Transitioning Results From Recent ONR WESTPAC Field Programs to Operational Use

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Grant #: N00014-11-1-0453
Grant #: N00014-13-1-0423

LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve predictive skill for Navy-relevant parameters in the littoral zone.

OBJECTIVES

a) Continue analyzing recent data sets from the Western Pacific operating region (WESTPAC) and facilitate transitioning these basic research outcomes to operational use.

b) Improve our understanding of the circulation in the western Subtropical Countercurrent (STCC) and its impact on the neighboring boundary currents and downstream variability in the western North Pacific Ocean.

APPROACH

Over the past fifteen years, ONR has organized several major field efforts in the WESTPAC region. The PI has personally organized, participated in, and published results from several of these areas including the Japan Sea, the East China, the South China Sea, and the Luzon Straits. Ongoing work continues in the eastern and western South China Sea and the Philippine Sea. All of these programs have identified oceanographic features with sufficient strength, persistence and spatial extent to have identifiable impacts on acoustic propagation and therefore tactical ASW exploitation. Examples of such features include the Kuroshio current, mesoscale eddies, surface mixed layers of varying strength and extent, and high-frequency non-linear internal waves. Coincident modeling studies during the field efforts demonstrated that Navy models can reproduce these features with some degree of forecast skill, thus facilitating their inclusion in tactical planning via the NAVO ASW reach-back cell. This grant is to continue analyzing recent data sets and facilitate transitioning these basic research outcomes to operational use.

WORK COMPLETED

A substantial effort in the grant is to work with the acoustics community (Peter Worcester, SIO; John Colosi, NPS; many others) analyzing the oceanographic data from several moorings deployed in the central Philippine Sea. The primary purpose of the program is to characterize and understand the acoustic propagation, but the hundreds of oceanographic instruments deployed also make the moorings conducive to basic ocean circulation studies. During April 2010-April 2011, seven moorings were deployed in a star pattern spanning roughly 17 – 23°N by 23 – 130°E (Figure 1). The six "transmit" moorings had an ADCP in the upper ocean spanning 260-360 m depth and many TSP instruments to 600 m depth. Additionally, the DVLA (receive) mooring observed current from 200-500 m and temperature to 4400 m depth. The data return was excellent with most instruments containing complete records for the duration of the experiment. The UNOLS vessels used to conduct the work operated hull-mounted ADCPs throughout the many cruises to the area. Several partner PIs (P. Worcester, SIO; J. Mercer, APL/UW; A. Baggeroer, MIT) collected CTDs are part of their work. The satellite altimetry data, now easily available on the web (see for instance the Colorado Center for Astrodynamics Research, http://eddy.colorado.edu/ccar/data_viewer/index) have also been very helpful in establishing context for the field experiment. An array of Seagliders was also deployed which sampled the temperature and salinity (L. Van Uffelen, UH). We have devoted considerable effort during this funding cycle integrating all the physical oceanographic observations. The excellent spatial coverage of this array allows study of the highly-energetic STCC eddy field as well as the ambient water mass properties.

RESULTS

Some of the most exciting results noted to date include:

- The eddy field consists of an even mix of cyclones and anticyclones which tend to be organized in zonal bands (Figure 1).
- The currents at the eastern moorings (T2, T3, T4, DVLA) resemble the flat-bottom deep ocean case in terms of the eddy energy (300 cm^2/s^2) and westward propagation (-10 cm/s).
- The western moorings however (T1, T5) exhibit strong boundary interactions and nonlinearity despite being over 200 km offshore. In this region topographic beta steers the eddies towards the southwest where they interact with other eddies incoming from the west (see for instance warm eddy W2 in Figure 1). The data set additionally contains at least one clear eddy/Kuroshio interaction, and one example of a reflected "short" Rossby wave.
- Eddy/boundary current and eddy/eddy interactions increased the eddy energy at T1 and T5 to order 900 cm^2/s^2.
- The dominant length and time scales of the mesoscale variability (350 km and 60 days) are in general a poor fit for planetary waves and appear to be in the realm of geostrophic turbulence [Kobashi and Kawamura, 2001; Zang and Wunsch, 1999].
- Isotherm displacements in the eddy field are order 100 m and 2°C.
- The relative vorticity in the eddies is order f, which suggests they are highly nonlinear with trapped cores
- The CTD sections also indicate trapped cores, with the anticyclones (warm) having a shallow (150 m) salinity maximum and associated high spiciness that is completely absent in the

cyclones (Figure 2). The anticyclones also had a weaker salinity minimum in the North Pacific Intermediate Water (600 m depth) suggesting source waters farther to the south.

- Several moorings display strong sub-mesoscale variability. This variability appears from satellite MODIS SST images (not shown) to be filaments and instabilities around the edges of the eddies, but needs further investigation.

The emphasis now is on publishing these results. Most of the graphics have been produced and the paper is about 80% written.

IMPACT/APPLICATION

This experiment is expected to break new ground in the field of blue-water deep-sea acoustic propagation. The array is also the first of its kind in region of the STCC, one of the most energetic mesoscale eddy regions of the world. Observing the eddy energetics and propagation speeds and directions will improve the quality of the oceanographic and acoustic nowcasts and forecasts for the region.

TRANSITIONS

Transitions have begun via a three-day visit by the PI to NRL Stennis, CNMOC, and NAVO at the Stennis Space Center, MS. The PI visited the ASW reach-back cell to learn what kinds of products are being moved to the fleet, i.e., what constitutes useful information. Specifically, using the PhilSea10 array data to improve/verify acoustic provincing techniques to more efficiently move up-to-date transmission loss information to the fleet looks promising. These collaborations will be with Dr. Josette Fabre at NRL Stennis. The PI also worked with Dr. Dong-Shan Ko, Dr. Pat Gallacher, and Dr. Martin Buijsman who are working on numerical models of the western Philippine Sea region.

RELATED PROJECTS

Peter Worcester, Scripps Institution of Oceanography, project leader

John Colosi, Naval Postgraduate School, deep water acoustics, internal waves

Bruce Cornuelle, Scripps, mesoscale modeling

Brian Powell, University of Hawaii, mesoscale modeling

Brian Dushaw, APL/UW, internal waves

Lora Van Uffelen, UH, acoustic tomography from mobile nodes

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Kobashi, F., and H. Kawamura, 2001: Variation of sea surface height at periods of 65-220 days in the subtropical gyre of the North Pacific. *J. Geophys. Res.,* **106**, 26,817-26,831.

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PUBLICATIONS

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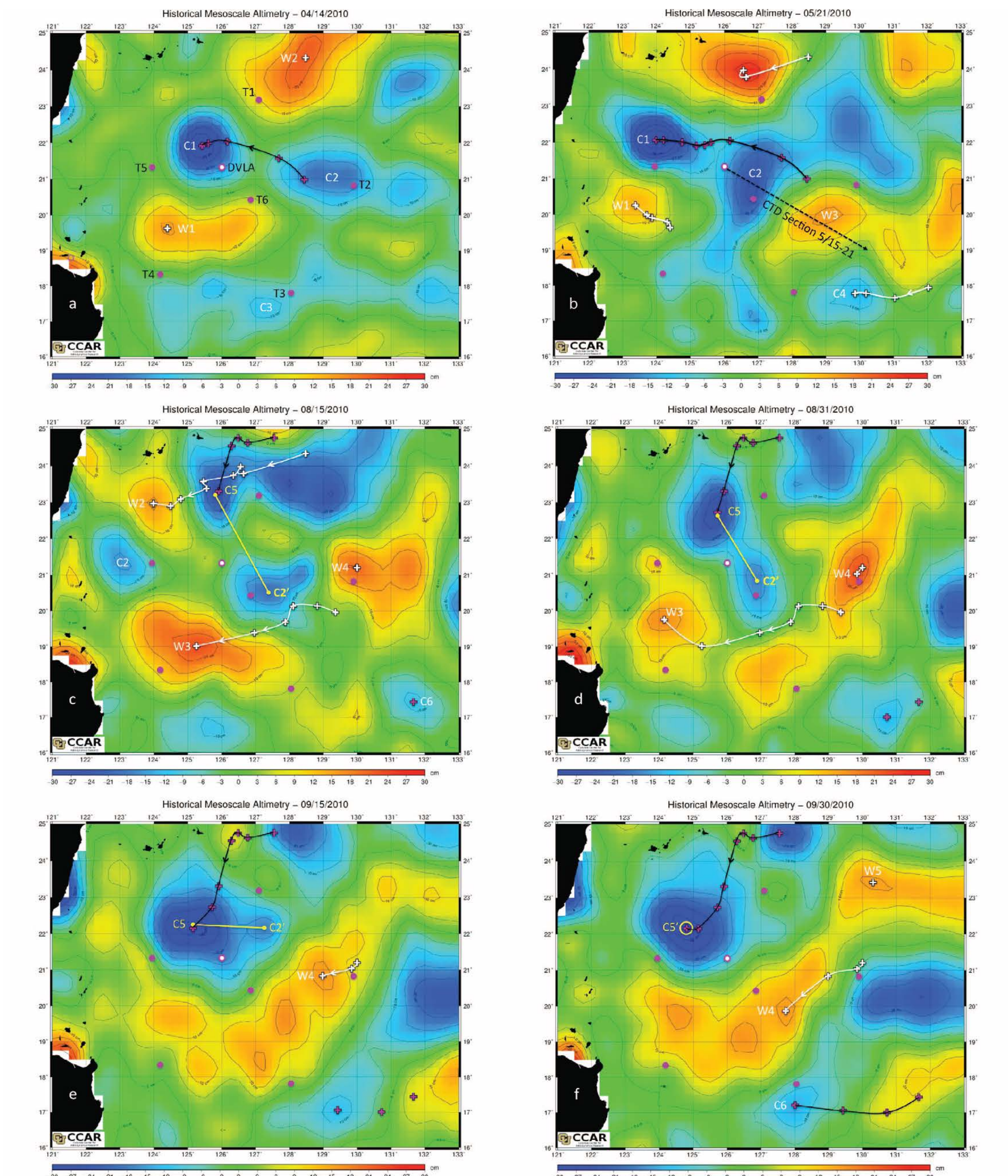

Figure 1. The distribution of cyclonic (cold, blue) and anticyclonic (warm, red) mesoscale eddies in the PhilSea10 array region. The mooring locations T1-T6 and DVLA are indicated in panel a. The same situation is revisited 37 days later in panel b, with eddy tracks superimposed. Warm eddy tracks are shown in white and cold eddies in black. The distance between "x's" is the distance traveled in 14 days and thus is an indication of relative eddy propagation speed. Panel b also shows the CTD/ADCP transect location for Figure 2. Panels c-f show an eddy/eddy interaction plus additional representative eddy tracks. See text for additional details. (Base maps from the Colorado Center for Astrodynamics Research, CCAR)

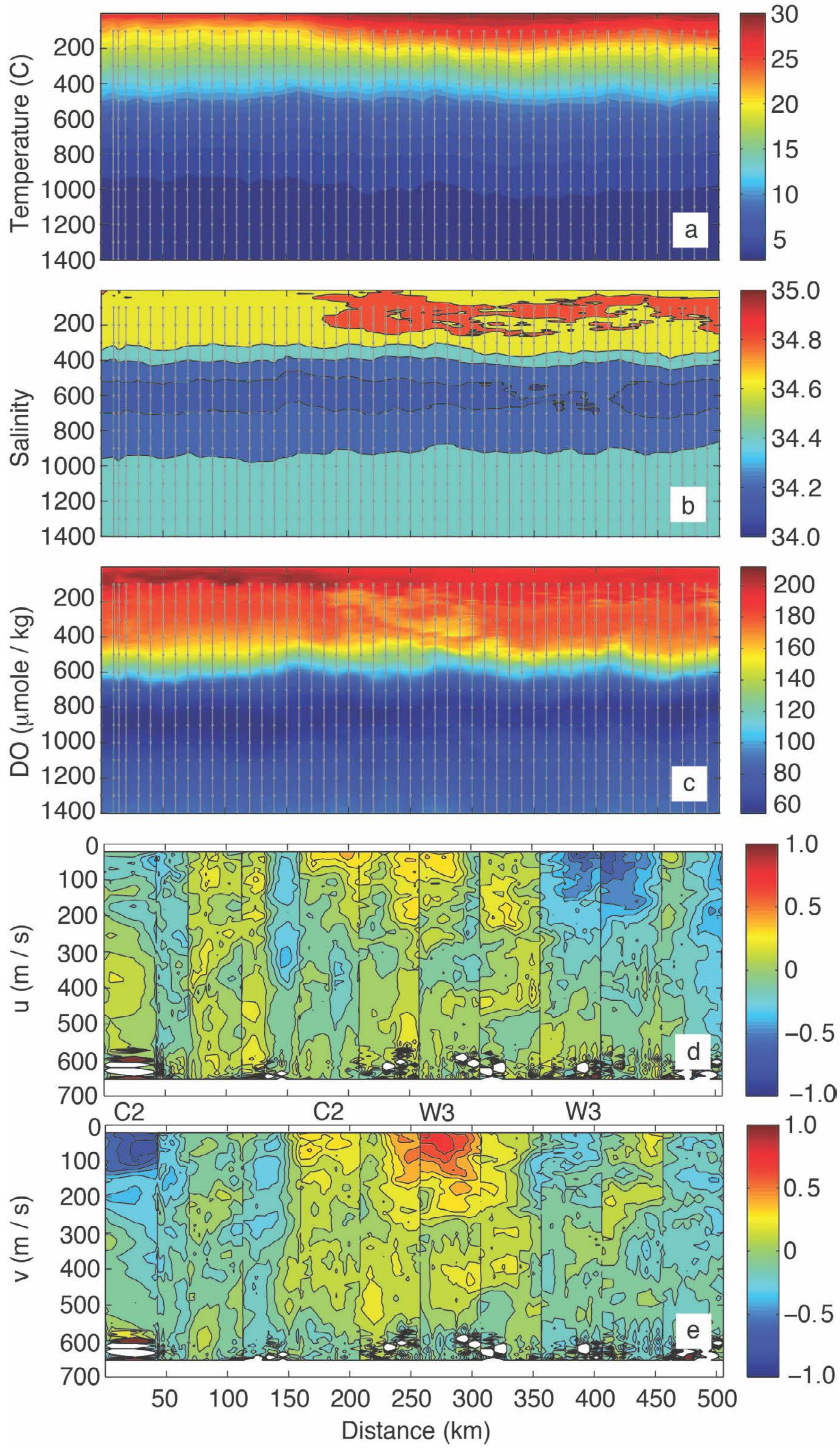

Figure 2. CTD and hull-mounted ADCP velocity sections across eddies C2 and W3. The section location is shown in Figure 1. From top to bottom, the sections display a) temperature, b) salinity, c) dissolved oxygen, d) zonal velocity, and e) meridional velocity. The velocity data are hourly averages from the 75 kHz ADCP.