Discover Water

Research

Long-term coastal observatory-high frequency radar: site selection study and considerations

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Abstract
High Frequency Radar (HFR) has gained world-wide use as a land based remote sensing technology capable of measuring ocean surface currents and ocean waves at ranges up to 200 km or more. Regional HFR networks support a variety of services including support for search and rescue, marine spill response, and resource management operations. HFR data is useful for validation and calibration of hydrodynamic models that are used to forecast storm-surge, combined flooding and surface currents. Long-term time series data are also needed to assess changes in ocean/estuary currents in response to changes in climate, hydrology, and major coastal infrastructure. The main objective of this paper is to document the site selection process applied for two HFR networks, commissioned in Galveston Bay and Sabine Lake in Southeast Texas. The general process involved several steps including: identify sites meeting technical requirements and constraints; site access negotiation, permitting, station design, station commissioning, network operation and maintenance. To some degree, these processes could be considered sequential; however, in practice intermediate steps were essentially iterative in nature.

1 Introduction

Coastal environments can be classified as stochastic pulsed systems where episodic events are responsible, in large part, for significant impacts to coastal ecosystems and human infrastructure [1]. The temporal scale of coastal processes can vary from seconds to decades, these differences in characteristic times scales are relevant to time series analysis to characterize effects of extreme episodic events to climate change [2]. Long-term high-resolution measurements of environmental parameters can provide insight with respect to coastal processes. The National Research Council recommended the development of large-scale sensor-based observation systems to address data gaps in environmental science [3]. Such large-scale observatories are applicable to investigations related to global climate change, pollutant fate-and-transport, land use, and other environmental issues. In addition, they are used to address more applied data uses such as extreme event modeling (e.g. example storm surge and spill trajectory) and navigation products. Observatories have been deployed across the United States for example: NOAA Physical Oceanographic Real-Time System [4].

The value of such observatories is recognized by the State of Texas, U.S.A. which lists long-term monitoring as a Tier 1 coast wide project [5]. In partial support of the Tier 1 coast wide projects, the Texas General Land Office (GLO), through its Coastal Management Program—Cycle 29, funded a Project of Special Merit to commission High Frequency Radar (HFR)

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networks to continuously measure estuarine currents in Galveston Bay and Sabine Lake that are homes to the Port of Houston and the Sabine-Neches Waterway, ranked 2nd and 4th for the U.S. ports in terms of total tonnage. Data derived from this program directly fills data gaps in the Texas Water Development Board's coast-wide hydrodynamic modeling efforts, specifically it provides empirical data needed to assess the performance of SCHISM (Semi-implicit Cross-scale Hydroscience Integrated Model System), a 3-dimensional baroclinic circulation model that spans creek-lake–river-estuary-shelf-ocean scales and is applicable for simulating storm surge and combined flooding, salinity dynamics, sediment transport, and oil-spill trajectory [6]. HF Radar current data is also applicable to the U.S. Army Corps of Engineers (USACE)' computational models that are used to assess the effects of hydrodynamics on Deep Draft Navigation and Flood Risk Management Products. HF Radar, specifically CODAR SeaSonde, has built in capabilities to measure significant wave heights, period, and direction [7]. As a remote sensing technology, SeaSonde HF Radar data provides current data at high spatial resolutions that can fill data gaps between sparsely distributed buoy-based measurements. Financial benefits of land-based remote sensing technology, such as HF Radar, can be attributed to lower-operational costs in comparison to off-shore measurement platforms.

This paper presents the general process that was followed to establish HF Radar Networks on two major Texas estuaries. A prerequisite to establishment of an observatory network is a tangible need for the observed data, where the need represents a real value to project stakeholders. Success of a long-term monitoring program is dependent on the perceived value of the information. Although costs associated with industrial or compliance monitoring can be readily justified against the amount of legal penalties for violations, justification of long-term non-compliance monitoring such as a coastal monitoring may be difficult to assess because the benefits are seldom realized by the current program managers [8]. With respect to granting agencies, project benefits generally address short-term objectives which are defined in the proposal as specific project deliverables. A common proposal requirement is to demonstrate project value with respect to societal impacts and relationship to the funding agency goals and/or strategic plans. Societal impacts may include qualitative assessments based on indirect benefits to vulnerable or disadvantaged populations. There are a number of web-based tools available to characterize populations impacted, either directly or indirectly, by project activities. For example, the U.S. Environmental Protection Agency (USEPA): Environmental Justice Screening and Mapping Tool [9] and the Agency for Toxic Substances and Disease Registry [10] provide standardized values of various environmental and socioeconomic indices to identify vulnerable populations or at risk or.

The goal of this paper is to provide an overview of considerations by those endeavoring to establish a long-term environmental monitoring program. Although the challenges described herein are specific to the commissioning of HFR networks, they represent a broad range of factors that may be applicable to the commissioning of other large scale continuous remote sensing monitoring programs to address a myriad of disciplines such as hydrology, climate change, and coastal processes.

2 Methods

Significant time and costs associated with the HRF network commissioning can be attributed to the planning process which considers a combination of technical design criteria and administrative steps [11]. Examples of technical and logistical criteria include proximity to targeted observation area, access to power and communication, personnel access, and radio frequency allocation, and presence/absence of significant interferences. Considering the various entities, agents, and or governments potentially involved in the commissioning process, administrative challenges may represent a rate limiting step in the planning commissioning process (Fig. 1). Worst case scenarios, where a proposed site fails to technical criteria or proposed activity poses a conflict with the site owner/agent, may necessitate selection of an alternative location. Thus, the site planning process should be considered an iterative process that considers the following: 1) targeted observation area; 2) appropriate operating frequency for the targeted area; 3) number of stations required to cover the observation area; 4) suitability and/or availability of station locations; 5) station accessibility; 6) owners and agents of the station locations; 7) availability of power and data communications; 8) proximity to the observation area; and 9) commissioning budget. Having a solid understanding of network design criteria is a prerequisite to initiate the network design process, representing a significant effort for which associated cost and time commitments should be considered. To enable compensation for the design phase, remote station reconnaissance and negotiation of property access agreements were specified as project deliverables.

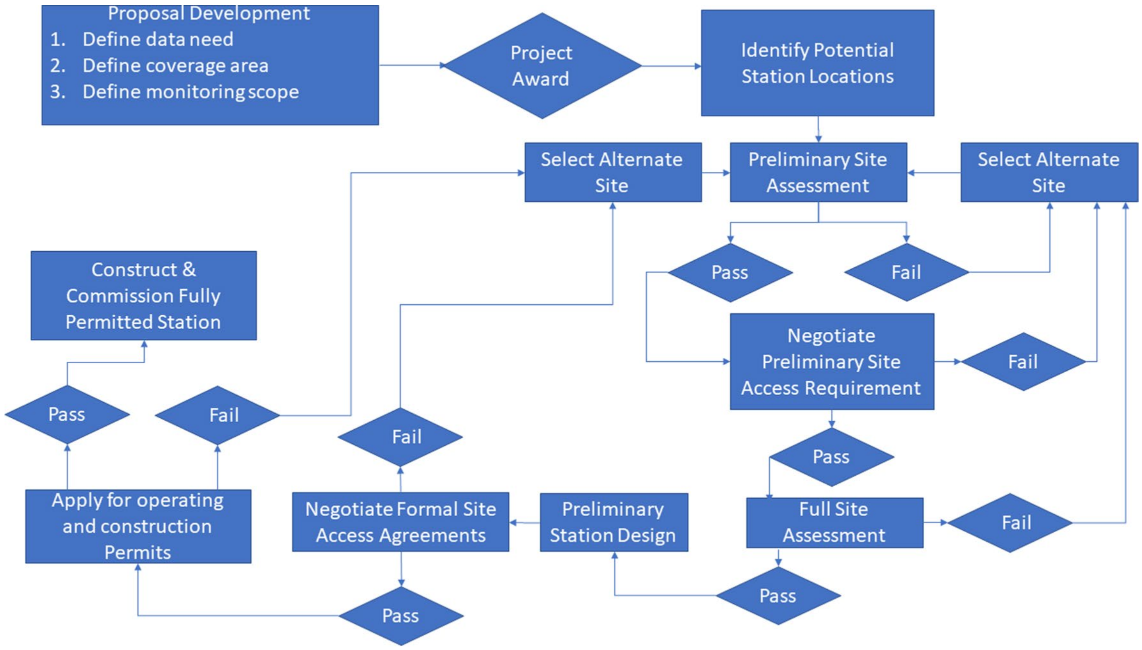

Fig. 1 HFR Network Commissioning Flow Chart

2.1 Proposal development

Preliminary network planning was generally conducted as a proposal development exercise where typical proposal sections do the following: 1) define data needs; 2) identify general observation area; and 3) define monitoring scope. For this project, the primary objective was to fill data gaps in existing coastal resiliency programs most notably: the Texas General Land Office (GLO)'s Oil Spill Response Program and the Texas Water Development Board's Coast Wide Hydrodynamic Modeling Program. Prior to the installation at Galveston Bay and Sabine Lake, existing HFR coverage along the Texas coast was limited to off-shore stations operated by Texas A&M University with data available via the Gulf of Mexico Ocean Observing System [12]. Thus, there existed a gap, identified by the Texas Water Development Board, in estuary circulation patterns to support their coastwide hydrodynamic modeling effort with TxBLEND, a two-dimensional, depth-averaged model that simulates water levels, water circulation, and salinity conditions in estuaries that is applicable to a variety of projects including freshwater inflow studies, oil spill response, storm surge modeling, salinity mitigation, and environmental impact evaluations [13]. Validation of TxBLEND hydrodynamic model output was achieved through comparisons to water velocity and surface elevation data from intensive field studies [14]. Surface currents measured with HFR is one option for obtaining required empirical derived surface current data at high spatial (e.g. 1 km grid spacing) and temporal resolutions (e.g. hourly) necessary for model calibrations and validations.

With data needs defined, it was then necessary to evaluate the proposed coverage area for HFR networks to enable the determination of equipment requirements. Coverage areas for the HFR network were estimated as a function of nominal transmission ranges of individual HFR stations, where the range of HFR coverage is inversely proportional to frequency. The targeted coverage areas of Galveston Bay and Sabine Lake have approximate dimensions of 30 km × 35 km and 10 km × 25 km, respectively. In the case of Galveston Bay, a nominal operating frequency of 25 MHz (λ= 12 m), with typical range of 30–50 km, was determined to be appropriate. For Sabine Lake, a nominal operating frequency of 42 MHz (λ= 7 m), with a typical range of 10–15 km, was selected. Frequency selection also considered anticipated wave environments of the targeted observation area. CODAR HFR systems determine surface currents from a doppler shift in echo signal from Bragg waves, where Brag waves are ocean waves with a wavelength equivalent to ½ of the wavelength of the transmitted signal. Transmit wavelengths can be calculated as in Eq. (1),

$$\lambda = c/f \tag{1}$$

where λ is the transmit wavelength in meters, f is the signal frequency (1/s), and c is the speed of light (3 × 10^8 m/s).

In comparison to Galveston Bay, the relatively shorter fetches of Sabine Lake were expected to generate waves of shorter wavelength and wave heights and thus better suited for current measurements at the shorter transmit wavelengths. Also, the use of higher frequency short range units was recommended for Sabine Lake where low specific conductance (i.e. low salinity) conditions are routinely observed. Under such conditions (i.e. low specific conductance) the range of CODAR signal is significantly reduced, as signal transmission relies on a conductive sea surface for maximum range.

Determination of total current vectors are calculated only at the intersection of 2 or more radial vectors, where radial vectors are measured from separate SeaSonde stations. To assess coverage areas, hypothetical coverage maps were generated using CODAR SeaDisplay Software as a function of possible stations locations and operating frequency. Separation distance between stations is recommended to be approximately ½ of the maximum expected range of the transmitters. For example, for 25 MHz stations, each with a nominal range of 40 km, the ideal recommended distance between stations is approximate 20 km. For Galveston Bay, with proposed 25 MHz stations located at MCPK- McCollum Park, SMPT- Smith Point, and MOLA-Moses Lake, coverage was for the highlighted area Galveston Bay, as shown in Fig. 2. The predicted coverage area includes important navigational channels including the Houston Ship Channel (HSC) and the Gulf Intracoastal Water Way (GIWW). To estimate the coverage area, an image of the coverage area (Fig. 2) was overlaid on a Google Earth Image. Using the Google Earth's polygon tool, a predicted Galveston Bay coverage area of 617 km^2 was estimated [15].

2.2 Identify potential station locations

Having a general understanding of station locations, Google Earth and Bing Maps were studied to identify potentially viable locations. For this project, publicly accessible locations such as city and county parks, federally owned properties, and county owned infrastructure were targeted. For example, a study of Google Maps was used to identify 3 potentially viable locations on Galveston and Trinity Bays, including: Moses Lake Tide Gate, Smith Point, and McCollum Park in Beach, as shown in Fig. 3. To identify relevant property owners, county CAD maps were reviewed when available. For potential locations at McCollum Park and Smith Point, review of the county CAD maps showed that both properties were owned by Chambers County [16]. Detailed property information available on the maps include parcel ID, Legal Description, Tract of Lot Block, and owner's address (Fig. 4). In some cases, ambiguity may exist regarding property owners identified

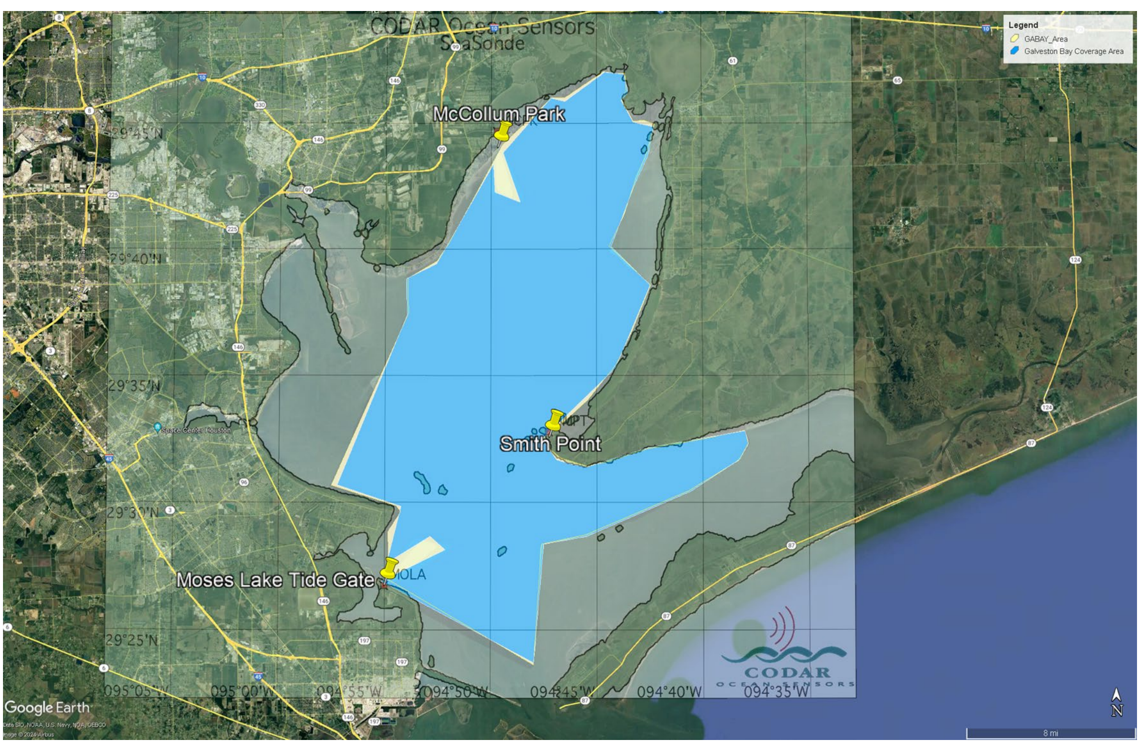

Fig. 2 Galveston Bay- predicted coverage area (blue shading) for 3 stations including locations. MCPK- McCollum Park, SMPT- Smith Point, MOLA- Moses Lake. **Coverage area of 617 km^2 estimated with** Google Earth with polygon tool [15]

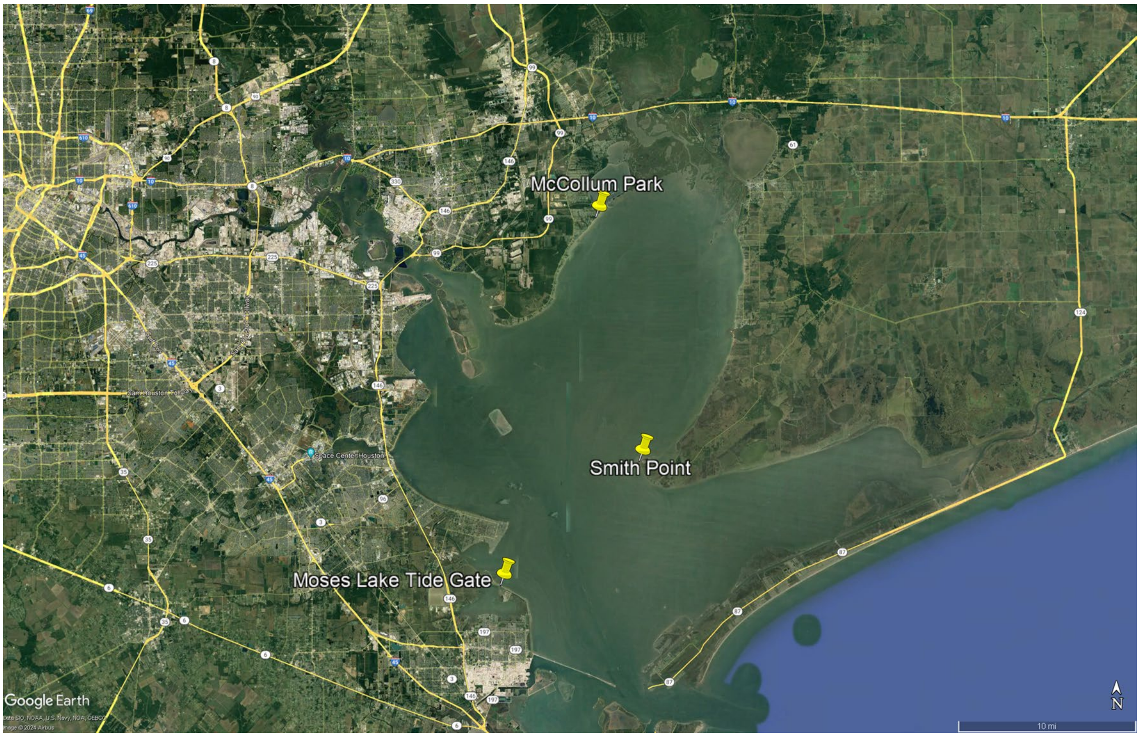

Fig. 3 Galveston Bay Station Location-Recon Planning [15]

on the County GIS portals. For example, a review of the Moses Lake Tidal Gate showed the owner of Parcel ID 140796 as a private investment company, however, the property boundary clearly passes through a publicly owned structure (i.e. tidal gate), as shown in Fig. 5. While failing to meet the preference for a publicly owned location, the ambiguity identified in the remote reconnaissance warranted further investigation and on-site investigation. Other site characteristics such as availability of power and potential deployment locations from HFR network infrastructure can be identified through inspection of aerial images provided on GIS portals and other web mapping applications.

2.3 Preliminary site assessment

Having identified probable station locations through a remote reconnaissance process, station suitability was assessed via onsite inspections. Initial on-site inspections of publicly accessible locations, conducted at will, provided important information with respect to general infrastructure design criteria, including access to power, antenna mounting locations, proximity to waterfront, identification of potential interfering infrastructure (e.g., power lines, chain link fence, outdoor lighting), and general infrastructure layout. Follow-up site inspections were conducted in the company of authorized site representatives who have intimate knowledge of each property. For example, for McCollum Park and Smith Point, arrangements were made to meet with park personnel to discuss installation plans. These meetings were critical for understanding unique characteristics including: typical location uses, locations of utilities, specific access requirements, planned construction/improvements, location vulnerability to episodic weather events. These meetings facilitated owner/agent involvement in station design and helped establish good working relationships with property agents who were indispensable in navigating the approval process.

During the formal site surveys, suggestions by property representatives were taken into consideration and proposed installation layouts were staked out. Global positioning system (GPS) positions of various station components and critical infrastructure (i.e., power) were then recorded as needed to generate station layouts. For example, during the on-site survey at Smith Point, the proposed installation area was located on shell spoils from a recent boat ramp dredging, which effectively provided desired elevation above the area's low-lying grade. Proposed locations for the antenna (Spike 1) and enclosure (Spike 2) were staked, with distances to available power pole (Electric Control Box) and Beach Marker (Fig. 6). The proposed antenna base location (Spike 1) was selected to avoid placement in a low-lying marshy area immediately to the west. The proposed enclosure locations (Spike 2) were selected to be within 61 m of the existing power

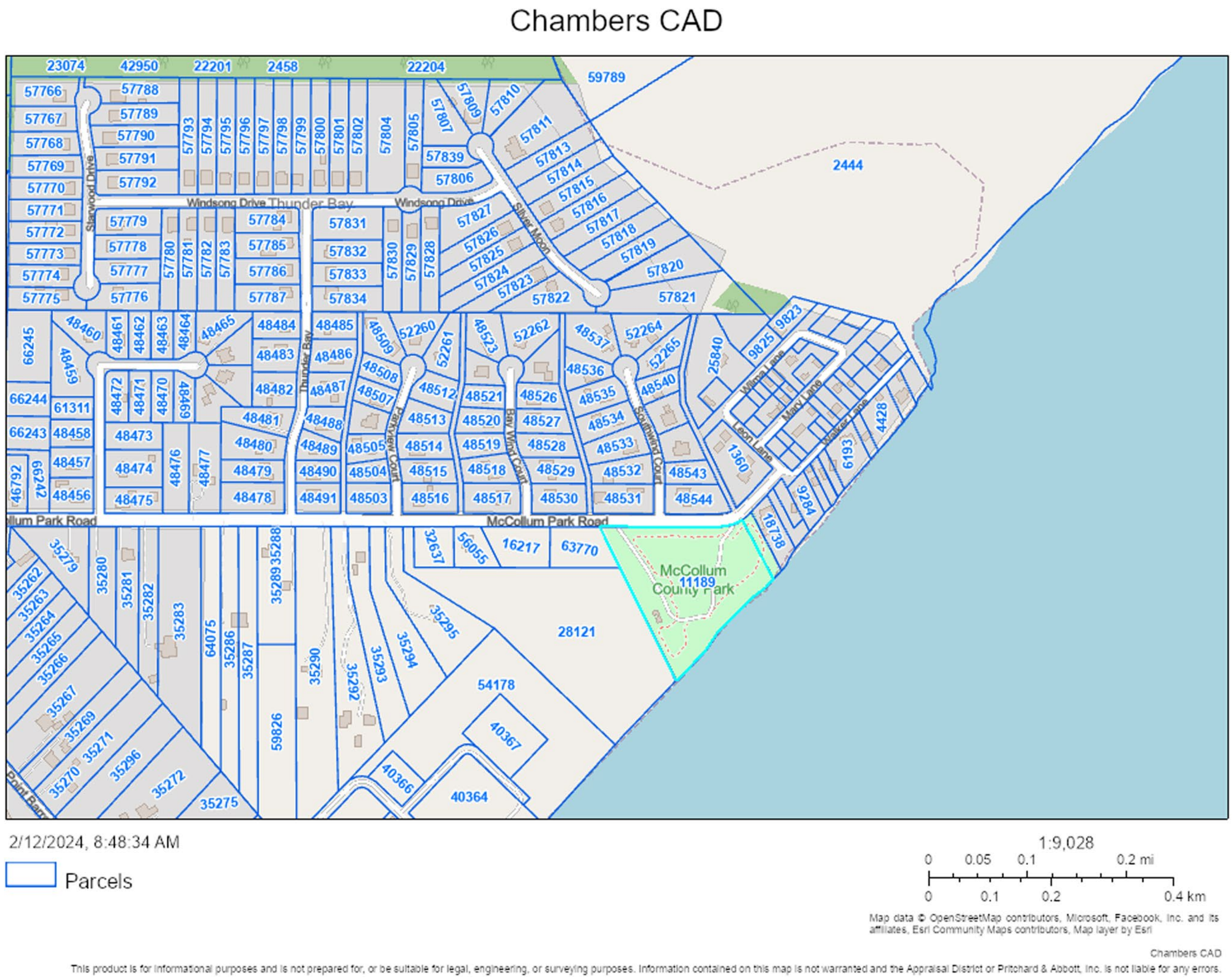

Fig. 4 Chamber County CAD Web App- results for McCollum Park [16]

transformer (Electric Control Box) and within 75 m of the proposed antenna location (Spike 1). Where the 61-m distance to the power transformer was the maximum distance for a standard electrical service order, and the 75-m represents the standard CODAR SeaSonde cable run length. Distances to the beach were shown for reference and verified that the antenna placement was within the recommended distance to the water. Other considerations in the proposed layout included: clear access to boat ramp; need to elevate enclosure to avoid flooding during coastal flood events; access to the location during coastal flood events.

Follow-up surveys may be required, especially in cases where the station installation may involve multiple entities and/or agents. For example, the proposed installation at Moses Lake Tide Gate actually involved 4 parties, including: – the performing party, Galveston County – owner operator of the Tide Gate, the US Army Corps of Engineer (USACE)—owner of storm levee, and a privately owned real-estate development company. As proposed, this installation would leverage the existing Tide Gate House (belonging to Galveston County) to house the electronics while the antenna base would be installed on privately owned property; and the coax cable would cross the USACE Levee. Following an initial site visit with Galveston County agents/engineers, a subsequent site visit was arranged with the USACE to discuss installation considerations with respect station construction impacts to levee integrity and sensitive coastal ecosystems (i.e. wetland classifications). During the on-site investigation with the USACE agents, it was determined that measures to avoid compromising the flood control levee cap would include the installation of the antenna base below the levee toe and on-grade (i.e. no trenching) installation of conduit for coax run. The USACE inspections showed the presence of wetland soils and plants. However, the proposed construction was determined to pose only de minimis wetland impacts. This experience illustrated the need to consider environmental impacts of the proposed installation in ecologically sensitive

Fig. 5 Galveston GIS Portal showing parcel at Moses Lake Tide Gate [17]

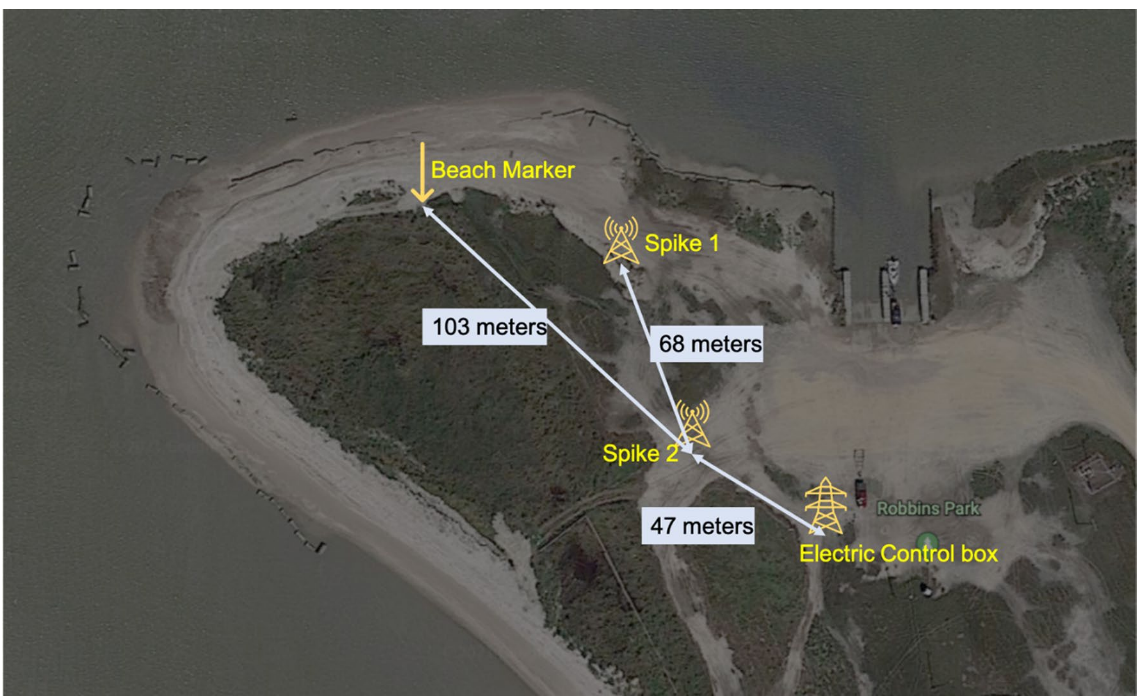

Fig. 6 Site Survey- Smith Point (Spike 1: Antenna, Spike 2: Enclosure). Base image source: Google Earth [15]

coastal zones. Follow-up surveys were further required for the originally selected Sabine Lake station, located at Pleasure Island Pier, where city planned construction activities necessitated an alternate location. These demonstrated the need for clear communication among interested parties and flexibility on the part of the performing party.

2.4 Detailed site assessment (radio frequency noise floor)

After having determined that the proposed station locations met minimum site characteristics and having made initial positive queries with respective property owners, the collection of ambient radio frequency data commenced to quantify and qualitatively assess the presence of interfering radio frequency (RF) signals at each location. CODAR recommended collection of RF spectra data for a minimum of 24 h. Data collected from these assessments were also used to properly tune Seasonde Transmitters to unused frequency bands allocated by the International Telecommunication Union (ITU) for oceanographic radars operating within the frequency range of 3–50 MHz [18].

RF spectra data was collected with a CloudSDR high performance software radio frequency receiver from RFSpace. Data collection and analysis was conducted with Spectra Vue Software (Version 3.39) through a Windows 11 computer. The CloudSDR was connected to the Windows computer via a wireless router. A Codar SeaSonde receiver antenna with single monopole fiberglass whip (-2.4 m) was connected via an RG-59 Coax to the 0.05 MHz to 50 MHz SMA connector. To enable collection of data over this time period, the use of a Recreational Vehicle (RV) equipped with a generator was employed to serve as the temporary radio station at each location, thus providing the necessary power and housing for both the technician and equipment.

Results from Galveston Bay systems indicated interference associated with the RV switching power supply that was providing power for the CloudSDR equipment. While no significant interferences were identified, some weak narrow band interference was detected at all sites where sources were determined to include outdoor lighting, brief voice signals, and other weak ambient noise signals. Although, RF noise floors were determined to be below thresholds expected to interfere with Codar SeaSonde operations, the analysis was based on limited data and was no guarantee of no interference during actual SeaSonde operation.

It was further recommended to conduct a temporary test installation with Codar Sea Sonde equipment at prospective sites for a more definitive assessment of RF interference and system range. However, such testing was not considered in project schedule and budget, and thus not performed. Considering the effort and capital cost associated with test deployments, it is suggested that test deployments be factored into project time-lines and budgets during the proposal phase.

2.5 Site access agreements

The process to secure access agreements varies with respect to applicable land-owner and or agent. In this case obtaining access agreements were required from various entities, including City and County Governments, a Federal Agency (USACE), and privately corporations, where each entity stipulated different requirements.

2.5.1 City of port Arthur memorandum of agreement

Sabine Lake station at Pleasure Pier Blvd is located on a Port Arthur City Park. Access was formally secured through a Memorandum of Understanding between the City of Port Arthur and the performing party. The first step in the MOU development process involved presenting the proposal to the City Council. This presentation was facilitated with the assistance of the City Engineer. The initial query to the City Engineer was made through the project co-PI who has previously worked with the City Engineer. Established working relationships with City Officials is not an absolute requirement, but having knowledge of city governmental operations streamlined the process.

Step 1: The City Engineer was provided with the proposal describing the project, proposed installation location, and proposed installation layout. The City Engineer provided feedback with respect to addressing any deficiencies and/or concerns with the proposal.

Step 2: The City Engineer placed the presentation and Preamble Resolution on the City Council Agenda. The presentation provided a description of the project, including project outcome and deliverables, benefits to the city, and any special request by the project sponsors. The Preamble Resolution defined the purpose of the resolution and described the relevant expectation from each party, e.g., which party will be responsible for project costs. In our case, all project costs associated with station and construction were the responsibility of the project sub-Recipient. The Pre-amble resolution included as a Resolution Line item in the Consent Agenda. A resolution authorizing the installation on city property was granted upon approval of Preamble Resolution.

Step 3: Having city council approval for the installation, a second Preamble Resolution was placed on the City Council Agenda to authorize the City of Port Arthur to enter into a Memorandum of Understanding with the project Sub-recipient. A Draft Memorandum was provided as an official Exhibit to the Preamble Resolution. Major sections (paragraphs) in the MOU included: Purpose; Collaboration; Liability Insurance Requirements; Indemnity and Hold Harmless; Non-Binding Agreement; Non-Agency Partnerships; Non-Exclusive Relationships; Publications; Compliance with Applicable Laws; Modifications; Further Agreements; No-Cost MOA; Press Releases; No Liability; and Term.

Step 4: The MOU was executed upon provision of all liability insurance documentation and signed authorization by city and performing party representatives.

2.5.2 Galveston county MOU for station at Moses Lake Tide Gate

The process for obtaining approval on county owned properties, such as installations at Moses Lake Tide Gate and Chambers County Park, was similar to that of city properties where proposed installations require Commissioner Court Approval. Likewise, the process was initiated first by contacting relevant county representatives, either the county engineer or parks director, who then assisted by placing a Preamble Resolution on their respective commissioners' court agenda. However, the antenna and associated cable installation that was on/over a U.S. Army Corps of Engineer levee was also located on property owned by 3rd party real estate investment company. Thus, the county required documentation of authorization for the proposed installation from both the USACE and the Real-Estate Investment company before their approval of the plan.

2.5.3 USACE nationwide permits

Approval by the USACE involved submission of a Nationwide Permit Pre-Construction Notification (Eng Form 6082, October 2019) [19]. In addition to applicant information and project description, the application required the following documents: the description of proposed mitigation measures (environmental); the purpose of permit activity; the quantity of wetlands, streams, or other types of waters directly affected; a list of any other applicable permits; explanation of a applicable wetland loss compensation; list of potentially affected endangered or threatened species; list of potentially affected historic properties; and if the property will occupy or use U.S. Army Corp of Engineers. Required exhibits in the application package included installation plan, plan and cross section drawings for excavation, excavation volume calculations, and discharge calculations. Although, the proposed activities involved no direct discharges to waters of the U.S., our on-grade coax installation was to be capped with top-soil which represented a potential discharge to the U.S. water, and thus we were required to calculate the volume of the top-soil applied as the cap. It was determined through the review and inspection of the USACE, that entire area was classified as a wetland.

2.5.4 USACE 408 real-estate permit

The US Army Corps of Engineers Section program regulates activities such by other parties to alter USACE Civil Works Projects to verify that changes to authorized USACE Civil Works projects are not injurious to public interest and will not impair usefulness of the project [20]. As our project involved installation of antenna footer and coax on/over a USACE Flood Control Levee, a Sect. 408 Application (SWG-OD-408-APP) was required. Upon an initial review of our permit application, a letter acknowledging receipt of application along with wire transfer payment instructions for fees to cover the evaluation process. It is important to note that payment of the administrative fees did not assure ultimate approval of the request. In an effort to have the significant administrative fees waived, requests were placed with our USACE collaborators who had previously provided a letter of support for this project with consideration of the public benefit to be provided by the project. With the support of our USACE District Engineer, the administrative fees were waived. Such benefits illustrate the value represented by supporting agencies and project stakeholders. Although the permit requirement was waived in our case, any proposed activity on Civil Works properties should consider the potential permitting costs.

2.5.5 Private landowner permission

As the antenna base and conduit would be installed on and over property owned by a private real estate corporation, it was necessary to document property owner permission in form of a letter of "no-objection." Prior to providing the letter of "no-objection" the owner expressed concerns about health risks associated with the continuous transmission of

Electro-Magnetic Field energy from the CODAR system. To address the owner's concern a Risk Assessment was performed based on the FCC Limits for Maximum Permissible Exposure Limits for Occupational/Controlled and General Population/Uncontrolled exposures [21] with a comparison of SeaSonde EMF exposure to exposure associate with cell phone use [22]

2.6 Operating and construction permits

2.6.1 FCC licensing

In the United States, the Federal Communications Commission (FCC) is responsible for licensing the electromagnetic spectrum for and by commercial and non-commercial users. FCC issuance of a Radio Station Authorization is required to legally transmit radio signals. Registration with the FCC's Commission Registration System (CORES) is prerequisite to submitting license applications [23]. Licenses can then be electronically filed through the FCC Universal Licensing System [24]. Information requested on the application includes, but not limited to: Applicant Information, Contact Information; Regulatory Status; Type of Radio Service; Basic Qualification; Transmitting Location and Elevation above ground; Description of Activity and Application; Transmission Frequency and Power; and Applicable Fees. Once submitted the licensing process commences with an administrative review followed by various technical reviews to confirm that requested licenses pose no interference with existing licensed operations or other critical radio frequency transmissions. Separate licenses applications were submitted for the Galveston Bay stations (25 MHz) and Sabine Lake stations (42 MHz). Licenses with unique Call Signs were granted approximately 8 weeks after applications were submitted.

2.6.2 Power (on-grid)

Access to power is among the most critical station design criterium for continuous real time monitoring networks. For the SeaSonde station, it was estimated that power consumption was on the order of 500W-continuous (12kW-hours/day) to support the CODAR equipment and ancillary equipment (i.e. central processing computer, climate control, data communication). Where and when available, power was provided by the landowner free of charge as part of the respective MOU (e.g. Chambers County McCollum Park and Moses Lake). When and where required, the process to obtain new electric service varied with the county and local power provider. In Chambers County, the responsible party, was required to first obtain a permit for new service before ordering new service from the provider. In the City of Port Arthur, customers were required contract with an approved electrical contractor, who was responsible for obtaining the permit and filing application to power provider for new service. Once new service permits were executed and new service ordered, meter poles were installed by the electrical contractors prior to connection to by power provider. It is important to note that the cost associated with new power service can vary significant with respect to the distance from existing power line and whether or not the new service requires buried or overhead power lines. In our case, cost of new service order varied between $0 for a standard overhead connection to ~ $12,000 for a buried service connection that required a directional bore in excess of 60 m.

Remote off-grid power, in the form of solar-array, was selected to provide power to the Sabine Lake Station on the USACE Dredging Material Placement Levee. Through a power analysis, it was determined that sufficient funds were available to install an off-grid system capable of maintaining continuous station operations (~ 90% up-time), with brief power outages occurring during winter months when low solar charging conditions existed. Although no permits were required for the solar array installation in our remote stand-alone application, it is advisable to verify applicability of local codes.

3 Results and discussion

The described process resulted in the successful commissioning of five SeaSonde stations on Galveston Bay and Sabine Lake in December 2023 and February 2024, respectively. In March 2023, radial data from all five stations were included in real-time vector (RTV) processing through a cooperative agreement with the Gulf Coast Observing System (GCOOS) with data being served to the public via the U.S. Integrated Ocean Observing System (IOOS). Data provided through the HFRnet diagnostics [25] (Fig. 7) provides information including station metadata and performance information for each HFR station including but not limited to: station name, latitude, longitude, center operating frequency; transmit power; system operating temperature; most recent radial file; time of most recent file; range; number of radial velocity solutions, and data base latency.

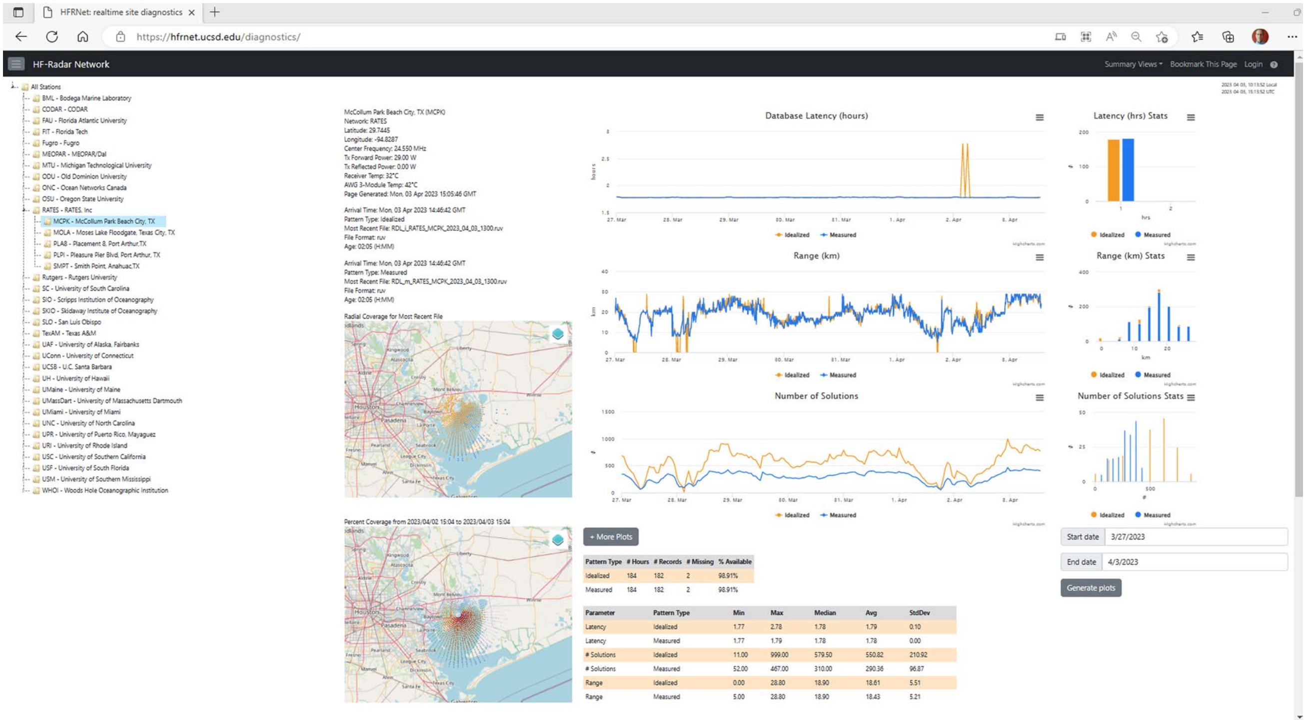

Fig. 7 HFRnet diagnostics page for McCollum Park [25]

Near real time data is provided through the NOAA HF Radar National Server [26] where Real Time Vector (RTV) data is displayed as total vector maps (Fig. 8) for the most recent total vector files generated from at least two (2) radial files. Total vector maps allow users to select either 25- hour average or hourly vectors obtained for the previous 25-h. Selection of

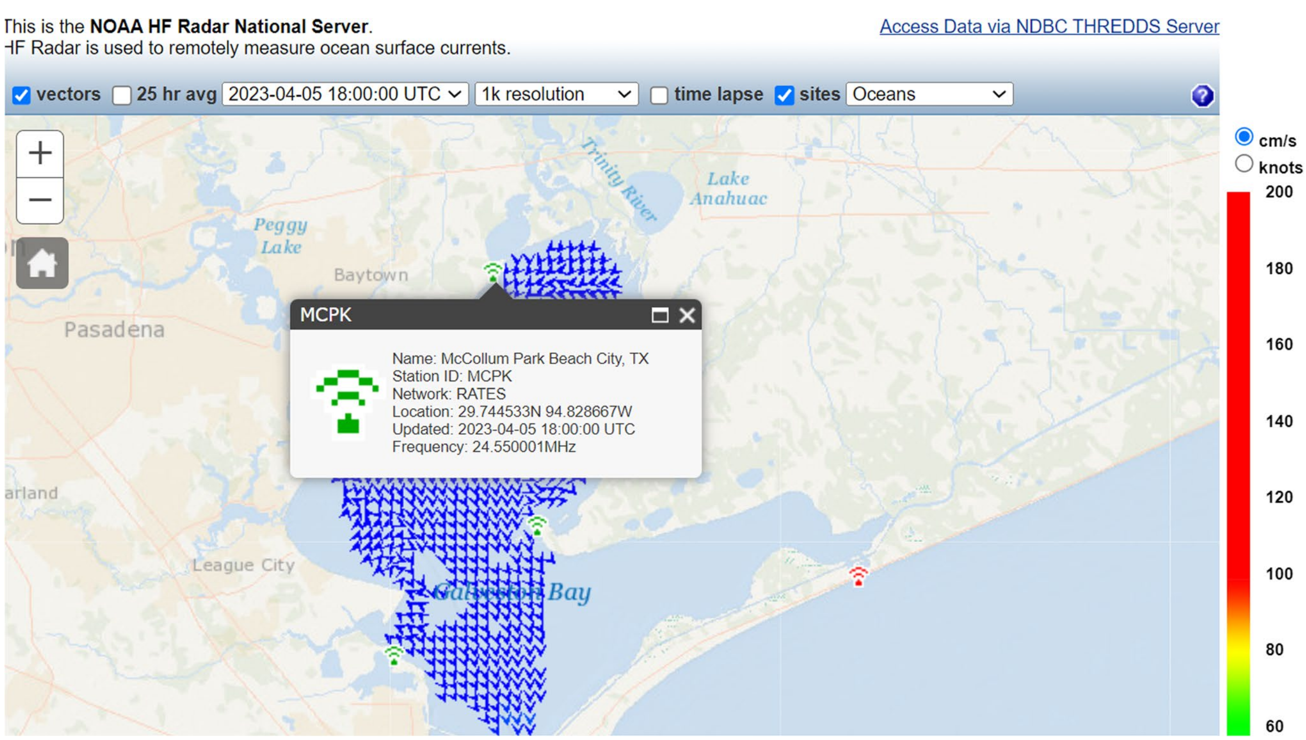

Fig. 8 Site specific information window for McCollum Park-Galveston Bay [26]

"site" allows users to view the stations location. Selecting a single station icon, results in summary window summarizing station Name, ID, Network Operator, Location, Date of Most Recent File, and Operating Frequency Data age, in hours, for selected stations is also illustrated through color-coded station icons. Total Vector Data for the previous 48- hours can also be viewed and downloaded in tabular form https://hfradar.ndbc.noaa.gov/tab.php. Archived data from all HF Radar Stations served by HFRnet be accessed via the https://www.ncei.noaa.gov/data/oceans/ndbc/hfradar/rtv/ as netCDF files.

Total current vector data from both Galveston Bay and Sabine Lake networks were applied to validate SCHISM modeled surface currents [27]. SCHISM models were developed with input parameters for April 2023 including pertinent hydrodynamic variables and a computational grid that delineated the Texas Coast. Current vectors for specific locations and times were extracted from coast wide SCHISM simulations. Model simulated current vectors were then compared to corresponding (with respect to time and space) Real Time Vectors [28] derived from the Galveston Bay and Sabine Lake HFR networks. It was observed that days characterized by predominant northward currents exhibited significant correlation coefficients exclusively in the northward direction in both the bay and lake. Similarly, days dominated by eastward currents, correlation coefficients for simulated and measured currents were significant only in the eastward direction for either the bay or lake. Notably, the SCHISM model and HF radar measurements effectively captured trends and magnitudes of surface currents on days with both eastward and northward currents.

4 Conclusions

HFR is a land-based remote sensing technology that provides valuable data with many coastal resiliency applications. Over a 36-month project period, a series of HFR networks were put into operation two estuaries in Texas, USA, providing valuable surface current data to address data gaps in Texas' coastal hydrodynamic modeling program. Data obtained from these new HFR networks were applied to validate currents derived from SCHISM model simulations.

The commissioning process required solutions to administrative and technical challenges that were reflected in the as built network design. Network design involved use of an assortment of publicly accessible GIS tools that aided site selection and identification of agents authorized to grant permits and licenses for station installation. Direct and close collaboration with identified authorized agents played a large role in project success as exemplified by USACE waiver of Section 408 construction permit fees. The effort and time involved to obtain authorization from all parties represented a significant fraction of the project budget. Perhaps more importantly, the permitting process spanned a period of ~ 24 months of 36-month project period, thus permitting process can be considered a rate limiting step. Permitting delays were due a myriad of factors, for example- scheduling meetings with authorized agents, city council and commissioners court agenda, changes in design due to changing priorities of the agents, and addressing environmental impact concerns. Solutions to these delays required some flexibility and ingenuity by the project partners to address technical issues as they arose.

A common issue among built environmental observatories is a lack of sustained funding necessary to continue operations as necessary to achieve intended project benefits. Efforts to secure such funding should include engagement activities to enable an exchange of project benefits and application and stakeholder needs. Further, the scope of data products and application should be expanded to the full extent possible. For example, HFR has built in applications to characterize wave environments that can be useful from the perspective coastal engineering and maritime safety objectives. Inclusion of the extended data, with little or no increase in overhead cost directly lower the unit data costs, thereby effectively meeting data needs of the larger customer base.

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Author contributions C.F., X.W., and L.H. drafted main manuscript. M.S. draft text related to power (Sect. 2.6.2) and prepared figures through out the manuscript. C.O. and R.F. drafted text regarding application of HF Radar data to hydrodynamic model validation in Sect. 3—Results. All authors reviewed relevant sections of the manuscript.

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Data availability HFR data can be accessed via IOOS at https://hfrnet.ucsd.edu/ and NOAA at https://hfradar.ndbc.noaa.gov/

Declarations

Competing interests The authors declare no competing interests.

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