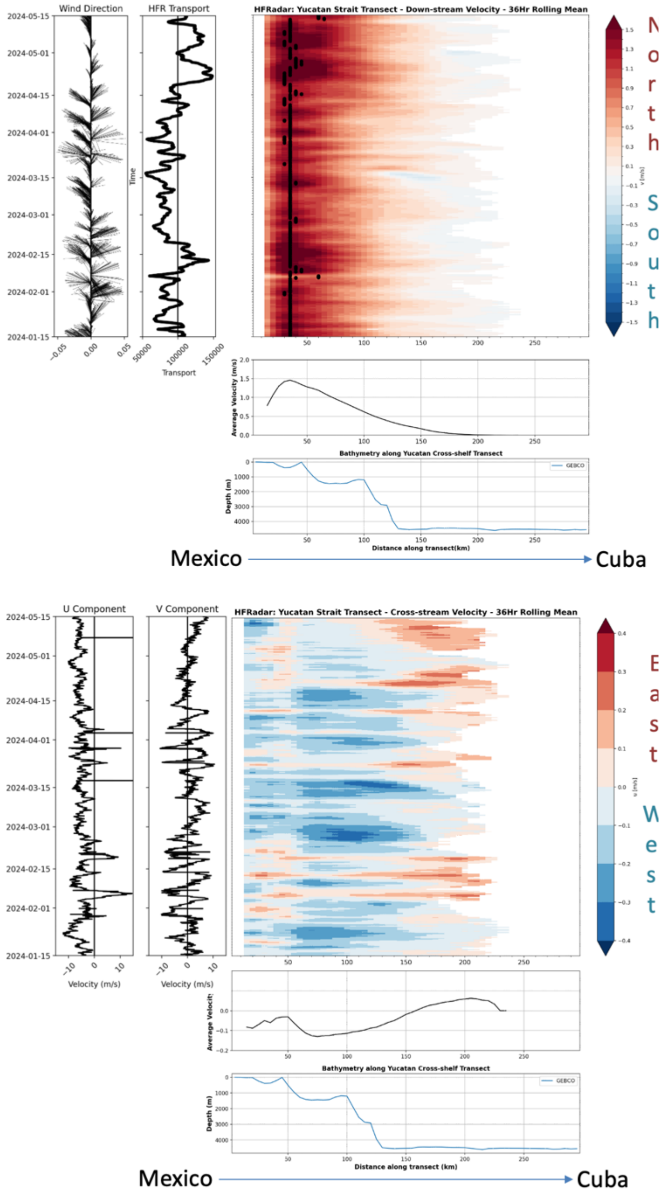

Figure 5: Time-distance Hovmöller diagrams along the Yucatan transect. Top: Along-channel (northward) surface velocity with overlaid wind direction, HFR-derived transport, and channel bathymetry. The core inflow typically shifts between nearshore and offshore modes, with a persistent velocity dip near 50–60 km from shore corresponding to the Banco Arrowsmith shadow zone. Bottom: Cross-channel (east-west) surface velocity showing predominantly westward flow. Episodic eastward reversals occur near the Cuban side of the channel and are often linked to frontal events or Loop Current transitions.

D. Model Comparison and Analysis

To quantitatively compare radar observations with model outputs, we collocated the HFR total currents with global and regional models. Primary among these is NOAA's RTOFS, a data-assimilative global ocean model that provides daily forecasts at ~8 km resolution, and the U.S. Navy's Earth Systems Prediction Capability (ESPC). Additionally, higher-resolution regional models like the Intra-Americas Sea Nowcast/Forecast System (IASNFS, formerly known as AMSEAS), and research models (e.g., NCSU's CNAPS, or a Gulf of Mexico configuration by private industry) were examined [2]. As seen in Figure 6, model surface current fields were sampled along the same cross-channel line as the HFR transect. Key metrics for comparison included the location of the maximum northward velocity core, the magnitude of that core, the total transport across the section, and the occurrence of any counter-flow near Cuba. Differences were evaluated over the 2023–2024 period to capture various Loop Current states (extended vs. retracted). These analyses informed both the oceanographic interpretation (e.g., understanding how the Loop Current state affects the Yucatan inflow structure) and the identification of biases in models.

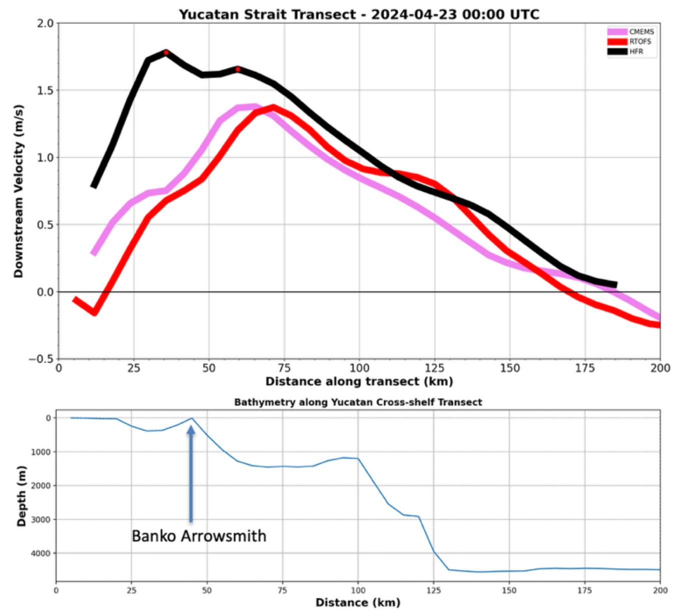

Figure 6: Comparison of downstream velocity across the Yucatan Strait on April 23, 2024, from HF Radar (black), RTOFS (red), and CMEMS (magenta) along the red cross-channel transect. HF Radar observes stronger and more inshore peaks than both models. Bathymetry below highlights the Banko Arrowsmith shoal's influence on current structure.

III. Results

A. Network Performance and Data Return

Since its commissioning, the Yucatan HFR network has operated nearly continuously, with only brief outages due to maintenance or power interruptions. Data return rates in 2023 exceeded 90% at ISCY and ~85% at UASA, reflecting some initial challenges with power and computer stability that were subsequently mitigated. The long-range radars achieved typical range coverages of 80–100 km during favorable conditions, slightly reduced during periods of high noise or low ionospheric propagation. Despite occasional data gaps, the overlap region between the two sites consistently yielded high-quality total vectors. The automated QA/QC filtering removed a small percentage of outlier measurements (most commonly during severe weather or radio interference events), ensuring the final current maps were robust. The success of the AIS-based calibration was evident in the consistency of radial currents at the overlap: when one radar's antenna pattern was temporarily set to a default (uncalibrated) pattern for testing, significant bearing discrepancies emerged in the total solutions, whereas with calibrated patterns the two radars' measurements converged smoothly. This underscores the importance of accurate antenna patterns for vector mapping [5]. Overall, the network demonstrated the feasibility of sustained HFR operations in a remote, transboundary setting. It also highlighted practical lessons for future deployments, such as the need for hardware resiliency and the benefit of real-time remote monitoring and alerts to quickly address downtime.

B. Model Comparisons

Side-by-side comparisons between HFR-derived currents and model outputs have revealed both agreements and biases. The HFR and RTOFS transect Hovmöller diagrams were generally consistent in depicting major Loop Current intrusion events, for instance, both showed a marked increase in transport and a core shift in early 2023 corresponding to a Loop Current extension. However, systematic differences were evident: the location of the maximum current in RTOFS was usually 10–20 km more offshore than observed, and RTOFS rarely if ever showed a dual-peak structure in velocity. The radar, on the other hand, often captured two maxima (as seen in Figure 6) and sometimes even a tertiary peak during complex transitions. Additionally, the magnitude of the peak velocity in RTOFS was often higher than observed (by ~20% on average), suggesting the model's Loop Current might be too barotropic or not mixing enough in the upper layer. In contrast, some higher-resolution regional models (e.g., a Gulf of Mexico model run by NCSU) had a better representation of the nearshore core but tended to under-represent the offshore extent of the flow. All models struggled to reproduce the intermittent Cuban side reversals; these were either absent or far weaker in the simulations. This is likely due to the coarse resolution of winds or an underestimation of topographic effects in models. These findings underscore the value of assimilating HFR surface current data into models: by constraining the position and shape of the inflow in real time, models could correct the noted biases. Plans are underway to feed the Yucatan HFR data into data assimilation systems for the Gulf, initially in hindcast mode for model calibration and eventually in forecast mode to improve operational predictions [2].

C. MASTR 2024 Field Campaign Outcomes

The participation of the HFR network in the MASTR (Mini-Adaptive Sampling Test Run) experiment provided a practical demonstration of its operational utility [6]. Throughout the January–May 2024 campaign, near-real-time surface current maps (with ~1–2 h latency) were delivered to the operations center coordinating autonomous vehicles and drifters. These maps were used to:

- **Navigate AUVs:** Gliders and autonomous underwater vehicles were directed toward features of interest (e.g., strong currents or eddy boundaries) identified in the HFR maps, improving their sampling efficiency.
- **Deploy Drifters:** Drifting buoys were released at locations upstream of the Loop Current core, guided by HFR data to maximize their likelihood of capturing eddy formation processes.
- **Target Ship Sampling:** The R/V just-in-time sampling strategies were adjusted based on the evolving surface currents, allowing researchers to collect measurements in the Loop Current core or eddy features as they developed.

The HFR network proved to be a reliable "eye on the flow," greatly enhancing situational awareness. Such adaptive strategies, enabled by HFR data, are expected to be a major component of the larger GrASE 2025 experiment. The success in MASTR also built confidence among stakeholders (e.g., NOAA and Mexican agencies) in the value of HFR for real-time operations. Notably, the HFR data stream was integrated with other UGOS program assets (gliders, floats, satellites) to provide a multi-faceted view of Loop Current dynamics in a way not previously possible. This synergy is a step toward a fully operational forecasting system for the region.

IV. Discussion

The experiences and results from the Yucatan HFR network's first two years highlight several broader impacts and lessons learned. First, from an oceanographic perspective, the radar observations have largely confirmed and quantified the known characteristics of the Yucatan Current while also revealing new details. The western intensification of the inflow and occasional eastern countercurrents align with historical measurements, but the continuous HFR record provides the ability to measure the duration, frequency, and magnitude of these features for the first time. This kind of long-term monitoring in a major boundary current chokepoint is analogous to other critical ocean "gateways" (like Florida Straits) where sustained observations have vastly improved understanding of ocean circulation variability. As our HFR time series grows, it will allow for analyses of seasonal patterns, interannual variability (e.g., related to large-scale climate oscillations), and the influence of extreme events such as hurricanes. In fact, even within the first year we observed the impact of moderate cold fronts: wind surges from the north corresponded to short-term drops in northward transport, indicating a direct wind-driven response in the surface layer. This suggests that the Loop Current's surface expression is not solely driven by remote ocean dynamics but can be modulated by local weather, a point that models will need to incorporate for accurate forecasts.

From a technical and operational perspective, the project demonstrated the viability of deploying and maintaining HFR in remote, environmentally sensitive locations through international partnership. The use of solar power and satellite communications at ISCY can serve as a model for future remote deployments where conventional power/Internet are unavailable. We learned that robust system design (e.g., redundancy in power, surge protectors, remote reboot capabilities) is vital to achieve high uptime. The success of the AIS-based calibration in lieu of traditional calibration is particularly noteworthy. It solved a practical challenge (the inability to run a transponder vessel in a protected or logistically complex area) with a solution that improves calibration frequency and possibly accuracy. This approach could be applied to other HFR sites worldwide that see regular ship traffic; it effectively turns commercial vessels into continual calibration targets. We are sharing our software tools and findings with the broader HFR community, contributing to initiatives like the U.S. IOOS National HFR network's open-source software repository [7]. Additionally, our implementation of comprehensive QARTOD QC and visualization of QC flags provides a template for real-time data quality monitoring in HFR operations [7].

The forecasting and societal implications of this work are significant. By providing real-time monitoring of the Yucatan inflow, we address one of the major uncertainties in Gulf of Mexico ocean models. Improving the initial ocean state (through data assimilation of HFR currents) is expected to yield better forecasts of the Loop Current evolution, which in turn impacts regional forecasts of ocean conditions that marine industries and navies rely on. More critically, because the Loop Current and its eddies modulate upper-ocean heat content, better resolving these features can improve the accuracy of hurricane intensity forecasts. Hurricanes draw energy from warm ocean waters; a deep, warm Loop Current or eddy can lead to rapid intensification of storms (as seen in past events like Hurricane Katrina). By assimilating HFR data, ocean models can more accurately represent the heat content distribution. Coupled hurricane-ocean models can then use those improved ocean initial conditions, potentially leading to better intensity predictions. This benefit extends to all countries around the Gulf and northwest Caribbean, underscoring the value of international cooperation in ocean observing. The open sharing of HFR data in this project reflects the philosophy of the Global Ocean Observing System (GOOS), a framework in which countries commit to free exchange of essential ocean data for mutual benefit [8].

Finally, this demonstration has catalyzed plans for a broader HFR network in the Caribbean. By proving the concept at Yucatan, we have laid groundwork for expanding HFR coverage to other strategic passages. In the near term, new sites in western Cuba and along the Mexican Caribbean coast will augment the Yucatan array. In parallel, discussions are underway with partners in other Caribbean nations to install HFR in the Lesser Antilles to measure inflows from the Atlantic. The Tropical Americas and Caribbean Ocean Observing and Forecasting System (TAC-OOFS) plan envisions a series of HFR stations monitoring currents entering and leaving the Caribbean basin. Combined with satellite remote sensing and other in situ assets, such a network would significantly advance the region's ocean observing capacity. It would also contribute to the Global HF Radar Network coordinated by GOOS, which seeks to link regional networks into a planetary-scale observation resource. Key challenges remain, including securing sustained funding and building technical capacity in the region to operate and maintain these systems. Capacity-building programs, leveraging the expertise of institutions like Rutgers, TAMU, and CODAR, and funded by international agencies, will be critical for long-term success. The Yucatan project has already provided training opportunities and technology transfer (e.g., workshops for Mexican and Cuban technicians), demonstrating how scientific collaboration can also strengthen diplomatic and educational ties.

V. Conclusion

This work has demonstrated a successful multinational technology collaboration to monitor a crucial ocean current in the Gulf of Mexico–Caribbean region. The Yucatan HFR network delivered the first continuous, high-resolution measurements of surface currents in the Yucatan Channel, revealing detailed flow structures and variability that were previously inferred but not directly observed. The innovations in system design, notably the AIS-based antenna calibration and comprehensive QA/QC, have ensured data quality and reliability, even in challenging deployment conditions. These data have immediate utility for model validation and have guided adaptive sampling campaigns, proving the concept that real-time ocean observations can enhance field operations.

The insights gained into the Yucatan Current's behavior (such as dual-core flow modes, response to wind events, and occurrence of countercurrents) improve our understanding of the Loop Current System and provide targets for numerical model improvement. Going forward, the integration of HFR data into ocean models will likely reduce forecast errors for Loop Current evolution and, by extension, improve hurricane intensity forecasts that depend on ocean heat content predictions. The planned expansion of the radar network to Cuba and further along the Yucatan coast will close remaining observational gaps and increase the resilience of the system (providing redundancy and wider coverage). By 2026, with the transition to operational agencies and inclusion in IOOS, the Yucatan HFR network is expected to move from a research demonstration to a permanent observing capability. This sets the stage for a basin-scale HFR network across the Caribbean that will contribute to international ocean observing efforts and forecasting systems.

In summary, the Yucatan HF Radar Network serves as a pathfinder for building out a broader ocean monitoring infrastructure in the Caribbean Sea. It highlights the power of international partnership and technology innovation in addressing critical gaps in ocean observation. The knowledge gained here not only advances regional science and preparedness (for events like hurricanes) but also feeds into the global understanding of western boundary current dynamics as part of the Earth's climate system. The continuation and expansion of such efforts will be vital for achieving the goals of initiatives like GOOS and TAC-OOFS, ultimately leading to better-informed decision making for coastal communities and maritime activities in the region.

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