The Integrated Ocean Observing System HF Radar Network:

Ten Year Status

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Abstract— **As the US Integrated Ocean Observing System (IOOS) high frequency (HF) radar network (HFRNet) approaches its tenth year of existence, we highlight the growth and enhancements that have occurred. High frequency radar systems measure the speed and direction of ocean surface currents in near real time. Starting with about 30 radars in 2005, the network has grown to over 130 radars with 33 participating organizations and approximately ten million radial files sent via the network. A key component of the network has been the data ingest, processing and distribution system that is the core of the national HF radar data servers. Due to the scalability that was designed into it, this IOOS HF radar data management system has kept pace with the network growth and continues to have high reliability. We will show how the gridded vector velocity data have repeatedly proven their value in a number of operational applications including offshore search and rescue, oil spill response and water quality monitoring.**

I. INTRODUCTION

The US Integrated Ocean Observing System (IOOS) high frequency (HF) radar network approaches its tenth year of existence, we highlight the growth and enhancements that have occurred during the last five years. A Marine Technology Society (MTS) IEEE 2006 paper [1] details the data management and near real-time distribution of the system with applications and updated status of the network published in a 2010 MTS journal. [2]

High frequency radar systems measure the speed and direction of ocean surface currents in near real time. These radars can measure currents over a large portion of the coastal ocean, from a few kilometers offshore up to 200 km,and can operate under any weather conditions. The antennas are located near the water's edge, and transmit a signal that is reflected back to the instrument by moving surface waves. The reflected signal is processed to remove the wave speed and determine the surface currents producing a radial vector map in reference to the antenna. Two, or more, receive antenna sites with overlapping coverage are necessary to extract the direction of the currents. The data from each instrument site are sent to central computers where the individual signals undergo quality control checks and then are combined to calculate the total vector currents. These near real-time total vectors (RTV) are visualized online, distributed via web services, and archived at the NOAA National Centers for Environmental Information (NCEI).

Starting with about 30 radars in 2005, the network has grown to over 130 radars and is often referred to as HFRNet. Approximately 33 IOOS partner institutions contribute their near real-time low-level radar data to the three IOOS national radar data servers housed at the National Data Buoy Center, Scripps Institution of Oceanography and Rutgers University. A key component of the network has been the data ingest, processing and distribution system that is the core of these national data servers. Due to the scalability that was designed into it, this IOOS HF radar data management system has kept pace with the network growth and continues to have high reliability. Every US state with a coastline, except New Hampshire and Louisiana, has at least one HF radar site. Also, Puerto Rico now has four HF radars in operation. The system has even enabled the ingest and distribution of radar sites outside of the US including Canada and Mexico. See http://cordc.ucsd.edu/projects/mapping/maps/ to view an interactive map of the radar sites and the near-real-time maps of the gridded current vectors computed, assembled and displayed by the national data server and Scripps Institution of Oceanography's Coastal Observing Research and Development Center (CORDC). The growth of the network in terms of number of radars and amount of terabytes of radial velocity data are given in fig. 1 and 2.

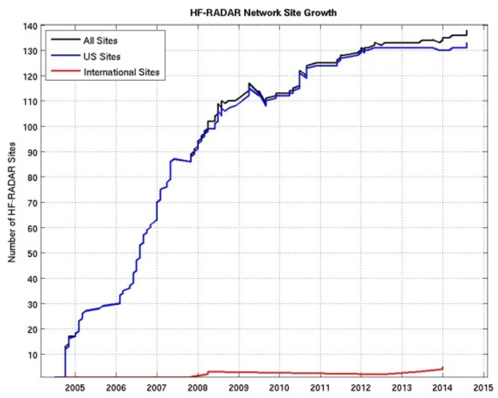

Figure 1. HFRNet site growth including Canada and Mexico sites

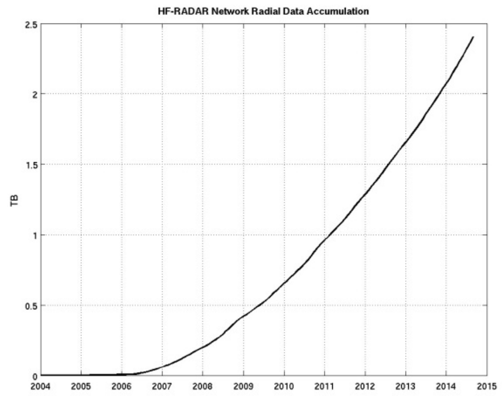

Figure 2. HFRNet data volume (TB) growth from 2005 through 2015

II. APPLICATIONS

A. Specific Events or Local/Regional Applications

IOOS funded HF radar derived surface currents have established data feeds to NOAA Office of Restoration and Response (OR&R), California State Office of Spill Prevention and Response (OSPR) and regional models such as Regional Ocean Model System (ROMS) for oil spill response within the California region. A recent operational example of HF radar derived surface currents usage occurred on May 19, 2015 with a ruptured oil pipeline just north of Refugio State Beach in Santa Barbara County, CA. Approximately 21,000 gallons of crude oil flowed to the coast and into the ocean triggering a response from participants within the Coast Guard led oil spill response area committee. These data were used to assist in analyzing and tracking the oil spill as it entered the region of coverage approximately 1km offshore. HF radar visualizations were used by local News Channel 3 in Santa Barbara for use during the weathercast in order to show circulation patterns in the area. In response to the Refugio oil spill, University of California, Santa Barbara (UCSB) HF radar operators from the Southern California Coastal Ocean Observing System (SCCOOS) established a temporary site at Gaviota in order to fill in coverage north of the spill and ran a local trajectory model advecting simulated particles through the current field to visualize the potential path of the slick. Scripps programmers integrated into HFRNet within an hour of being online to provide improved coverage to operational users within the region.

The Mandy Ness, a commercial fishing vessel, sank on Tuesday January 17, 2012. The Coast Guard had marked is position after sinking. When the Coast Guard attempted to locate the vessel for salvage it had moved from its original position. Rutgers University created drift scenarios with the 5 and 13 MHz radar network to aid the Coast Guard in their search for the vessel. One thousand virtual particles were released at the last known location for the Mandy Ness. The particles were advected using the HF radar surafce currents along with a random-flight model [5]. The drifter simulations showed a consistent drift towards the southeast that was utilized by the Coast Guard in the search efforts.

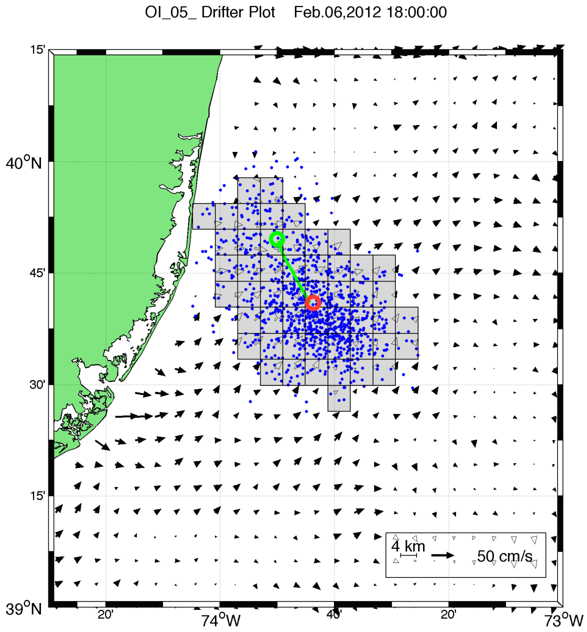

Figure 3: Drift scenario for the Mandy Ness fishing vessel. Surface currents showed a consistent drift towards the southeast. The 1,000 virtual particles are the blue dots, the path of the mean particle position is the green line with green circle indicating start and red circle showing end. The gray boxes encompass 95% of the virtual drifters.

Another regional application of the HF radar measurements was the detection of a meteotsunami off the coast of New Jersey on June 13, 2013 [6]. A derecho, which is a long-lived straight-line wind storm, had passed the area in the morning. The propogation speed of the weather front (40 knots, 25 m/s) matched the phase speed of a shallow water ocean wave to initiate the tsunami wave. The tsunami wave propogated east and then reflected off the shelf break and then made landfall later that afternoon. The 13 MHz HF radars detected the meteotsunami 23 km offshore, 47 minutes before it arrived at the coast.

Recently, the California Environmental Protection Agency (EPA) began efforts to create a marine debris tracking application and sought to use the HF radar api, adding the data layer combined with additional information for a holistic picture. These types of applications and requests continue to increase as the public, managers, and scientists use ocean observations to further our stewardship of ocean resources.

B. National Applications and Activities

Nationally, use of HF radar-derived currents continues with the US Coast Guard Search and Rescue Optimal Planning System (SAROPS) as well as NOAA's Office of Response and Restoration capability to react to offshore oil spills. Their GNOME Online Oceanographic Data Center (GOODS) routinely ingests HFR data. These efforts were discussed in [2].

Two new capabilities have been added recently. First, the NOAA National Weather Service's Automated Weather Information Processing System (NWS AWIPS) has been updated to ingest HF radar vector velocity gridded data in near-real-time. It is envisioned that HF radar will be useful to operational marine coastal forecasters and developers of numerical guidance. In some regions, the data will be compared to Real-Time Ocean Forecast System (RTOFS) output and, in the future, to the Extra-tropical Surge and Tide Ocean Forecast System (ESTOFS). A key prerequisite for this task was to convert the data from the NOAA National Data Buoy Center (NDBC) in its native network format to the GRIdded Binary (GRIB2) format. The data are then transmitted over the NWS Satellite Broadcast Network which provides access to the data for each AWIPS office. Since this is a new activity for AWIPS, at the time of this writing, we do not have specific weather events for which HF radar data have been used. Second, the HFR data have been ingested by the National Centers for Environmental Prediction (NCEP) for use in ocean circulation model development. Two levels of HFR data are being ingested in Binary Universal Form for the Representation of meteorological data (BUFR) format: radial velocities and vector velocity gridded data.

NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) has released a product with national implications: an HF radar web product that provides near real-time surface current observations and tidal current predictions. The new web product is presently available in Chesapeake Bay, San Francisco Bay and New York Harbor (http://tidesandcurrents.noaa.gov/hfradar/) providing both near real-time HF radar surface current observations and tidal current predictions. The expectation is that the primary users of the new information provided by this product are the marine navigation community. Additional geographic locations where the product could be developed are being explored.

III. DATA MANAGEMENT AND DIAGNOSTICS

The HFRNet surface current mapping data management network is characterized by a tiered structure that extends from the individual field installations of HF radar equipment (a site), a local regional operations center which maintains multiple installations (an aggregator), and centralized locations which aggregate data from multiple regions (a node). This data system relies on robust aggregator to node communications with centralized data repositories that are updated in near real-time. Hourly Radial files are generated locally at the site and transmitted through the national network for inclusion in the total vector calculation which then produces a near real-time total vector (RTV). RTV's are generated on grids with multiple resolutions (500m, 1km, 2km, and 6km).

The backend processes require ongoing maintenance and updates to ensure processing speeds can keep up with near real-time in an environment of increasing site locations and expanding area of coverage. FY12-13 focused on a "tech refresh" effort, necessary to retain system consistency and reliability. CORDC replaced site aggregating systems operating for four years or more and deployed new centralized nodes at the three participating organizations to ensure processor speed and reliability was maintained for the growing network.

In 2013, a draft performance metric was defined to characterize the operational availability of data reporting from IOOS supported sites and contributing to HFRNet. The performance metric is based on the operation of the U.S. array over a 12 month fiscal cycle (October through September) or otherwise defined reporting cycles (e.g. quarterly cycle). The HF Radar IOOS metric is defined as the percentage of time NOAA IOOS funded radars are operational during a given reporting period. Operational radial files are considered to be a radial file where the number of observed radial solutions meets or exceeds a nominal number of radial solutions and the file was reported within twenty five hours of the observation. The number of operational radial files reported to the network are divided by the expected number of radial files and reported as a percentage of time the network was operational at full capacity.

The need to have a well-structured data archiving process for HF radar data was recognized and documented more than ten years ago [3]., This need was reiterated and described in more detail in [4]. Beginning in 2015, both gridded total vector velocity and radial velocity data types are being archived by the NOAA National Centers for Environmental Information (NCEI). Each month, the data files are transferred from the

NDBC data server to NCEI for archival. This effort will ensure data availability for future access and retrieval.

IV. GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS (GEOSS)

GEOSS aims to coordinate and connect producers of environmental observations and information systems with end users to address global issues related to the Earth system. GEOSS is organized into nine "Societal Benefit Areas": disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. The Group on Earth Observations (GEO) is leading this effort with a focus on creating and managing a GEOPortal which allows access and discovery of relevant data sources, models, and decision making tools to promote and advance international cooperation. The Global Ocean Observing System (GOOS) is the oceanographic component of GEO and U.S. Integration Ocean Observing System (IOOS) is the U.S. contribution to GOOS. IOOS contributes ocean surface currents from HF radar to the GEOPortal enabling distribution of HFRNet data.

U.S. HFRNet has participated in the GEO Global HF Radar task since its inception in March 2012 at the first meeting held at Oceanology International in London, England. The goals of this task are to: 1.) Increase the number of coastal radars operating around the world; 2.) Ensure that HF radar data are available in a single standardized format in real-time; 3.) Establish worldwide quality standards; 4.) Distribute a set of easy-to-use standard products; 5.) Assimilate the data into ocean and ecosystem models. Subsequently, there have been international meetings held in Bergen, Norway (2013), Kaohsuing, Taiwan (2014) to promote these directives. Efforts have been focused on standardizing data management, cataloging applications and success stories, and promoting capacity building. The U.S. network efforts are being leveraged on a global level from a visualization and distribution perspective. Ideal data management standards include a standard gridded velocity format (e.g. Network Common Data Format (NetCDF), standard metadata naming conventions (e.g. Climate Forecast Interoperability), and a standard distribution service (e.g. THREDDS Data Server (TDS)). Scripps CORDC supports a global visualization http://cordc.ucsd.edu/projects/mapping/global/fullpage.php from distributed services that can be encapsulated into partnering visualizations and showcase international collaborations.

Increasing partnerships and data sharing globally promotes scientific and operational advances in coastal areas. The radiowave operators working group (ROWG) and GEO Global HF Radar Task promote national and international knowledge exchange and cooperation within the community.

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