International Radiowave Oceanography Workshop (ROW2024)

University of Plymouth Marine Station, Plymouth, United Kingdom

3-5 September 2024

Workshop Programme and Book of Abstracts

UNIVERSITY OF PLYMOUTH

Index

Thank You to the Sponsors

CODAR Ocean Sensors

Oceanographic High Frequency Radar Systems, the global leader in high frequency (HF) radar systems for ocean surface current and wave monitoring. The world's experts in HF radar theory and system design, including all hardware and software. Providing product research, design, manufacturing and support.

Helzel Messtechnik GmbH

Our OTHR and WERA HF radar systems are highly flexible, modular and can be optimised according to your specific requirements. We offer compact and array type antenna systems, multi-frequency and active antennas to reduce the visual impact. We provide surface currents, mapping of wave parameters and wind direction, tsunami detection and vessel surveillance with the highest temporal resolution in the market.

qualitas remos

Qualitas remos creates solutions that integrate data, technology and artificial intelligence for an enhanced maritime intelligence and a smarter coastal space management. Monitoring the surface currents, waves and sea state around our coasts with SeaSonde HF radar stations that integrate cameras make the solutions we deliver unique to achieve safe and efficient marine services in search and rescue, navigation, pollution response, coastal infrastructure operation, storm surge and tsunami early warning and also to improve our knowledge and understanding of the ocean climate both at the time of extreme events and its long term change. Further information at www.qualitasinstruments.com , www.codar.com and www.qaisc.com .

Workshop Venue: University of Plymouth Marine Station

Dedicated to teaching and research, the Marine Station serves all our marine-based courses including civil engineering, earth sciences and marine biology.

Situated on the shores of Plymouth Sound as part of our 'Waterfront Campus', the facility offers labs and classrooms extending out into the natural environment. It is the base for our research vessels and a centre of excellence for diving that enables you to get professional diving qualifications and develop valuable industry-relevant skills.

Please click here to watch a short video about the Marine Station

The Marine Station is located in Queen Anne's Battery, on the shores of Plymouth Sound. View our Plymouth City map to see our waterfront location.

Plan your visit with maps and information on travel, journey times and parking.

Address
University of Plymouth Marine Station
Artillery Place
Plymouth
Devon
PL4 0LU

Oral and Poster Presentation Instructions

Oral presentations should be 15 minutes with an additional 5 minutes for questions. For delegates submitting a poster, please ensure it is in A0 portrait format. Poster boards and fixings will be provided.

Please bring your oral presentation with you on a USB stick in either a .ppt or .pdf format. The Marine Station is equipped with full AV/IT.

Workshop Programme

Tuesday 3 September – University of Plymouth Marine Station				
09:00 – 12:00	EuroGOOS HF Radar Task Team in-person progress meeting			
12:00 – 13:00	Registration, Lunch and Welcome			
13:00 – 13:20	ROW2024 Welcome			
Session 1: Currents I – Session Chairs, Prof Jeffrey Paduan and Thanh Huyen Tran				
13:20	Prof Jeffrey Paduan	Adjunct Professor of Ocean Sciences	University of California Santa Cruz	A decade of surface current mapping along the U.S. West Coast: What does it say about vertical circulation magnitudes, distributions, and forcing?
13:40	Thanh Huyen Tran	Oceanographer	Helzel Messtechnik GmbH	Small-scale eddies detected by VHF radar in the Western Scheldt estuary, The Netherlands
14:00	Dr Charles-Antoine Guerin	Professor	University of Toulon	High-Frequency Radar observation of strong and contrasted currents: the Alderney race paradigm
14:20	Dr Abïgaëlle Dussol	Executive Director	Arctus Inc.	Stokes Drift Mapping Using a Single High-Frequency Radar
14:40	Dr Lucía Quirós-Collazos	Research Engineer	Institute of Marine Sciences (ICM-CSIC) & ICATMAR	Characterisation of the turbulent properties of surface velocities in the North-Western Mediterranean Sea: analysis of the first year of measurements
15:00-15:20	Coffee Break and Poster Viewing			

Session 2: Currents II – Session Chairs, Dr Anna Rubio and Thanh Huyen Tran				
15:20	Tran Thanh Huyen	PhD Student	Université du Littoral Côte d'Opale	Coastal circulation along the middle-southern coasts of Vietnam characterized by HF radar and modelling
15:40	Dr Guiomar López	Scientist of HF Radar Facility	SOCIB	An evaluation of gap-filling methodologies for HF radar
16:00	Sloane Bertin	PhD Candidate	LOG (Wimereux, France) - AZTI (Pasaia, Spain)	Identifying coastal Current Convergence Structures in the southeastern Bay of Biscay by a combination of HF radar and Lagrangian measurements of surface current velocities: application to Floating Marine Litter.
16:20	Dr Anna Rubio	Principal Researcher, Head of the Operational Oceanography group	AZTI	Combining HF radar and glider data to study physical-biogeochemical coupling in the SE Bay of Biscay
16:40	Prof Hwa Chen	Director of Advanced Research Center for Earth Sciences	National Central University, Taiwan	First Observation of Tsunami- Kuroshio-Tide Interaction by Taiwan High-Frequency Radar Network
17:00 – 17:20	Currents Discussion			
17.20	Icebreaker Reception at the Marine Station			

Wednesday 4 September – University of Plymouth Marine Station				
Session 3: Radar Developments - Session Chairs, Prof Lucy Wyatt and Liang Yu				
09:00	Dr Brian Emery	Associate Researcher	University of California	Estimating Scattering Patch Area for a Direction Finding HF Radar
09:20	Dr Anthony Kirincich	Senior Scientist	Woods Hole Oceanographic Institution	Revisiting HF ground wave propagation losses over the ocean: a comparison of long term observations and models
09:40	Liang Yu, Prof Xiongbin Wu,Xiaoyan Li,Prof Lan Zhang	Wuhan University, Hubei Province,China	Wuhan University	A MIMO-Based Dual-Frequency High-Frequency Surface Wave Radar System
10:00	Prof Weimin Huang	Professor	Memorial University	Target Joint Detection and Tracking Using Reinforcement Learning for Compact HFSWR
10:20-10:40	Coffee Break			
10:40	Dr Dale Trockel	Data Scientist	CODAR Ocean Sensors Ltd.	Innovativer Tools For HF Radar Challenges
11:00	Prof Pierre Flament	Professor	University of Hawaii at Manoa	The Generic High Frequency Doppler Radar: progress report and recent developments
11:20	Prof Eric W. Gill	Professor Emeritus	Memorial University of Newfoundland	Recent Developments in HF Radar at Memorial University's Radar Remote Sensing Laboratory

Session 4: Wind, Waves – Session Chairs, Dr Guiomar Lopez and Maria Fernandes				
11:40	Xiaoyan Li, Prof Xiongbin Wu, Liang Yu, Prof Xianchang Yue	Wuhan University, Hubei Province, China	Wuhan University	Experiment Verification of Ocean Surface Wind Fields Using MIMO HFSWR
12:00	Prof Cedric Chavanne	Professor	ISMER-UQAR	Estimation of the wind field with a single high frequency radar
12:10	Prof Lucy Wyatt	Technical Director	Seaview Sensing Ltd	Seaview Sensing recent software developments
12:30:13:30	Lunch Break and Poster Viewing			
13:30	Dr Charles-Antoine GUERIN	Professor	University of Toulon	Recent progresses in HF radar estimation of ocean wave parameters and application to the Toulon site
13:50	Dr Maria Fernandes	R&D Scientist	Qualitas Instruments	Recent developments on SeaSonde wave measurement
14:10	Prof Reza Shahidi	Assistant Professor	Memorial University of Newfoundland	Rank filtering for significant wave height estimation from HF radar data
14:30:14:50	Wind and Wave Discussion			
14:50-15:10	Coffee Break and Poster Viewing			
Session 5: Networks and Applications – Session Chairs, Prof Daniel Conley and Emanuele Ingrassia				
15:10	(1) Yi-Chieh Lu, (2) Jian-Wu Lai, (3) Prof Laurence Zsu-Hsin Chuang	(1) PhD Student, (2) Research Fellow, (3) Prof	National Academy of Marine Research	Machine Learning-Based Short-Term Forecasts through High-Frequency Radar Ocean Current Maps to Enhance Maritime Emergency Response
15:30	Dr Fulvio Capodici	Researcher	UNIVERSITA' DEGLI STUDI DI PALERMO	Radar Hf installation along the Italian coasts in the PNRR MER project framework
15:50	Giuseppe Ciraolo	Professor	University of Palermo	The CALYPSO HF network in the Sicily-Malta channel: past activities and future perspectives

16:10	Dr Jian-Wu Lai	Research Fellow	National Academy of Marine Research, Taiwan	Integration of Ocean Radar Observation Networks: Operational Considerations and Insights
16:30	Lorenzo Corgnati	Research Engineer	CNR-ISMAR	The European HFR Node: High Frequency data from providers to users
16:50	Thomas Helzel	Shareholder	HELZEL Messtechnik GmbH	WERA for dual-use applications to protect off-shore infrastructure
19:00 – 22:00	Workshop Dinner at The Boathouse Bar and Restaurant at Plymouth Barbican			

Thursday 5 September – University of Plymouth Marine Station	
Workshops and Fieldtrips	
09:00 – 12:00	Innovations and recent advances around SeaSonde HF radar side event
09:00 – 12:00	New features of WERA systems and discussion with users about experience
12:00 – 18.30	Field trip to Over the Horizon Radar (OTHR) site at Perranporth (depart from University of Plymouth Marine Station)

Optional Side Events

All side events are optional and free to attend. All take place at the University of Plymouth Marine Station.

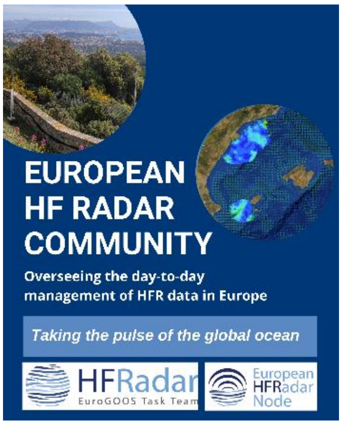
EuroGOOS HF Radar Task Team In-Person Progress Meeting

Tuesday 3 September, 0900 – 1200, University of Plymouth Marine Station

Join the EuroGOOS HF Radar Task Team in-person progress meeting!

We will review the status of work lines and draw together the Implementation Plan for 2024–26. The EuroGOOS HFR Task Team helps coordinate the European activities around the development and use of coastal HF radars.

This meeting is open to all, members of the task team and radar experts wanting to know more.



Innovations and Recent Advances around SeaSonde HF Radar

Thursday 5 September, 0900 – 1200, University of Plymouth Marine Station

Join CODAR and QUALITAS staff and fellow SeaSonde users to discuss the latest software and hardware features, ongoing areas of research and topics important to both new and experienced operators. Topics include Radial Suite Release 23 and new features like the faster, more compact current processing app, new wave settings, quality control and metadata; AIS Pattern Suite Release 22 including improved reports, routine pattern performance and change monitoring and evaluation; an update on the Long Range 5MHz Combined T/R antenna from the most recent install in the Florida Keys; and presentation of The PORTUS Marine Information System 3.0., a completely redesigned state-of-the-art, multi-user, web-based Marine Information System that boosts visibility and value of your oceanographic and meteorological data with a special focus on SeaSonde HF radar surface currents and wave data.

New Features of WERA Systems and Discussion with Users about Experience

Thursday 5 September, 0900 – 1200, University of Plymouth Marine Station

The new features of the WERA systems are introduced in detail, such as;

1. dual frequency operation
2. new antenna systems
3. a simple user interface for pilots
4. software tools for site planning and system monitoring.

With the WERA users we will talk about their experience and discuss new ideas for further improvements and new applications.

Optional Field Trip to Dual-Frequency HF Radar Site

Thursday 5 September, depart University of Plymouth Marine Station at 1230, return to Plymouth by 1830. Transport will be provided from the Marine Station.

There is an opportunity to take part in a field visit to the University of Plymouth operated Perranporth site, which has been recently upgraded to simultaneously operate two HF radars: a long range Over the Horizon Radar (OTHR) and a medium range WERA system.

Workshop Dinner at The Boathouse Restaurant and Bar

Wednesday 4 September, 1900 – 2200

Please join us the workshop dinner at The Boathouse, a waterfront restaurant and bar specialising in seafood caught by their own boats, and is the perfect spot for laid back breakfasts, cosy coffees, delicious dining or simply drinks at the bar with friends.

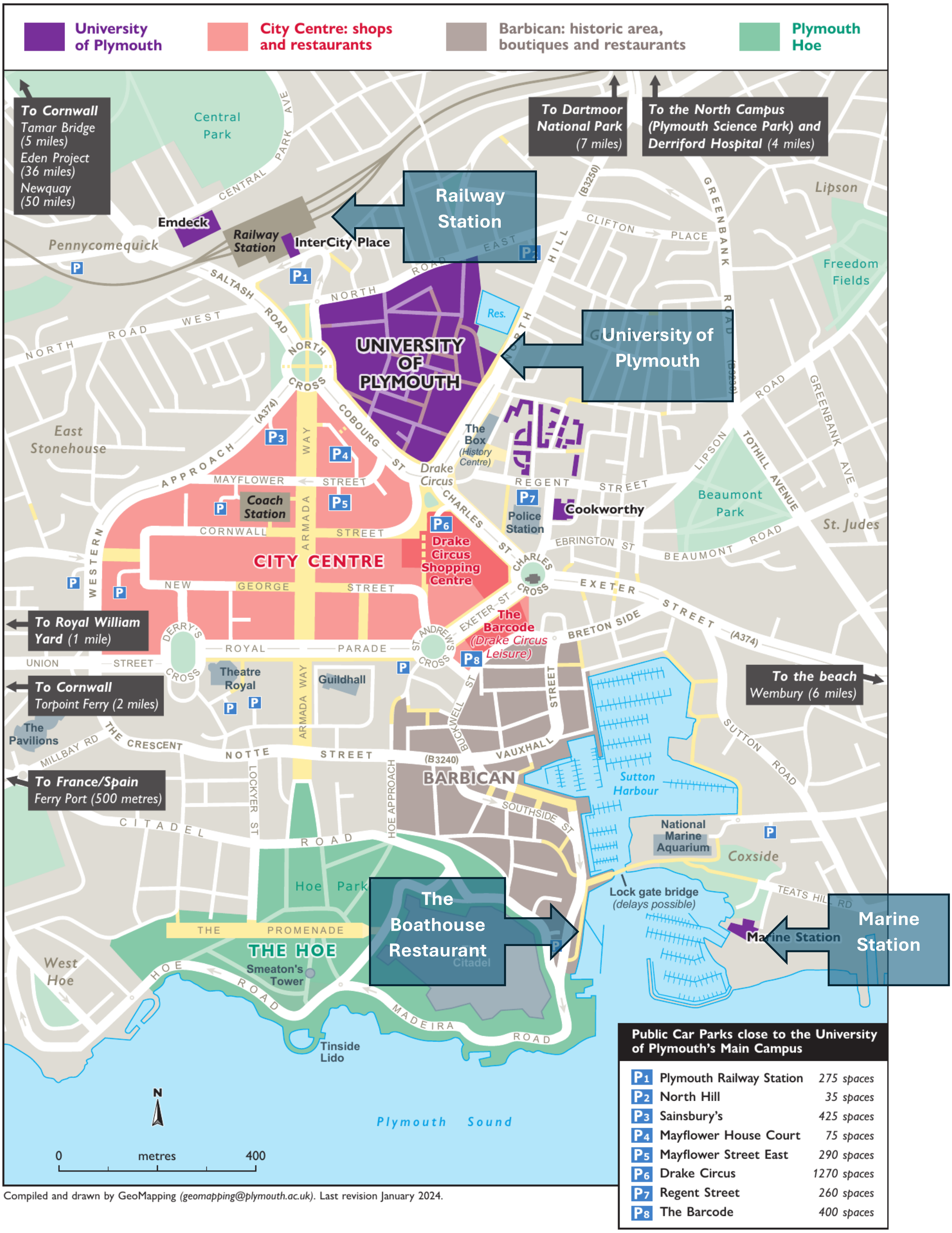
A retractable roof for sunnier days means you can dine al fresco while enjoying the wonderful, waterfront views. The restaurant is situated overlooking the famous Mayflower Steps, just a stone's throw from Plymouth's historic Barbican and in close proximity to the workshop venue. This is included within the conference fee.

https://www.theboathouseplymouth.co.uk/

Location of the Boathouse Restaurant

2-4 Commercial Wharf, Madeira Road, Plymouth, PL1 2NX

Map Showing the Location of the Marine Station and The Boathouse Restaurant



Compiled and drawn by GeoMapping (*geomapping@plymouth.ac.uk*). Last revision January 2024.

Book of Abstracts

Presenter Index in Alphabetical Order by Surname

Oral Presentations (in Alphabetical Order by Surname)

1. Identifying Coastal Current Convergence Structures in the Southeastern Bay of Biscay by a Combination of HF radar and Lagrangian Measurements of Surface Current Velocities: Application to Floating Marine Litter

Sloane Bertin

PhD Candidate, LOG (Wimereux, France) - AZTI (Pasaia, Spain)

The southeastern Bay of Biscay (SE BoB) has been identified as an accumulation zone for Floating Marine Litter (FML). Coastal Current Convergence Structures (CCS), associated with vertical motions at river plume edges or estuarine fronts can be at the origin of the aggregation of FML, often accumulating along small-scale filament-like streaks. Enhancing our understanding of small-scale processes behind these aggregations is essential to better quantify and to help mitigate this type of pollution. To that end, an optimization method was developed and applied on High-Frequency (HF) radar surface velocity measurements, using the data from in-situ surveys involving the deployment of Lagrangian drifters within the HF radar footprint. Surface current maps with enhanced resolution were obtained using the variational interpolation (2dVar) of HF radar measurements. Then, surface current fields and drifter velocities were optimally interpolated in space and time. Adopting a Lagrangian point of view, Finite Size Lyapunov Exponents (FSLE) and Finite-Domain Lagrangian Divergence (FDLD) were used to identify Lagrangian Coherent Structures in the study area, proxy of CCS likely to accumulate FML. FSLE and FDLD maps were computed for both the initial and optimized 2dVar solution and compared to other available surface current fields in the area (Open Mode Analysis of the HF radar surface current fields, and 3-dimensional model outputs). The findings demonstrate that combining Lagrangian observations with HF radar data results in a substantial enhancement of velocity reconstruction for both survey periods, leading to a more accurate representation of the location of CCS in the SE BoB.

2. Radar HF Installation along the Italian Coasts in the PNRR MER Project Framework

Dr Fulvio Capodici

Researcher, UNIVERSITA' DEGLI STUDI DI PALERMO

Orasi A., Capodici F., Taddei S., Ciraolo G., Zambianchi E., Brandini C., Bianco A., Nardone G., Giorgi G.

The PNRR MER (Marine Ecosystem Restoration) project is the largest marine project of the Italian National Recovery and Resilience Plan and ISPRA is the implementing institute. MER project includes measures to restore and protect the seabed and marine habitats, to strengthen the national system for monitoring marine and coastal ecosystems and to map coastal and marine habitats in Italian waters. Among the many activities included in the project are the installation of 13 new high-frequency radars and the maintenance of eight existing radars, managed by the LaMMA consortium, the University of Palermo and the University of Parthenope, in the areas of Tuscany/Tuscan Archipelago, Lazio/Campania and Sicily, in order to improve the study of the physical and biogeochemical characteristics of the areas under investigation, covering a total sea area of approximately 9800 km2. The extension of the HF radar network along the Italian coasts will provide observations of surface currents and waves, essential for a better understanding of the ecosystem and the connectivity of marine protected areas, the development and refinement of circulation models, the planning and management of coastal strips, the development of forecasting and monitoring tools for the management of maritime accidents and search and rescue operations, navigation and effective intervention in the event of pollution at sea.

3. Estimation of the Wind Field with a Single High Frequency Radar

Prof Cedric Chavanne

ISMER-UQAR

Over several decades, High-Frequency (HF) radars have been employed for remotely measuring various ocean surface parameters, encompassing surface currents, waves, and winds. Wind direction and speed are usually estimated from both first-order and second-order Bragg-resonant scatter from two or more HF radars monitoring the same area of the ocean surface. This limits the observational domain to the common area where second-order scatter is available from at least two radars. Here, we propose to estimate wind direction and speed from the first-order scatter of a single HF radar, yielding the same spatial coverage as for surface radial currents. Wind direction is estimated using the ratio of the positive and negative first-order Bragg peaks intensity, with a new simple algorithm to remove the left/right directional ambiguity from a single HF radar. Wind speed is estimated from wind direction and de-tided surface radial currents using an artificial neural network which has been trained with in-situ wind speed observations. Radar-derived wind estimations are compared with in-situ observations in the Lower Saint-Lawrence Estuary (Quebec, Canada). The correlation coefficients between radar-estimated and in-situ wind directions range from 0.84 to 0.95 for Wellen Radars (WERA) and from 0.79 to 0.97 for Coastal Ocean Dynamics Applications Radars (CODAR), while the root mean square differences range from 8 ∘ to 12 ∘ for WERAs and from 10 ∘ to 19 ∘ for CODARs. Correlation coefficients between the radar-estimated and the in-situ wind speeds range from 0.89 to 0.93 for WERAs and from 0.81 to 0.93 for CODARs, while the root mean square differences range from 1.3 m/s to 2.3 m/s for WERAs and from 1.6 m/s to 3.9 m/s for CODARs.

4. First Observation of Tsunami- Kuroshio-Tide Interaction by Taiwan High-Frequency Radar Network

Prof Hwa Chien

Director of Advanced Research Center for Earth Sciences, National Central University, Taiwan

On April 3, 2024, the Taiwan High-Frequency Radar (HFR) Network detected tsunami-induced currents resulting from a magnitude 7.2 earthquake near Hualien, Taiwan. The earthquake triggered tsunamis that caused strong currents, leading to collisions between drifting vessels in two harbors on Taiwan's east coast. At Hualien harbor, the tsunami waves reached a height of 1.8 meters. These near-field tsunami waves rapidly traveled along the eastern coasts of Taiwan and even reached the southern Okinawa, Japan. Findings reveal that the radial current induced by the tsunami can reach up to 0.4 m/s with a dominant fluctuation period of 20 minutes. Interactions between the Kuroshio and coastal currents in Yilan Bay, northeastern Taiwan, are likely to amplify the observed tsunami current during ebb tide. Understanding these dynamics is crucial for developing an integrated early warning system that utilizes real-time HFR monitoring and a tsunami forecasting model. Since 2019, 19 HFR stations have been deployed in the coastal region around Taiwan. These stations are capable of detecting surface currents in water depths up to 100 meters with a minimum velocity limit of 0.02 m/s. This study underscores that such a remote sensing system can provide valuable insights into tsunami-induced hazard risks in coastal environments.

5. The CALYPSO HF Network in the Sicily-Malta Channel: Past Activities and Future Perspectives

Prof Giuseppe Ciraolo

University of Palermo

Aronica S.1, Azzopardi J.2, Borzì M.3, Campanella S.4, Cannata A.3, Cannavò F.5, Capodici F.6, Ciraolo G.6, Corbari L.6, Cosoli S.7, D'Amico S.2, Deponte D.8, Drago A.9, Fontana I.1, Gauci A.2, Giacalone G.1, Ingrassia E.6, Lombardo D.8, Lo Re C.10, Maltese A.6, Nasello C.6, Orasi A.10, Paradiso E.5, Ruvolo V.4, Sinatra R.3, Ursella L.8, Zammit A.2

1.CNR-IAS (Italy), 2.UM (Malta), 3. UNICT (Italy), 4 ARPA-Sicilia (Italy), 5. INGV (Italy), 6.UNIPA (Italy), 7 UWA (Australia), 8. OGS (Italy), 9 MCAST (Malta), 10.ISPRA (Italy)

The Mediterranean Sea is a crucial hotspot of biodiversity with a high level of vulnerability, and is constantly under ecological pressure due to human socio-economic development. In the framework of the Italy-Malta INTERREG Programmes (2007-2013 and 2014-2020), an High Frequency Radar (HFR) network was deployed in the Sicily Channel in 2012 to measure the sea variables between Sicily and the Maltese islands and is being further expanded under the ongoing PNRR MER - Marine Ecosystem Restoration project. This network provides real-time observations of surface currents and waves to address transboundary challenges resulting in safer marine transportation, protection of human lives at sea, and safeguarding coastal resources from pollution incidents and wave storms. Since its deployment, the radar network has rapidly expanded from the initial two stations deployed in the Maltese archipelago to the current total of nine HFR stations (four in Malta and five in Sicily). In addition to infrastructure development, the research group developed services based on models, HFR data, and other sources (e.g., in-situ buoys, microseism, and Lagrangian drifters). These services aim to improve understanding of the ecosystem and physical-biological connectivity as well as enhance the monitoring capability of the sea state in an area where the frequency of extreme weather events has significantly increased in the last decade due to climate change. Significant effort has been put into developing and refining circulation models, forecasting and monitoring tools, and Decision Support Systems (DSS). Further work went into sea current data gap filling, integration of HF radar data with other sources, and developing a spectra-to-sea wave inversion algorithm. By integrating data from a wide range of sources, these tools enable stakeholders and responsible entities to manage emergencies more efficiently. This contribution aims to share with the ROWG community the main achievements of the group over the past 12 years.

6. The European HFR Node: High Frequency Data from Providers to Users

Lorenzo Corgnati

Research Engineer, CNR-ISMAR

The EU HFR Node (https://www.hfrnode.eu/) was established in 2018 by AZTI, CNR-ISMAR and SOCIB, under the coordination of the EuroGOOS HFR Task Team, as the focal point and operational asset in Europe for coordinated HFR data management and dissemination, for promoting networking between EU infrastructures, marine data portals and the Global HFR network.

The EU HFR Node is fully operational since December 2018 in distributing practices, tools and support for standardization to the HFR providers and in delivering standardized Near Real Time (NRT) and delayed-mode HFR radial and total current data to Copernicus Marine Service In Situ TAC, EMODnet Physics and SeaDataNet.

The node is now managing data from 20 European HFR networks (built by 59 radar sites) and is also integrating and delivering data from the US HFR network.

The EU HFR Node implements the operational chain which encompasses data acquisition and harvesting, harmonization, formatting, QC, validation/assessment, NRT data delivery and historical data distribution with different reprocessing levels.

The collaboration between the EU HFR Node and data providers has significantly advanced the integration of historical and NRT HFR data. This progress has enhanced multiplatform integration approaches, leading to more precise monitoring of coastal currents. Additionally, it has facilitated the uptake of surface current coastal data across various application domains, including coastal oceanography, marine environment, safety, coastal management, fishery, navigation, and renewable energy.

7. Stokes Drift Mapping Using a Single High-Frequency Radar

Dr Abïgaëlle Dussol

Executive Director, Arctus Inc

Surface gravity waves play a major role in coastal circulation and upper-ocean mixing. Waves induce a net drift in the direction of wave propagation known as the Stokes drift. Stokes drift affects multiple processes in the ocean such as wave-induced sediment transport and Langmuir circulation cells responsible for upper-ocean Langmuir turbulence. Moreover, Stokes drift estimations are required to determine Lagrangian velocities, which affect dispersion of pollutants, including oil and biological organisms such as fish larvae. As direct measurement is challenging, Stokes drift is usually estimated from in-situ measurements of directional wave spectra, which limits the spatial resolution of the Stokes drift field. Using in-situ observations of wave spectra by a bottom-mounted Acoustic Wave and Current Profiler (AWAC) deployed in the lower St. Lawrence estuary, and observations of the wind speed and direction at a nearby meteorological station, we show that observed wave spectra closely follow the parametric form proposed by Toba (1979), and can thus be obtained from the wind speed, direction and fetch. We use a new method to estimate the wind field from the first-order Bragg-resonant peaks observed by a single High-Frequency (HF) radar, which we apply to data from a Wellen Radar

(WERA) and a Coastal Ocean Dynamics Applications Radar (CODAR) monitoring the location of the AWAC. Two-dimensional maps of Stokes drift are then estimated from the wind field obtained from each HF radar using Toba wave spectra. Correlation coefficients between the radar-estimated and AWAC-estimated Stokes drifts are 0.87 for the WERA and 0.86 for the CODAR.

8. Estimating Scattering Patch Area for a Direction Finding HF Radar

Dr Brian Emery

Associate Researcher, University of California

We use the radar equation along with in situ observations of Bragg-resonant ocean waves to estimate the scattering patch area for each radial velocity observation from a direction finding HF radar operating at 13 Mhz. Estimated areas for range cells 2-10 (3-15 km) vary from less than 1 km2 to more than 10 km2, with a mean of 2.5 km2 and standard deviation of 2.3 km2. Assuming a 1.8 km effective range cell width, and given the known ranges, these are approximately equivalent to a mean angular width of 8.5o, and a standard deviation of 10.0o. The scattering patch areas follow a Weibull distribution, with scale and shape parameters 2.5 and 1.2. Patch area uncertainties, expressed as a percentage of the patch area, average 36%, with most below 50%. Knowledge of the scattering patch area could allow improved data combining methods (e.g. appropriate weighting, or variable resolution totals), and improve the ability of HF radar networks to resolve small scale flows and eddies. Understanding the scattering patch size may also contribute to improved HF radar based observations of coastal winds, as it plays a role in the relationship between wind speed and backscattered power.

9. Recent Developments on SeaSonde Wave Measurement

Dr Maria Fernandes

R&D Scientist, Qualitas Instruments

As all major maritime countries, the Portuguese coastal zone is an important area for the development of local economy, either in terms of recreation, energy exploitation, weather forecasting or national safety and security. Field measurements are in the basis of understanding how coastal and oceanic processes occur. These processes also involve a variety of factors such as waves, winds, tides, storm surges, currents, etc. The southern Portugal is sheltered from the most dominant and important swell source, the North Atlantic. Besides the long travel distance, storms generated in the North Atlantic must circumvent the southern Portuguese continental shelf to reach the coast, specially Sagres region. These factors contribute to an important dissipation of wave energy, which can consequently introduce different patterns into storm variability. The local wave climate is also influenced by stormy waves originated in the Gibraltar Strait region or even by local strong thermal winds. Sagres presents quite often bimodal seas, with the presence of different sets of swell or local wind waves, both of them characterized by having different bulk parameters.

In the past few years, the measurement of waves using SeaSonde HF Radars has had several developments. Such a method is already established as a powerful tool for measuring surface currents pattern, but its adoption by Metocean agencies for wave measurements is recent. In this presentation we present the developments on how HF radar systems can present itself a reliable tool on wave data acquisition and how well the wave outputs compare with buoy sensors.

10. The Generic High Frequency Doppler Radar: Progress Report and Recent Developments

Prof Pierre Flament

University of Hawaii at Manoa

The radlab group (Pierre Flament, Lindsey Benjamin, Johanna Saavedra, Philip Moravcik, Maël Flament, Bénédicte Dousset at the University of Hawaii ; Xavier Flores at the Universidad Autónoma de Baja California ; Cédric Chavanne at Université du Québec à Rimousky; Antony Kirincich, Ian Fernandez at the Woods Hole Oceanographic Institution; Charina Repollo, Aiko Del Rosario at the University of the Philippines Diliman; Louis Marié at IFREMER ; Chang Huan Meng at the National Central University Taiwan; Peter Milne, John McClean at D-Tacq Solutions Ltd.)

A generic open-design phased-array HFDR has been produced in series over the past decade, maximizing commercial-off-the-shelf components to minimize overall cost, and minimizing power consumption to enable solar/wind operation. It uses frequency-ramped continuous wave transmissions generated by direct digital synthesis, and analog homodyne reception based on complex demodulation, translating the high frequency spectrum to a narrow audio base-band. The receive antennas array can be scaled from 4 antennas for direction-finding, to an arbitrary number of antennas for beam-forming, several installations featuring 32-antennas arrays. Digitization at 750 Hz with 32k oversampling provides highly compressed low-bit rate time series with full 24 bit dynamic range, requiring only 1Tb/year for raw data storage in netcdf (8 antennas). The electronics can operate from 3 to 50 MHz with no modification other than adjustment of out-of-band-noise rejection filters. Over one hundred units have been built and deployed in Hawai'i, Mexico, New England, France, Québec, the Philippines and Taiwan. Recent developments include: Grant of Equipment Authorization following FCC Rules Part 90 at all ITU region-2 frequency allocations; GNSS time-stamping, allowing wireless synchronization of separated transmit and receive antenna arrays; chip-scale atomic time reference, allowing multi-static operation with sub-mHz Doppler resolution; implementation of low-pass filtering and decimation within the FPGA/DSP hardware; design of a class-D switching radio-frequency amplifier with 85% efficiency, for situations of limited power availability; integration of a solid-state high temperature propane fuel cell for off-grid applications. Various shared post-processing tools have been developed by the community of users for estimating radial currents, including phase-based MUSIC direction-finding for large antenna clusters (WHOI), minimum-phase-error direction-finding for 4-antenna arrays (UABC), beam-forming and variants (National Central University, IFREMER). A complete package for mapping currents, wind and waves, has been commercialized by SeaView Sensing Ltd. Data collected by these generic radars can also be readily ingested into the University of Hamburg HFDR FORTRAN processing programs, as well as into the Université de Toulon MUSIC direction-finding package, which are distributed by these entities.

11. Recent Developments in HF Radar at Memorial University's Radar Remote Sensing Laboratory

Professor Eric W. Gill, Michael Royle, Joseph Craig

Department of Electrical and Computer Engineering, Faculty of Engineering and Applied Science, Memorial University of Newfoundland

Since the early 1980s, a team from Memorial University (MUN) has added significantly to the body of scientific and engineering knowledge respecting HF radar in the context of remote sensing in a maritime environment. The developments have included both theoretical and applied advances in the modelling of scatter from rough surfaces as well as inversion techniques for ocean surface measurements.

Most recently, the more analytical nature of the work has focused on the development of radar cross sections (RCS) combining scatter from surface targets and the ocean itself. It has long been known that the presence of hard targets (for example, ships and low flying aircraft) may be manifested in Doppler spectra dominated by ocean clutter, and such manifestations can negatively influence measurements of ocean surface parameters. Situations in which scatter occurs from both stationary and moving targets, before or after scatter from the ocean itself, are considered. The new RCS models are a first step in seeking to quantify the impacts of this sequential scattering.

Besides the new scattering model developments, the observation of inertia oscillations near a HF radar site in Placentia Bay, Newfoundland are also considered. Physical oceanography models, HF radar measurements and current meter data are used to arrive at the relevant conclusions.

12. High-Frequency Radar Observation of Strong and Contrasted Currents: The Alderney Race Paradigm

Professor Charles-Antoine Guerin

University of Toulon

The Alderney Race has been identified as a future site for the development of tidal energy, due to its bidirectional strong current reaching 5 m/s during spring tides. This hydrodynamics is very difficult to measure by in situ or remote sensing means. High-frequency coastal radars can provide a synoptic and near-real-time view of such a complex circulation, but the classical processing algorithms are not adapted to the extreme situation of strongly sheared currents. We propose an improved high-resolution direction-finding technique for the azimuthal processing of such radar data. It uses phased-array systems and combines the advantages of the usual beam-forming technique to eliminate many problems related to the distortion of Doppler spectra by extreme currents. The method is evaluated with a unique data set of radar measurements at two radar frequencies (13 and 24.5 MHz) and three spatial resolutions (200, 750, and 1500 m). The radar-based surface currents are analyzed in the light of a high-resolution numerical model and also compared with in situ measurements. While high azimuthal resolution can be achieved in this way, it is shown that the typical range resolutions of 750 and 1500 m are insufficient to account for the strong spatial variations of the surface current at some specific times and locations.

13. Recent Progresses in HF Radar Estimation of Ocean Wave Parameters and Application to the Toulon Site

Prof Charles-Antoine Guerin

University of Toulon

The classical method for estimating the main sea state parameters from a single radar station was proposed by Barrick in 1977. It is based on the use of weighted integrals of the Second-Order Doppler Spectrum (SODS), a technique that has both theoretical and practical limitations. We propose an alternative approach based on the amplitude modulation of the main Bragg peaks over time, a simple physical model that exploits the nonlinear interaction between short and long waves. Because it uses the dominant radar signal, this First-Order Bragg Peak (FOBP) method can achieve a larger range than the SODS method; it is also simpler to implement. We apply and compare both techniques with an annual data set from a phased-array HF radar in Toulon operating at 16.15 MHz using a nearby buoy as ground truth. The SODS is found to be accurate in measuring the significant wave height (SWH) in the near range but requires a fine-tuning of the separation frequency between the first- and second-order components; it is, however, much coarser in estimating the peak wave period (PWP). The first-order based method shows comparable accuracy for estimating the SWH but is more robust to the distance; it requires a calibration factor, that can be set once for all by using a mean annual SWH. The PWP estimation, on the other hand, is calibration-free and is found more consistent with the reference measurement while significantly extending the range of the SODS method.

14. WERA for Dual-use Applications to Protect Off-Shore Infrastructure

Thomas Helzel, Matthias Kniephoff, Roberto Gomez, Leif Petersen

HELZEL Messtechnik GmbH, Kaltenkirchen, Germany

The topic of “surveillance of civil off-shore infrastructure” is increasingly becoming a significant issue. For this reason, it is important to know that the operational civil ocean radar systems WERA can be upgraded to monitor ship activities far behind the horizon.

Several “WERA” ocean radar systems are located on the European coastline. In particular, the systems at the German Bight, the Dutch North Sea coast, the French and Italian coast are well suited for this technical application.

The WERA ocean radar is registered as a “dual-use” system because these systems are suited for over-the-horizon ship detection and tracking. It can be used for the surveillance of very large areas of the coastal ocean to identify suspicious ship manoeuvres.

To extend an existing ocean radar WERA for this ship tracking application, the systems may need to be refurbished and extended to 16 receive channels.

This technology should be of interest to all countries with off-shore infrastructure at their coast. For new surveillance projects, the HELZEL OTHR systems should be used, as these systems are designed and optimized for long range ship tracking applications. It is worth mentioning, that such a “military” OTHR system can be used for civil applications as well. These dual use applications include all WERA features such as ocean current monitoring for environmental protection and search and rescue. ***P.S. This presentation is linked to the planned field trip to the WERA/OTHR installation at Perranporth***

15. Target Joint Detection and Tracking Using Reinforcement Learning for Compact HFSWR

Prof Weimin Huang, Xiaotong Li, Weifeng Sun, Yonggang Ji

Memorial University

Due to its low transmit power and reduced aperture size of the receiving antenna array, compact high-frequency surface wave radar (HFSWR) often suffers increased challenges in detecting and tracking sea-surface targets continuously. In tracking scenarios with dense clutter or multiple targets, weak target signals are often missed due to improper detection thresholds, leading to track fragmentations during target tracking. In order to improve target detection probability to enhance target tracking continuity, a joint detection and tracking (JDT) paradigm, which establishes a closed loop between the detector and tracker, is proposed. When a target of interest is tracked, the tracker sends its predicted range, Doppler velocity, and azimuth information back to the detector, then the detector builds a detection gate centered at the predicted range and Doppler velocity on the range-Doppler (R-D) map. Within the detection gate, an optimal detection threshold dependent on the detection background and tracking environment is determined using reinforcement learning. In this way, a potential target plot may be detected with a higher detection probability and the detected plot is provided for track update. Experimental results with field data demonstrate that compared with the traditional detection before tracking (DBT) scheme, the proposed JDT paradigm achieves a superior performance with the average tracking time on target being increased by 13.33 minutes and the average plot loss rate being reduced by 0.8%.

16. Coastal Circulation Along the Middle-Southern Coasts of Vietnam Characterized by HF Radar and Modelling

Tran Thanh Huyen

PhD Student, Université du Littoral Côte d'Opale

Coastal circulations along the middle-southern coasts of Vietnam (VMSC) are characterized by various patterns and phenomena: South-China Sea western boundary currents, a dipole structure characterized by cyclonic and anti-cyclonic gyres offshore Vietnam and a South Vietnam upwelling which usually occurs in summer. For the first time, at coastal regions of Vietnam, a 1km-resolution surface current dataset during one month were obtained from HF radar measurements. This high-resolution surface current data was used firstly to compare with modelling results and subsequently to optimize wind forcing for improving model surface current simulation. The results have shown globally significant improvements in modeled surface current fields. Analysis wind field showed good agreements at some days in the analysis period compared with satellite wind data. High-resolution measurement data i.e. HF radar surface currents thus are necessary for obtaining better simulation products for complex dynamic coastal areas.

17. Revisiting HF Ground Wave Propagation Losses Over the Ocean: A Comparison of Long Term Observations and Models

Dr Anthony Kirincich

Senior Scientist, Woods Hole Oceanographic Institution

Understanding variations in the received power levels for land-based high frequency radar systems is critical to advancing radar-based estimates of winds and waves. We use a long-term record of one-way high frequency radar power observations to explore the key factors controlling propagation losses over the ocean. Observed propagation loss was quantified using an 8-month record of RF power from a shore-based transmitter, received at two locations: an offshore tower and a nearby island. Observations were compared to environmental factors such as wind speed and air temperature as well as models of path loss incorporating smooth and rough surface impedances and varying atmospheric properties. Significant differences in the observations at the two sites existed. One-way path loss variations at the tower, a wavelength above mean sea level, were closely related to atmospheric forcing, while variations at the distant island site were dominated by wind-driven surface gravity wave variability. Seasonal variability in ocean conductivity had no significant effect on over-ocean path losses. Simplistic analytical models of path loss were found to have more skill than either ground wave propagation models or more complex numerical models of field strength in matching the observations, due in part to under-observation of the atmosphere but also the differences in rough surface impedance between models of ocean waves.

18. Integration of Ocean Radar Observation Networks: Operational Considerations and Insights

Dr Jian-Wu Lai

Research Fellow, National Academy of Marine Research, Taiwan

Compared to traditional wave and current monitoring systems, ocean radars—such as microwave marine radars, high-frequency phased array radars, and high-frequency compact-type radars—have evolved through the interdisciplinary integration of radio science and oceanography, developing more suitable operational observation systems. With their wide coverage, high spatiotemporal resolution, excellent system stability, and low maintenance costs, ocean radars are unique tools for observing sea surface wave fields and surface current fields from mesoscale to small scale. Over the past two decades, ocean radar remote sensing products have demonstrated numerous best practices and concrete outcomes in oceanographic research and maritime affairs planning.

This study explores the integration of various ocean monitoring departments in Taiwan into a second-generation, nationwide ocean radar observation network to support maritime affairs decision-making. The goal is to enhance operational efficiency in maritime recreation safety, search and rescue, marine pollution response, and navigation safety. The analysis references experiences from the United States and the European Union, reviews Taiwan's efforts in promoting regional ocean radar observation networks, and proposes key considerations and insights for the planning and development process. This aims to provide guidance for ocean

radar system maintenance organizations and product application agencies, promoting the radar observation network as a crucial component of Taiwan's ocean monitoring system.

19. Experiment Verification of Ocean Surface Wind Fields Using MIMO HFSWR

Xiaoyan Li, Prof Xiongbin Wu, Liang Yu, Prof Xianchang Yue

Wuhan University, Hubei Province, China

The accuracy and detection range of ocean surface wind speed measurements by High-Frequency Surface Wave Radar (HFSWR) are constrained due to limited array aperture, low signal-to-noise ratio (SNR) and high nonlinearity of second-order echoes. Recently, the inversion of wind speed using first-order radar echoes has become a developing trend, yet challenges remain in effectively utilizing the information from first-order echoes. In this study, the results of an experimental verification of ocean surface wind fields using a Multiple Input Multiple Output (MIMO) HFSWR are presented, demonstrating the reliability of the proposed algorithm for wind fields inversion using the radar system. The employed MIMO radar system, named Advanced Marine Radar (AMR), operated at dual frequencies simultaneously. Observation data from two stations were used for subsequent inversion of ocean surface wind fields. Unlike traditional algorithms, the first-order radar echoes with higher SNR were utilized for wind speed inversion in AMR system. Initially, for each operating frequency, the wind direction and the spreading factor of Bragg resonant waves were derived from the first-order radar echoes from the two stations. Then, the dual-frequency spreading factors were used to extract wind speed information, addressing the ambiguity issue associated with using a single-frequency spreading factor. The experimental methods, including radar configuration, data collection, and processing techniques, are described. The accuracy and effectiveness of the AMR system in monitoring ocean surface wind fields were validated by comparing radar measurements with other meteorological observation data.

20. An Evaluation of Gap-Filling Methodologies for HF Radar

Dr Guiomar López

Scientist of HF Radar Facility, SOCIB

HF radar measurements frequently exhibit gaps, either spatial, temporal or both, resulting from a variety of factors such as equipment malfunctions and environmental interference. Despite the recurring nature of this issue and the critical need for gap-free data in lagrangian calculations (essential for common HF radar data applications like search and rescue or pollution tracking), there is no consensus on a single optimal gap-filling method, and in fact, there is likely no single solution suitable for all scenarios. Therefore, it is important to continuously evaluate and compare established and newer methods, in order to provide HF radar operators with useful information to assist them in selecting the most suitable method based on their requirements.

This study aims to address this issue by evaluating four gap-filling techniques for HF radar data: Open-boundary Modal Analysis (OMA), Data Interpolating Empirical Orthogonal Functions (DINEOF), Data-Interpolating Variational Analysis in multiple dimensions (DIVAnd), and a 2D

variational algorithm (2dVar). By analyzing results obtained using data from two distinct HFR networks, located in the Bay of Biscay (northeastern Atlantic Ocean) and the Ibiza Channel (Mediterranean Sea), each presenting unique oceanographic characteristics, our findings aim to highlight the performance of each method under various conditions. This research contributes to the European willingness to standardize the provision and distribution of gap-filled HF radar data by: 1) assessing the strengths and weaknesses of each method; 2) defining essential metadata for transparency and reproducibility.

21. Machine Learning-Based Short-Term Forecasts through High-Frequency Radar Ocean Current Maps to Enhance Maritime Emergency Response

Yi-Chieh Lu, PhD Student, National Cheng Kung University, Tainan, Taiwan, Assistant Research Fellow, National Academy of Marine Research, Kaohsiung, Taiwan

Jian-Wu Lai, Research Fellow, National Academy of Marine Research, Kaohsiung, Taiwan

Laurence Zsu-Hsin Chuang, Professor, National Cheng Kung University, Tainan, Taiwan

National Academy of Marine Research, Taiwan

In the past two decades, high-frequency (HF) radars have been widely used to observe ocean surface currents because of its advantages of broad coverage, continuous data, and near real-time. However, the immaturity of HF radar observation data to predict ocean current changes in the next few hours limits the application of HF radar in maritime search and rescue missions. In order to enable high-frequency radar data to more effectively support the Coast Guard's search and rescue plan, this study develops a machine learning model that can produce short-term (within12 hours) ocean current field forecasts based on HF radar data.

The process involves data quality control and harmonic analysis to generate residual data, which is then forecasted using a long short-term memory (LSTM) model. The predictions, integrated with tidal data, leverage both physical laws and machine learning to improve accuracy. We benchmark against HYCOM model predictions, and evaluate reliability with Global Drifter Project (GDP) data through statistical analyses such as separation distance (SD) and skill score (SS). The results demonstrate that the short-term forecast model developed in this study is highly reliable and can effectively capture the characteristics of ocean currents observed by radar, thereby accurately predicting ocean currents within the next 12 hours.

The research result is expected to significantly improve the accuracy and reliability of ocean current forecasts based on radar observations, which can be used not only for maritime search and rescue operations, but also for maritime oil spill response in the waters around Taiwan.

22. A Decade of Surface Current Mapping along the U.S. West Coast: What does it say about Vertical Circulation Magnitudes, Distributions, and Forcing?

Prof Jeffrey Paduan

Adjunct Professor of Ocean Sciences, University of California Santa Cruz

An extensive network of over 60 HF radar systems have been deployed along the U.S. west coast for more than a decade. This study reviews those observations of hourly ocean surface currents

at, approximately, 6 km horizontal scales for the period 2012 through 2023. In addition, over-water wind stress estimates from a high-resolution atmospheric model (COAMPS) were analyzed for comparable horizontal scales. The original hypothesis was that sub mesoscale (~10 km) surface current divergence patterns would match over-water wind stress curl patterns did not turn out to be true. Instead, ocean current divergence and, hence, vertical circulation patterns, are dominated by the non-linear terms in the momentum equation.

23. Characterisation of the Turbulent Properties of Surface Velocities in the North-Western Mediterranean Sea: Analysis of the First Year of Measurements

Dr Lucía Quirós-Collazos

Research Engineer, Institute of Marine Sciences (ICM-CSIC) & ICATMAR

The turbulent nature of the oceanic upper layers makes necessary to approach the analysis of ocean velocities measured by high-frequency radars (HFR) using characteristic methods of turbulent flows. Here, we use some of these methods to analyse the velocities provided by the new HFR network deployed by the Catalan Institute of Research for the Governance of the Sea (ICATMAR) along the Catalan Coast (North-Western Mediterranean Sea). This new HFR network is composed by an array of 7 CODAR antennas, 5 of which are already operating and the rest will be commissioned before the end of 2024 covering, once completed, around 300 km of the coastline. At present, only the antennas of Cap de Creus (CREU) and Cap sa Sal (BEGU) have been functioning long enough to provide measurements for at least one year. Using these first 1-year time-series of radial velocity measurements we have computed probability density functions, structure functions, correlation functions and spectra in order to start characterizing the properties of longitudinal velocities in this region. In a second phase, we have also explored the topological properties of the total velocities derived from these two stations using the Okubo-Weiss parameter.

24. Combining HF Radar and Glider Data to Study Physical-Biogeochemical Coupling in the SE Bay of Biscay

Dr Anna Rubio

Principal Researcher, Head of the Operational Oceanography group, AZTI

Previous works have showcased the potential of HF radar data for the detection and study of (sub)mesoscale processes in the SE Bay of Biscay. By means of different Lagrangian techniques in combination with other in-situ data (drifters), models and satellite observations insight has been provided into surface transport processes and coherent Lagrangian structures. The recent availability of two gliders in the EuskOOS coastal observatory (info.euskoos.eus) provides an additional possibility for the study of coupling between physical advection/convection processes and biogeochemical processes. In November 2023, an 11-day glider mission was conducted within the HF radar footprint area. The glider was equipped with hydrographic and biogeochemical sensors, measuring temperature, salinity, turbidity, chlorophyll-a, dissolved oxygen, dissolved organic matter, and nitrates. Thus, allowing to describe the evolution of the Adour River plume at an unprecedented spatiotemporal resolution in the area. During the mission, maximum surface currents measured by the radar reached 74 cm/s, favoring the westward extension of the river plume along 85 km during the period of 23-27 November. FSLE maps, computed from HF radar surface currents to infer Lagrangian coherent structures, delineate the plume frontal area, in agreement with satellite SST and Chl-a maps, as well as in existing numerical simulations. In the water column, well-stratified conditions were observed due to the plume, with marked Chl-a, temperature, salinity and nitrate anomalies within the upper 15 m. At the end of the mission, the glider revisited the area affected by the plume, which enabled to study the effect of mixing processes in its evolution.

25. Rank Filtering for Significant Wave Height Estimation from HF Radar Data

Prof Reza Shahidi

Memorial University of Newfoundland

In previous work, we have shown that up to first-order, the standard deviation of the received voltages from a HF radar reflecting off a patch of the ocean surface is linearly proportional to the significant wave height of the ocean on that patch. In the current work, we use the fact that the envelope of the ocean surface wave height is known to roughly follow a Rayleigh distribution, to show that taking the mean of the top n received.

voltage magnitudes, for some small integer n (usually less than or equal to 30) over some time period also gives us a quantity linearly proportional to the significant wave height. This greatly simplifies the calculation of the significant wave height as it only requires comparison and averaging operators, which can easily be implemented in hardware, if need be. Good estimates of significant wave height are shown to be obtained from HF radar field data from Argentia, Newfoundland and Labrador, Canada.

26. Small-scale Eddies Detected by VHF Radar in the Western Scheldt Estuary, The Netherlands

Thanh Huyen Tran

Oceanographer, Helzel Messtechnik GmbH

In modelling approach, tidal intrusion, meandering rivers, dynamic bathymetry i.e. submerged sand banks are the prominent challenges to the simulation of the hydrodynamics of the estuarial areas at fine-scales (several minutes in time and less than 1 kilometer in space). These distinctive features can cause strong turbulences i.e. small-scale eddies which cannot be resolved at modelling scales. Such eddies are usually dangerous to the operation of ships and vessels going through the channel. This study uses sea surface current data obtained from WERA, a very-high-frequency (VHF) radar system, located at the Western Scheldt estuary, The Netherlands, to detect small-scale eddies occurring in the area during December, 2022. Twenty-one eddy snapshots have been captured by applying a threshold set of the Okubo-Weiss parameter and the velocity gradient. Most of the eddies were formed behind the submerged sand bank in the left of the domain (Figure 2) and occurred 1-2 hours after high water, especially during spring tide periods with the duration of the eddy ranging from 15 minutes to nearly 1 hour. This typical interaction of tidal intrusion and inhomogeneous topography in the estuary causes high curl values which are the indicators for the occurrence of eddies. This application of HF radar measurements can be done operationally for supporting nautical authorities in ship guidance and safety management.

27. Innovative Tools for HF Radar Challenges

Dr Dale Trockel

Data Scientist, CODAR Ocean Sensors Ltd

In the more than 23 years since the very first ROW meeting, HF radar has transformed from a relatively unknown, niche technology promoted by a small number of scientists into a backbone element of coastal ocean observing systems worldwide. As the networks have grown and the technologies advanced, CODAR has continued its tradition of innovation by adopting a cross-disciplinary approach, adapting cutting-edge methods from various fields to advance both operations and data products. With the push for more offshore wind energy and the ever-increasing size of the turbines, CODAR identified a need for new tools to mitigate their impact on HFR networks. Along with our research partners, we have developed computer vision, machine learning, and other data processing WTI mitigation techniques. Additionally, CODAR has applied AI to various other aspects of our processing tool-chain, from vessel detection to radar calibration. In this talk, we explore these cross-disciplinary advances and how they have been successfully used to increase HF radar performance and reliability.

28. Seaview Sensing Recent Software Developments

Prof Lucy Wyatt

Technical Director, Seaview Sensing Ltd

In this paper I will discuss developments to our software package and also work in progress that is not yet incorporated into the package.

Accurate single radar inversion would provide data when one of two radars was not working or when signal to noise is not sufficient for dual radar inversion. Networks of radars are also becoming more common. Our current software is limited to the inversion of dual radar data. Although we have inverted bistatic data this involved bespoke changes to the software that were not in the operational package. V6 of our software package is aimed at addressing these issues. We have tested it with dual and single radar data (https://doi.org/10.3390/rs15235536) which showed that single radar inversion is both less accurate and takes much longer to process than dual radar data. We are working on both these issues. The software will work with more than 2 radars but we have not yet had suitable data for testing. The bistatic enhancement also remains to be done.

Other developments in the pipeline are (i) removing spurious low frequency waves mid-identified as swell; (ii) extending our machine learning method for wind speed measurement (https://doi.org/10.3390/rs14092098) to account for bathymetry and look directions to allow wind speed mapping; (iii) developing a new radial current algorithm which appears to be more robust in noisy and low-signal-to-noise cases.

Our software has been used with Helzel WERA and Oceanphysics G-HFDR radars. In the latter case we also do the beam-forming and Doppler processing.

29. A MIMO-Based Dual-Frequency High-Frequency Surface Wave Radar System

Liang Yu, Prof Xiongbin Wu,Xiaoyan Li, Prof Lan Zhang

Wuhan University, Hubei Province,China

This article introduces a new dual-frequency high-frequency surface wave radar system (Advanced Ocean Radar, abbreviated as AMR), which utilizes technologies such as Multiple-Input Multiple-Output (MIMO), fully digital direct sampling, distributed synchronous networking, sparse antenna array layout, and artificial intelligence-assisted spectrum detection and prediction. The paper provides a detailed introduction to the composition of the AMR radar system, the design of the receiving and transmitting systems, the design of radar calibration and verification equipment, the design of the radar working waveform, the design of the broadband antenna array, the design of the radar calibration and verification system, radar performance indicators, and the application of the system. The system has been tested and applied in the Taiwan Strait of Fujian, China, and the results show that compared with the previous generation of OSAMR(Ocean State Measuring and Analyzing Radar）, the AMR radar system has a smaller array while maintaining the same detection accuracy, and its anti-jamming performance is better, and the detection performance of ocean dynamic parameters such as wind, waves, and currents is higher.

Poster Presentations (in Alphabetical Order by Surname)

30. Estimation of the Wind Field with a Single High Frequency Radar

Prof Cedric Chavanne

ISMER-UQAR

Over several decades, High-Frequency (HF) radars have been employed for remotely measuring various ocean surface parameters, encompassing surface currents, waves, and winds. Wind direction and speed are usually estimated from both first-order and second-order Bragg-resonant scatter from two or more HF radars monitoring the same area of the ocean surface. This limits the observational domain to the common area where second-order scatter is available from at least two radars. Here, we propose to estimate wind direction and speed from the first-order scatter of a single HF radar, yielding the same spatial coverage as for surface radial currents. Wind direction is estimated using the ratio of the positive and negative first-order Bragg peaks intensity, with a new simple algorithm to remove the left/right directional ambiguity from a single HF radar. Wind speed is estimated from wind direction and de-tided surface radial currents using an artificial neural network which has been trained with in-situ wind speed observations. Radar-derived wind estimations are compared with in-situ observations in the Lower Saint-Lawrence Estuary (Quebec, Canada). The correlation coefficients between radar-estimated and in-situ wind directions range from 0.84 to 0.95 for Wellen Radars (WERA) and from 0.79 to 0.97 for Coastal Ocean Dynamics Applications Radars (CODAR), while the root mean square differences range from 8 ◦ to 12 ◦ for WERAs and from 10 ◦ to 19 ◦ for CODARs. Correlation coefficients between the radar-estimated and the in-situ wind speeds range from 0.89 to 0.93 for WERAs and from 0.81 to 0.93 for CODARs, while the root mean square differences range from 1.3 m/s to 2.3 m/s for WERAs and from 1.6 m/s to 3.9 m/s for CODARs.

31. New Radar Signal Processing Methods for Surface Current Mapping

Dr Dylan Dumas

Research Engineer, CNRS

Azimuthal processing is often the most challenging step in surface current mapping from HF radars. Traditionally, it is performed with the Beam Forming (BF) technique for phased-array radars and Direction Finding (DF) techniques for compact antenna systems, each method having its advantages and disadvantages. At the MIO laboratory (CNRS & university of Toulon) we have developed a series of techniques to adapt the DF approach to antenna arrays. They allow a higher spatial resolution while mitigating the usual drawbacks of DF such as lacunarity, outliers, and wrong bearing assignment caused by radio frequency interference or ships. In the case of strong and contrasted surface currents, which can lead a to an overlap of the first- and second-order components in the omnidirectional Doppler spectrum, a preconditioning of the first-order Bragg region by the BF technique allows for a significant reduction of such errors and reduces the sources of external noise. Based on these techniques, a dedicated software with a simple graphical interface has been developed; a test version has been distributed to a few beta users and the final version will be released to the HFR community soon. The application of these techniques to various HF radar sites will be shown at the conference together with a live demonstration of the software.

32. High-Frequency Radar Observation of Strong and Contrasted Currents: The Alderney Race Paradigm

Professor Charles-Antoine Guerin

University of Toulon

The Alderney Race has been identified as a future site for the development of tidal energy, due to its bidirectional strong current reaching 5 m/s during spring tides. This hydrodynamics is very difficult to measure by in situ or remote sensing means. High-frequency coastal radars can provide a synoptic and near-real-time view of such a complex circulation, but the classical processing algorithms are not adapted to the extreme situation of strongly sheared currents. We propose an improved high-resolution direction-finding technique for the azimuthal processing of such radar data. It uses phased-array systems and combines the advantages of the usual beam-forming technique to eliminate many problems related to the distortion of Doppler spectra by extreme currents. The method is evaluated with a unique data set of radar measurements at two radar frequencies (13 and 24.5 MHz) and three spatial resolutions (200, 750, and 1500 m). The radar-based surface currents are analyzed in the light of a high-resolution numerical model and also compared with in situ measurements. While high azimuthal resolution can be achieved in this way, it is shown that the typical range resolutions of 750 and 1500 m are insufficient to account for the strong spatial variations of the surface current at some specific times and locations.

33. A Comprehensive Evaluation of Portugal's High-Frequency Radar Network

Vânia Lima

Instituto Hidrográfico (Portugal)

The Portuguese High Frequency Radar Network was established in 2012, as part of the Portuguese EEZ real-time monitoring integrated system, MONIZEE. To ensure the accuracy and reliability of the data collected by these systems, comprehensive validation strategies have been implemented, especially in recent years. These methods include comparing the HF Radar data with in-situ measurements, drifters, modelling results, and advanced statistical analyses. In this work, we discuss the historical evolution of this HF Radar network, detail the adopted validation methodologies, and present an evaluation of the data quality and reliability of the HF Radar network. This work underscores the importance of data validation, enhancing the utility of HFR networks for scientific research and coastal management.

34. Extending the HF Radar Network of Toulon: Geometrical Considerations

Yanis Roig

Student at Toulon University and on an internship at Degreane Horizon

The University of Toulon and the Mediterranean Institute of Oceanography (MIO) operate a network of phased-array High-Frequency Radars(HFR) of WERA type in a multistatic configuration. It consists of 2 TX and 2 RX located in 3 remote locations. This network is dedicated to the monitoring of currents and waves in the coastal area of Toulon; it partially captures the Northern Mediterranean Current that flows from Italy to Spain.

In this study, we examine the possibility of extending the network eastward. The first part of our study is dedicated to the analysis of the current network in terms of coverage and signal-to-noise ratio (SNR), based on the actual radar data. We also evaluate the geometric loss of accuracy in the estimation of total current vectors with multistatic elliptical velocities, an effect known as the Geometric Dilution of Precision(GDOP). Another limiting aspect is the presence of islands in the study area.

We evaluate their impact on received power and SNR and use the estimated attenuation to optimize an extended network. The selection of new sites results from a trade-off between the available spatial coverage, the level of SNR including the effect of islands, and the expected accuracy of the total current considering the GDOP. We evaluate these different properties for a limited number of configurations, corresponding to a few possible receiving and transmitting sites towards the East. Finally, we estimate the expected performance of the proposed sites for monitoring the total current measurements, with the help of a regional ocean circulation model.

35. Small-scale Eddies Detected by VHF Radar in the Western Scheldt Estuary, The Netherlands

Thanh Huyen Tran

Oceanographer, Helzel Messtechnik GmbH

In modelling approach, tidal intrusion, meandering rivers, dynamic bathymetry i.e. submerged sand banks are the prominent challenges to the simulation of the hydrodynamics of the estuarial areas at fine-scales (several minutes in time and less than 1 kilometer in space). These distinctive features can cause strong turbulences i.e. small-scale eddies which cannot be resolved at modelling scales. Such eddies are usually dangerous to the operation of ships and vessels going through the channel. This study uses sea surface current data obtained from WERA, a very-high-frequency (VHF) radar system, located at the Western Scheldt estuary, The Netherlands, to detect small-scale eddies occurring in the area during December, 2022. Twenty-one eddy snapshots have been captured by applying a threshold set of the Okubo-Weiss parameter and the velocity gradient. Most of the eddies were formed behind the submerged sand bank in the left of the domain (Figure 2) and occurred 1-2 hours after high water, especially during spring tide periods with the duration of the eddy ranging from 15 minutes to nearly 1 hour. This typical interaction of tidal intrusion and inhomogeneous topography in the estuary causes high curl values which are the indicators for the occurrence of eddies. This application of HF radar measurements can be done operationally for supporting nautical authorities in ship guidance and safety management.