Impacts of high-frequency radar-derived wind observations on COAMPS® forecasts

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Abstract 1500-character max

Shore-based high-frequency (HF) radars are routinely used to observe ocean currents and surface wave characteristics remotely. Because surface waves are closely related to near-surface winds, many investigators have explored methods in deriving winds from HF radars, with limited success until now. Most recently, a technique has been developed that uses HF radar Doppler spectra data with the adjoints of a HF radar model and a wave prediction model to derive winds. This technique has been applied to HF radar data collected along the Santa Barbara, California coast during October 2017. These remotely sensed near-surface wind observations are likely to be valuable in initializing mesoscale analyses and forecasts in the littoral zone, as satellite-derived surface winds are generally not available near the coast. Since ocean wave models are dependent on atmospheric winds, better forecasts of near-surface winds impact almost all Naval operations near shore—especially transits in and out of ports. This work proposes to investigate the impact HF radar-derived winds have on the quality of Coupled Ocean/Atmosphere Mesoscale Prediction System® (COAMPS) analyses and forecasts using the new COAMPS-4D Variational data assimilation system. An observing system experiment is proposed to evaluate impacts from real HF radar observations on COAMPS followed by a historical observing system simulation experiment to determine potential impacts from simulated wind retrievals.

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1. Statement of the problem

The U.S. Navy requires accurate meteorological and oceanographic characterization and prediction of the environment for effective naval operations. Poorly predicted weather events or mischaracterization of the surrounding environment can lead to mission failures, damage to naval assets, and even casualties to sailors. Environmental forecasting capabilities have improved remarkably in recent decades due to improvements in computing resources, ensemble forecasting methods, model physics, and assimilation of observed conditions of the atmosphere (Bauer et al. 2015). New strategic initiatives from the Department of Defense and the Office of Naval Research, however, require significant advancements in the skill of environmental forecasting (Department of Defense 2018; Office of Naval Research 2017). One area that must be improved is the forecasting of near-surface winds over the ocean and within littoral regions by the Coupled Ocean/Atmosphere Mesoscale Prediction System® (COAMPS). Forecasts of near-surface winds are crucial for Navy flight operations, port transits, expeditionary warfare, and special operations—and can also impact predictions of the sea state, ocean currents, and upwelling in ocean models using the modeled atmospheric forcing. Generally, COAMPS near-surface winds are biased calm, especially during late fall, winter, and early spring.

One approach for improving forecasts is to assimilate new observations that improve model initial conditions which subsequently produce better forecasts from the numerical weather prediction (NWP) model. While scatterometer data is available to help constrain analyses of near-surface winds over the open ocean, the littoral zone is often data sparse and generally limited to only buoy observations. Recently, a new method has been developed to derive near-surface winds near the coast using high-frequency (HF) radars, which are regularly used to observe ocean currents and wave characteristics. A limited dataset of wind retrievals during October 2017 from HF radars near Santa Barbara, California has been generated using this new technique. This proposed research will evaluate the impact this data has on COAMPS near-surface wind analyses and forecasts using an observing system experiment (OSE) methodology.

Unfortunately, the quality and quantity of test data constrain conclusions that can be drawn by the OSE methodology, which, for new observation types, is generally limited due to the expense of deploying additional platforms or reconfiguring existing sensors. Because of the limited amount of available wind retrievals, an observing system simulation experiment (OSSE) will also be used to determine wind retrieval impacts from a simulated HF radar network. OSSEs are commonly used to estimate the impact future observing systems will have on forecasts before these systems are built or deployed. They also help prepare the NWP framework assimilate the new observations (Masutani et al. 2010; Hoffman and Atlas 2016). For example, the impact of the GOES-16 Advanced Baseline Imager brightness temperature observations on simulations of a severe weather event over the central United States was tested before the satellite was launched and showed improvements to the model’s water vapor structure (Cintineo et al. 2016). This research proposal will utilize a variation on the traditional OSSE methodology, known as the historical OSSE (Baker and Posselt 2018), currently being explored by the Naval Research Laboratory (NRL) as a way of evaluating impacts from new or undeployed sensors at a reduced computational and personnel cost compared to the traditional methodology.

2. Background and relevance to previous work

The Navy relies on the COAMPS model for environmental analyses and forecasts vital to their operations. COAMPS (Hodur 1997) is a coupled regional model developed by NRL that includes interactions between its atmosphere, ocean, and wave components. The system is run operationally at the Fleet Numerical Meteorology and Oceanography Center (FNMOC) for over 100 different regional areas at all classification levels. Generally, the system is configured to use atmospheric boundary conditions from the Navy Global Environmental Model (NAVGEM; Hogan et al. 2014) and ocean boundary conditions from the Hybrid Coordinate Ocean Model (HYCOM; Bleck 2002). Ocean initial conditions are provided by the Navy Coupled Ocean Data Assimilation system (NCODA; Cummings 2005), a 3D-Variational (3DVar) system; atmospheric initial conditions will soon be provided using a 4D-Variational (4DVar) methodology through COAMPS-4DVar (Xu 2013). COAMPS-4DVar assimilates a wide variety of atmospheric observations collected and processed by FNMOC, including radiosondes, automated weather stations, ship, aircraft, satellite-derived atmospheric motion vectors, scatterometers, satellite radiance, and Global Positioning System radio occultation.

Impacts of observing platforms on the skill of NWP forecasts are often determined through OSEs, in which various observing platforms are withheld from or added to the assimilation cycle to evaluate their contribution to forecast error reduction (James and Benjamin 2017). Observation impacts can also be quantified through forecast sensitivity observation impact (FSOI; Langland and Baker 2004), which allows for the quantification of observation impact for each assimilated observation without running data denial experiments. Computation of FSOI requires the adjoint of the forecast model and data assimilation system, both of which exist for COAMPS-4DVar and can be used to compute these metrics as part of the regular forecast update cycle. Knowledge of these observation impacts computed through OSEs or FSOI can help inform decisions about real-time scheduling of model runs with regards to data latencies, directions of investments for future observing systems, and forecast degradation caused by system malfunction or platform obsolescence. Unfortunately, these methods are only applicable to observations already deployed; testing new observing systems that have not been deployed requires the use of the more expensive and complex OSSE approach.

In traditional OSSE studies, simulated observations are generated from a realistic simulation of the environment, known as the “nature run,” which is usually a free-running model independent of the target modeling system. Because the nature run is free-running and not constrained by observations through the normal data assimilation update cycle, rigorous evaluation of the nature run must take place to ensure it simulates physically realistic weather. The nature run is used to simulate all observations assimilated by the target data assimilation system—the experimental observations to be tested as well as the entirety of the global observing system—with errors that represent the observation errors of each sensing platform. The simulated observations are then assimilated into the modeling system and run for two cases: 1) observations that represent the present observation network (the control run) and 2) observations with the existing network plus a hypothetical observation network of interest. Forecasts that included the hypothetical observation system are compared with the control run and the nature run from which the simulated observations were derived. Improvements or degradations in forecast skill are attributed to the inclusion of the hypothetical observation network. These experiments help direct development efforts for future observing systems, but they are complex and rely on a synthetic environment based on the nature run.

NRL and the NASA Jet Propulsion Laboratory are currently investigating the utility of the historical OSSE (Baker and Posselt 2018), a variation of the traditional OSSE approach, in an attempt to reduce computational costs, personnel costs, and time required to run the traditional OSSE method. The historical OSSE approach is similar to the traditional OSSE but uses a model simulation of real conditions (the reference) instead of a synthetic nature run. The historical OSSE reference, which is independent of the target data assimilation and modeling system, simulates conditions for a time during the historical record and is used to simulate only the observations of interest (and not routine observations of the existing observation network) and for experiment validation. Besides the reduced costs, the benefit of the historical OSSE over the traditional method is that it can quantify forecast improvements due to additional observations for real weather events instead of analogs found in the nature run. The approach is currently being investigated through the simulation of in-situ sensors and their assimilation into COAMPS. This proposal would extend the investigation to remotely sensed HF radar wind retrievals.

For decades, HF radar has been used to remotely measure the ocean currents and wave characteristics up to 200 km from shore (Paduan and Washburn 2013). These observations have been used in ocean current and wave models. There have been several attempts since the 1980s to retrieve wind observations from these platforms through various methodologies, as ocean surface currents and waves are closely tied to near-surface winds (Huang et al. 2002). A new technique has been developed by SRI International to derive wind retrievals from HF radars using Doppler spectra data with the adjoints of the HF radar model and a wave prediction model (Muscarella et al. 2018). This new method is being tested and tuned for radar observations collected during the second phase of the Coupled Air-Sea Processes and Electromagnetic Ducting Research (CASPER) project, known as CASPER-West (Wang et al. 2018). SRI International is currently testing and tuning their wind retrieval technique with data collected by three HF radars near Santa Barbara, California. Preliminary results from the initial tests have been extremely positive, as the wind retrieval technique has produced winds close to those observed by buoys in the region (Muscarella et al. 2018). By the end of September 2019, SRI International will have a month-long dataset of wind retrievals from three HF radars near Santa Barbara, California covering October 2017 (David Walker, SRI International, personal communication). The primary sources of observations of near-surface winds in littoral regions are buoys outfitted with anemometers, which are generally few (Figure 1). HF radar wind retrievals may fill a vital gap for off-shore wind observations, as scatterometer data is unable to measure near-surface winds within 25 km of the shore and requires an overhead satellite overpass that is not contaminated by rain (Figure 2).

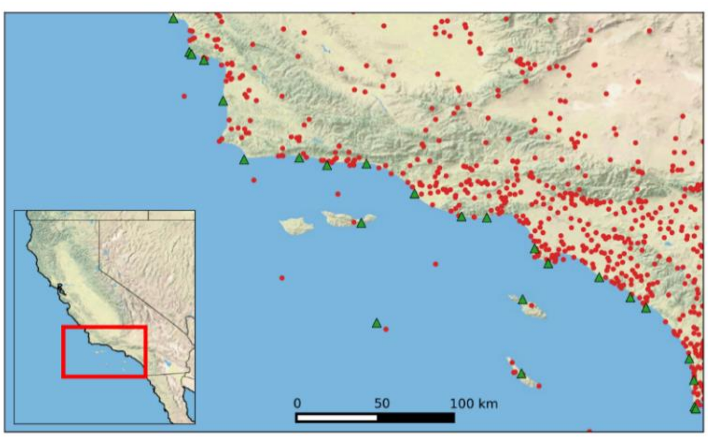

FIG. 1 Southern California coast surface wind observation network available 14 October 2017. Locations of the HF radar network are denoted by green triangles and automated weather stations and buoys are denoted by red dots.

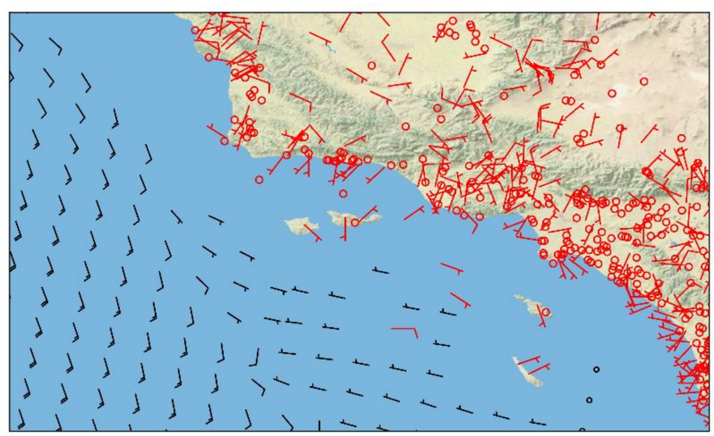

FIG. 2 Observed near-surface vector wind at 17:25 UTC 14 October 2017 from MetOp-B ASCAT scatterometer (black) and automatic weather stations and buoys (red). Half and full barbs denote 2.5 and 5 m s^{-1}, respectively.

3. General methodology

The goals of this proposed research are two-fold. First, this project will assess the benefit of real HF radar wind retrieval observations from October 2017 on COAMPS analyses and forecasts using an OSE approach. The impact of the observations will be assessed using a combination of standard forecast metrics, FSOI, and newer diagnostics in development at NRL (e.g., fit to observations and feature based diagnostics). Second, this project will evaluate the utility of the historical OSSE methodology for HF radar wind retrievals and use the method to assess the benefit of reconfiguring the existing HF radar network to output the required data needed to compute wind retrievals. The target modeling framework for this work is COAMPS using the newly available COAMPS-4DVar data assimilation system. The proposed work will require conversion of the HF radar data into standard FNMOC observation formats, updating the data pre-processors used by COAMPS-4DVar and adapting required quality control, configuring the model reference for the historical OSSE work, running the COAMPS suite, and comparing output between experiments. This work has been designed to be completed within a 3-year work period.

The first year of effort will focus on tasks related to running the OSE portion of this research. Python converters will be developed that convert the radar retrieval files provided by SRI International into standard FNMOC observation formats. This work will ensure a smoother transition of the data to FNMOC should the data prove beneficial. Additionally, the data preprocessors within COAMPS-4DVar will be updated to process and quality control these new observations properly. COAMPS will be configured for the CASPER-West domain and will be run with and without assimilating the new wind retrievals into COAMPS-4DVar. FSOI and feature-based verification metrics will be used to compare model initial conditions and forecast output for the two simulations using the NCAR Model Evaluation Tools (MET; Gotway et al. 2018).

The second year of this project will focus on the OSSE portion of this research. The Coupled-Ocean-Atmosphere-Wave-Sediment Transport (COAWST; Warner et al. 2010) modeling system will be used as the model reference for the historical OSSE, requiring the development of Cylc-based run scripts to run the system. COAWST is a coupled system incorporating the Weather Research and Forecasting (WRF) atmospheric model (Skamarock et al. 2019), the Regional Oceanic Modeling System (ROMS; Shchepetkin and McWilliams 2005), the Simulating Waves Nearshore (SWAN; Booij et al 1999) wave model, and the WAVEWATCH III (NOAA 2019) wave model. The COAWST system is a suitable reference for the historical OSSE methodology as its components are independent of the target modeling framework, COAMPS. COAWST will be run over October 2017, and its output will be verified against observations using MET to ensure it is an adequate reference for the historical OSSE. The verified COAWST output will be used to generate the required necessary inputs to create the simulated wind retrievals at the three HF radar sites tested in the OSE portion of this work. The simulated observations will match the format and resolution of the real observations supplied by SRI International during the first year and will include expected errors and biases. These simulated observations will then be used to complete a series of simulations like those conducted with the real observations using the COAMPS-4DVar system, but for specific time periods of high-impact wind events outside of the CASPER-West field campaign.

The final year of this project will assess the results of the OSE and historical OSSE performed by this proposed research. Similar observation impacts between real observations and their simulated counterparts will verify the suitability of the historical OSSE technique on HF radar wind retrievals. If this is the case, this allows the technique to be used to generate HF radar wind retrievals at additional radar locations to quantify the combined impacts of producing retrievals at all sites. Results will be documented in the second half of the third year of work; the proposed work will likely result in two journal manuscripts.

4. New or unusual methods

The described method for obtaining wind retrievals from coastal HF radars developed by SRI International is unique and expands the benefit of the network beyond its intended use. Demonstrating the potential benefit of this new wind dataset for data assimilation and improved NWP is an exciting advance in remote sensing of coastal winds. While OSSEs have been used in the past to quantify the benefit of new systems, the historical OSSE approach departs from the traditional OSSE framework. This variation of the methodology is currently being tested using COAMPS-4DVar by simulating in-situ observations using WRF and comparing simulated observation impacts to their real counterparts. This testing is scheduled to be completed by December 2019.

5. Expected results, significance, and application

Naval operations depend on accurate analyses and forecasts of the atmospheric, oceanic, and wave conditions. The quality of these analyses and forecasts can often be improved through the assimilation of observations. Currently, near-shore wind observations are restricted to a limited number of buoys, but HF radar-derived wind data can potentially fill this observation gap and lead to improved wind and wave forecasts. This work first proposes to use an OSE to quantify the impact of HF radar wind retrievals on analyses and forecasts produced by the COAMPS suite. Impacts can be beneficial or non-beneficial. We hope to demonstrate that these winds are of value for Navy applications. Beneficial impacts from the wind retrievals will help motivate their use in the FNMOC operational forecast cycle. The second portion of this work will further validate the historical OSSE method for remotely sensed observations and be used to assess the potential impact that an expanded HF radar network could have for a larger area and for a variety of weather scenarios. The historical OSSE approach allows for a more cost effective and timely analysis of the HF radar data than a traditional OSSE. Improvements to COAMPS forecasts from the new HF radar wind retrievals will motivate the reconfiguration of the existing HF radar network to output the needed parameters to create the retrievals, as well as motivate the deployment of new HF radars where they do not yet exist. Minimal or destructive impacts from the wind retrievals may motivate further additional refinement on the retrieval methodology by its developers.

SRI International has already been able to generate preliminary retrievals that match buoy observations in the region and continues to refine the retrieval methodology. While the OSE portion of this proposal is currently achievable, the second and third years of this proposal are less certain as the historical OSSE methodology is still being evaluated (using in-situ observations), but that work will be completed near the start of this proposed research. Potential contingency plans for the second and third years of this project (should the historical OSSE methodology prove unsuccessful) include making current FSOI metrics better suited for Navy needs or running OSEs on other observing platforms of Navy interest using the tools developed in the first year.

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