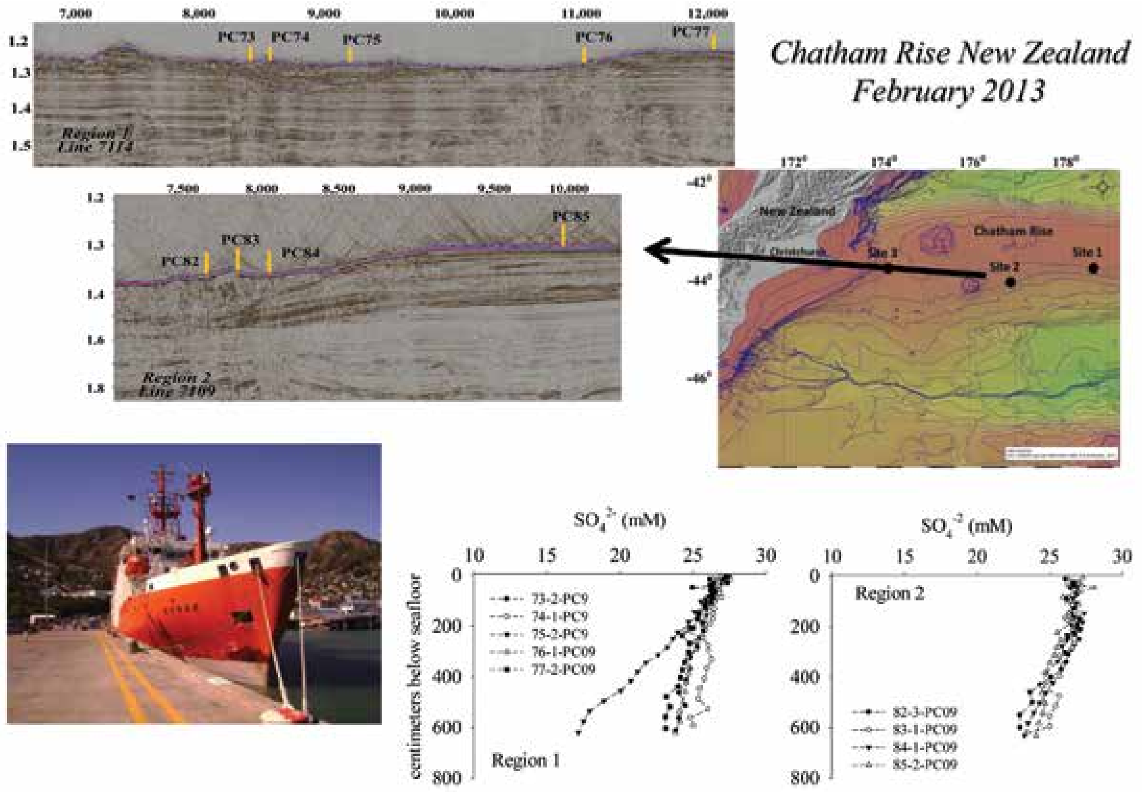

FIGURE 4
A comparison of geochemical and seismic data from a 2013 expedition aboard the RV *Sonne*, off the coast of New Zealand across the Chatham Rise. Two seismic lines were studied at this location to evaluate the vertical methane flux. Here we present sulfate data related to the spatial variation in sediment methane concentrations. These sulfate profiles show there was no vertical methane flux at any location.

(almost all methane) entering the ocean–atmosphere system, but also in many cases to determine the origin and history of the carbon in that gas. The seismic data allow us to constrain the possible fluid pathways on scales of meters (high-resolution systems like DTAGS) to hundreds of kilometers for larger surface-towed airgun systems. The successful marriage of these two disciplines continues to be an effective means of quantifying the dynamics of gas hydrate in ocean sediments.

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Monitoring Maritime Conditions with Unmanned Systems During Trident Warrior 2013

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Introduction: Before predicting future conditions in the maritime environment, we must sense what the ocean is doing now. Humans perceive the environment through our senses; comparable perception is also becoming available in autonomous observing platforms. These can feel the warmth of the ocean, taste its saltiness, and see and hear changes in light and sound. Ocean forecasts are improved through the assimilation of these data; our challenge is efficiently obtaining observations and using them in ways that have the greatest impact. NRL researchers teamed with other Navy and academic institutions to address this challenge under the aegis of July's Trident Warrior 2013 (TW13) exercise off the Virginia shore. TW13 hosted deployments of two types of unmanned ocean observing platforms: undersea ocean gliders (Slocum and Spray models) to see, feel, and taste visibility, temperature, and salinity; and surface wave gliders (Sensor Hosting Autonomous Remote Craft or SHARC model) that emit sounds and listen for reflected changes in response to ocean currents. Experiments tested how to guide, adapt, and use observations from these unmanned underwater (UUV) and surface (USV) vehicles. The observations were supplemented with traditional in situ and satellite measurements for assimilation into real-time forecasts of the maritime environment relevant for antisubmarine and mine warfare (ASW/MIW).

Exercise: Trident Warrior is an annual exercise coordinated by the U.S. Fleet Forces Command that provides an operational Fleet environment to assess the impact of new tactics and technology on warfighter needs. The experiments in TW13 were conducted with the cooperation of several ships and aircraft from various participating Navy and Air Force commands, in and around the waters east of Virginia and Maryland during July 13 through 18. Researchers from NRL's Oceanography Division joined with contributors from other NRL, Navy, and university groups in an effort coordinated by the Office of Naval Research (ONR) to demonstrate the effectiveness of unmanned observing systems for characterizing the ocean environment within the framework and constraints of a Fleet exercise.

Gliders: Figure 5(a) shows NRL personnel deploying one of the 10 profiling gliders released and recovered from the R/V *Knorr* during the exercise. Data from the two NRL and two Naval Oceanographic Office (NAVOCEANO) gliders were transmitted to Stennis Space Center, processed using the Local Automated Glider Editing Routine (LAGER), and displayed in the NRLSSC real-time display laboratory. Oregon State University controlled and provided data from the six remaining ocean gliders. Four SHARC gliders from UC-San Diego Scripps Institution of Oceanography were also deployed; these provided Acoustic Doppler Current Profiler (ADCP) 3D measurements of the ocean currents as well as measurements of the surface meteorology. Figure 5(b) shows a schematic representation of one wave glider and two ocean gliders superimposed on the real-time forecast of ocean temperature. Glider location tracks (Fig. 6(a)) were updated in real time for the duration of the exercise. In addition to the standard measurements of temperature and salinity, the NRL gliders included bio-optical observation packages with measurements of chlorophyll-a, colored dissolved organic matter (CDOM), beam attenuation coefficient at 660 nm, and backscatter coefficient at 532 nm. Cross

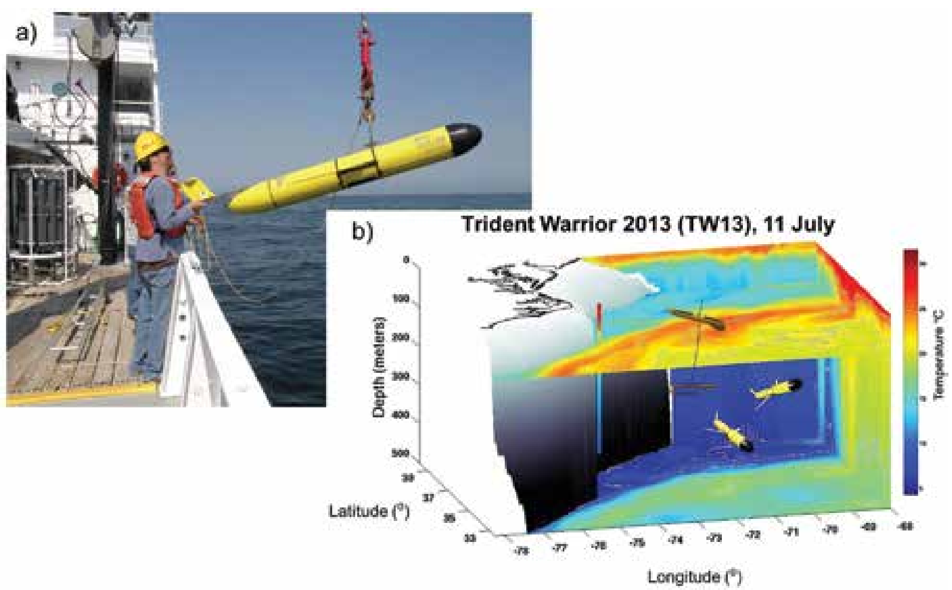

FIGURE 5
(a) NRL personnel deploy a profiling Slocum ocean glider. (b) Two ocean gliders and one SHARC are superimposed on a 3D TW13 ocean temperature forecast valid at 00:00 UTC 11 July 2013.

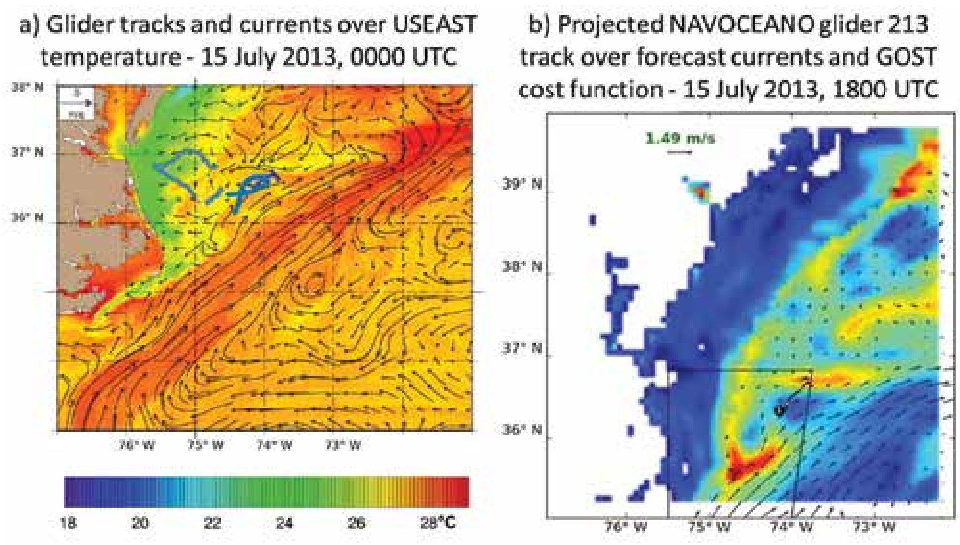

FIGURE 6
(a) NRL and NAVOCEANO gliders focus on optical properties in the inshore region and temperature and salinity for acoustics in the offshore. (b) GOST projects a path for NAVOCEANO glider that is optimized according to the mission-dependent cost function, identifying high-value samples in red. The polygon informs GOST of the waterspace management mandated for the exercise, restricting the gliders to remain south of the main shipping lanes into Chesapeake Bay.

sections of the data received and processed by NRLSSC were on display in real time along with corresponding satellite data and ocean model outputs and products from the region.

GOST: The Glider Observation Strategies (GOST) system developed by NRL identifies glider paths that are likely to cover times and locations with the most impact on assimilative ocean forecasts in the operational area while avoiding areas restricted by waterspace management or challenging operating conditions.[1] GOST uses the forecasts to identify efficient paths through the shifting currents and targets areas where predictions of sound speed or other conditions are uncertain or changing in ways that influence warfighter decisions. During TW13, GOST ran on NAVOCEANO's operational systems and implemented communication links between the ocean modeling and glider operations groups, using model forecasts to project glider paths anticipated to be best suited for the mission and providing this as guidance for the glider pilots (Fig. 6(b)). A new GOST rendezvous option was demonstrated, identifying glider trajectories that maintain high observation value while enabling timely recovery by the R/V *Knorr.*

Optical Forecasts: Additionally, some of the optical and physical ocean data from the gliders are combined with satellite-derived surface optical properties (Fig. 7) and physical models to tune coefficients in a 3D optical model.[2] The Tactical Ocean Data System (TODS) 3D Optical Generator (3DOG) provides optical parameters in a 3D volume at 1 km grid spacing. These data are combined with ocean current forecasts to feed BioCast, a system to solve for the three-dimensional advection-diffusion-reaction of dissolved or

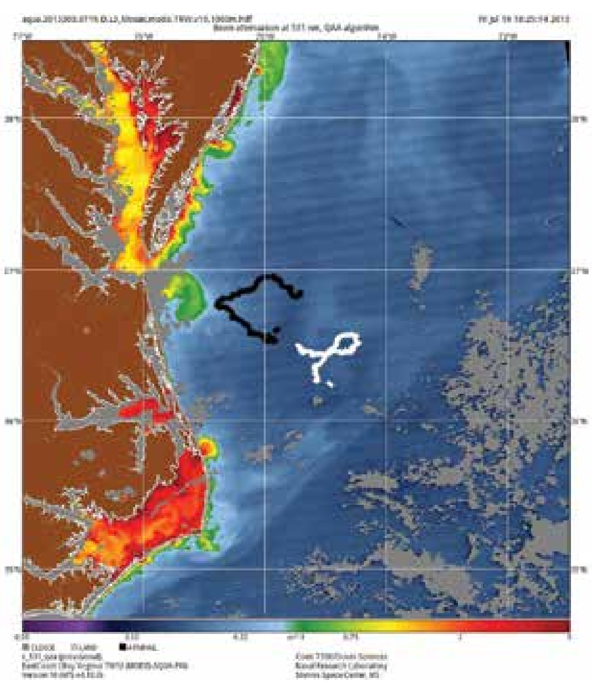

FIGURE 7
Trajectories of NRL's gliders superimposed on a satellite image processed to estimate beam attenuation at 531 nm. The satellite and glider data are combined in TODS to predict 3D optical parameters and are forecast using RELO-NCOM.

particulate tracers in aquatic environments and forecast changing optical properties out to 24 hours.

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Probing the World's Greatest Source of Variability — Madden Julian Oscillation

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Introduction: The Madden–Julian Oscillation (MJO), named after Roland Madden and Paul Julian, who first described this phenomenon, is a primary mode of atmosphere/ocean variability. The MJO consists of a large, planetary-scale convective anomaly propagating eastward along the Equator over the Indo Pacific warm pool with a phase speed of about 5 to 8 m/s. It influences the atmosphere and ocean on various temporal and spatial scales — from tropical cyclones through monsoons and El Niño in the tropics, to mid-latitude, and even polar, atmosphere, and ocean circulation patterns. The effects of this tropical phenomenon can be observed as far away as ocean current anomalies in the Drake Passage.

MJO behavior depends on multiscale interactions between the global circulation and local convective patterns, as well as feedback between the atmosphere and the ocean. The MJO "cycle" consists of the dry (suppressed) phase, in which clear skies and large insolation allow for heating of the upper ocean and energy is accumulated in the atmosphere/ocean system, and the active phase, in which the energy is released in the form of atmospheric convection (precipitation). A synthesis of the MJO based on model simulations, field measurements, and a conceptual model is shown in Fig. 8(a-d).

MJO Forecast: From the forecasting point of view, the MJO represents a link between the weather and climate. Its relatively long time scale forms a base for extended weather prediction and, therefore, understanding of the MJO became a Holy Grail for the forecasting community. However, in spite of its importance, the MJO presents a formidable forecasting challenge, mostly because of its multiscale nature. The MJO system includes eastward and westward moving tropical disturbances with various spatial and temporal scales that interact with the large-scale "MJO envelope"; the air-sea interaction creates another level of complexity.

An interdisciplinary NRL team participated in an international effort, called Cooperative Indian Ocean Experiment on Intraseasonal Variability (CINDY) / Dynamics of Madden–Julian Oscillation (DYNAMO), directed toward understanding MJO dynamics, with the focus on MJO initiation in the Indian Ocean that appears to be especially difficult to predict. During the CINDY/DYNAMO field campaign (October to December 2011), three MJO episodes were observed, providing a wealth of data for MJO investigation. In this campaign, the NRL air-sea-ocean-wave Coupled Ocean–Atmosphere Mesoscale Prediction System (COAMPS) model was used, the first fully coupled high-resolution model run in real time. The model consists of the atmospheric regional model, ocean model Navy Coastal Ocean Model (NCOM), and wave model Simulating WAves Nearshore (SWAN) with the boundary forcing provided by Navy global models and data assimilation in the atmosphere and in the ocean. The model nested grid setup used for the DYNAMO forecasts, with the cloud resolving nest centered on the DYNAMO observational array, reflected the multiscale nature of the MJO. With this model, combined with the atmospheric and ocean observations collected during the field program, we analyzed the transitions from the suppressed stage to the active stage of the

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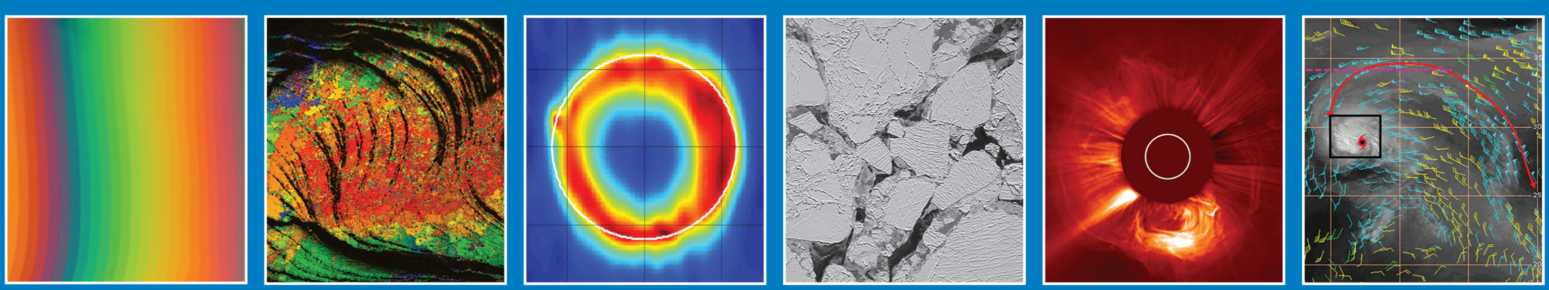

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