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The Barny Program: fourteen years of NURC-NRL collaboration

Henry T. Perkins, Jeffrey W. Book, Federico de Strobel, Lavinio Gualdesi, Ewa Jarosz, William J. Teague

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About NURC

Our vision

- To conduct maritime research and develop products in support of NATO's maritime operational and transformational requirements.
- To be the first port of call for NATO's maritime research needs through our own expertise, particularly in the undersea domain, and that of our many partners in research and technology.

One of three research and technology organisations in NATO, NURC conducts maritime research in support of NATO's operational and transformation requirements. Reporting to the Supreme Allied Commander, Transformation and under the guidance of the NATO Conference of National Armaments Directors and the NATO Military Committee, our focus is on the undersea domain and on solutions to maritime security problems.

The Scientific Committee of National Representatives, membership of which is open to all NATO nations, provides scientific guidance to NURC and the Supreme Allied Commander Transformation.

NURC is funded through NATO common funds and respond explicitly to NATO's common requirements. Our plans and operations are extensively and regularly reviewed by outside bodies including peer review of the science and technology, independent national expert oversight, review of proposed deliverables by military user authorities, and independent business process certification.

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This document, which was written in commemoration of the NATO Undersea Research Centre's 50th Anniversary, has been approved by the Director.

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H.T. Perkins, J.W. Book, F. de Strobel, L. Gualdesi, E. Jarosz, W.J. Teague

Executive Summary: This report describes the Barny Program, which has provided accurate representations of sea surface height and currents in a succession of shallow water regions. It is a response to the change of naval interest from deep water to shallow that followed the breakup of the Soviet Union. The program has involved prolonged collaboration between NURC and the US Naval Research Laboratory (NRL).

Two enabling technologies for shallow water measurements have been developed. One is the "Barny" trawl resistant bottom mount (so named after its barnacle-like shape) that allows acoustic Doppler current profilers and bottom pressure gauges to be deployed for intervals of several months. There have been over 300 consecutive successful Barny deployments to date, many in regions of extremely heavy fishing. The other is "variational data assimilation" that permits numerical models to be forced by data located inside the model domain rather than on model boundaries where data is often scarce or uncertain. Models of this type forced by Barny-provided currents and pressures have led to predictions of tidal currents and heights of unprecedented accuracy.

These new technologies have been applied in six regions.

1. Korea/Tsushima Strait. Two lines of Barnys, one across each end of the Strait, were deployed for eleven months beginning in May 1999. These have greatly expanded our knowledge of currents in the Strait.

2. Gyunggi Bay (Approaches to Inchon and Seoul, Korea). In this area of extreme tides, extensive tidal flats, and small-scale bathymetric features, the assimilation model has provided accurate descriptions of tidal currents and surface heights.

3. North Adriatic Sea. Sixteen Barnys were deployed from fall 2002 to spring 2003 to determine ocean response to the sudden, intense winds (bora and scirocco) that occur repeatedly during winter.

4. Northern Gulf of Mexico. An array of 6 Barnys and other instruments was deployed at the shelf edge south of the Mississippi coast from May 2004 to May 2005. The interval included passage of Hurricane Ivan directly over the array.

5. Central Adriatic Sea. A line of 12 Barnys extending northward from Italy's Gargano Peninsula was maintained for 11 months starting in October 2005 to determine exchange processes across the Palagruza Sill.

6. The Dardanelles and Bosphorus Straits. Eight Barnys were deployed in pairs at the ends of these areas September 2008 to measure the two-layer exchange processes between the Aegean and Black Seas. A reduced array will remain deployed until September 2009.

This work has resulted in a continuing stream of publications in the oceanographic literature.

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Abstract: Shallow ocean environments, with their rapid variability, short spatial scales and often intense fishing, pose a special challenge for physical oceanographic study. Since 1995, a series of collaborative programs between NURC and the US Naval Research Laboratory (NRL) have addressed this issue. That effort has resulted in an improved capability for measurement and interpretation in water depths to 200 m, on spatial scales from hundreds of meters to hundreds of km, and on temporal scales from tidal to annual. Here we report on two aspects of this work: first, the technologies which have enabled progress in data collection and interpretation; and second, a summary of six major field programs, conducted mostly through a series of Joint Research Programs between NURC and NRL, in which those technologies have been brought to bear. Taken altogether, an effective, highly mobile and affordable approach for studying ocean shallows is demonstrated.

Contents

1 Introduction

This paper tells the story of the development and application by the NATO Undersea Research Center (NURC) and the US Naval Research Laboratory (NRL) of the Barny trawl resistant bottom mount (TRBM) for long-term deployment of acoustic Doppler current profilers (ADCPs) on the sea floor. Although simple in concept, the Barny (named after its barnacle-like shape) has had a major impact on the conduct of shallow water physical oceanography. It has been the primary instrumentation in 6 major research programs, each spanning several months, and as of this writing (March 2009) has undergone well over 300 consecutive successful deployments. The story is also one of 14 years of fruitful collaboration between NURC and NRL, which still continues. The 50th anniversary of NURC seems the ideal occasion for a review.

In section 2.1 we recount the development and testing of Barny and discuss the attributes responsible for its success. Arrays of Barnys reveal the current structure of selected areas on a variety of scales. Tidal heights and currents in particular can be described in unprecedented detail, and a technique for doing this, variational data assimilation, is briefly discussed in section 2.2. The remainder of the paper, sections 3.1 to 3.6, reviews the six programs noted above. A detailed account of all these topics is well beyond the scope of this report. Instead, we give an overview of objectives, describe the major results, and direct the reader wanting more detail by citing a few key entries in what has become a substantial body of publications.

2
Technical Development

2.1 Barny

Following the breakup of the Soviet Union, the primary domain of naval ocean research shifted abruptly from deep to coastal oceans. These two differ in their dominant physical processes and their spatial and temporal scales: the latter have more rapid variability, shorter spatial scales, and stronger currents associated with tides and with coastal and bathymetric constraints. Also, the intensity of fishing in most of the word's shallows precludes long-term deployment of moorings such as are conventionally used for deep water. Hence the new requirement for shallow ocean research could not be adequately addressed just by using deep water practices in shallow water. To address this situation, NRL began in 1995 to develop its capability for shallow water oceanography based on the newly available compact ADCPs through funding from its Capital Procurement Program.

Figure 1: *Upper left: Barny on the bottom in data collection mode. An ADCP looks upward from the apex. Upper right: normal recovery. Released acoustically, the circular orange float is bringing the ADCP and a recovery line to the surface. Lower left: emergency recovery. The ballast ring has been dropped and the instrument housing is rising to the surface. Lower right: emergency recovery from overturned position.*

There being at that time no suitable way to install these instruments on the bottom, an agreement was negotiated with NURC, with support of its then-director David Bradley, to develop a trawl resistant bottom mount (TRBM) with emphasis on reliability and mobility. Broad requirements for what came to be called Barny (Figure 1) were laid out by NRL and detailed designs were made at NURC by the late Umberto Cortis. Prototypes were built in La Spezia by Giancarlo Bartoli at his firm Proteco Sub under NURC oversight and management. Initial tests were made by NURC (Figures 2, 3), further testing was done by NRL in the Gulf of Mexico, and final production was carried out by Proteco Sub. Intellectual property rights are held equally by the two institutions.

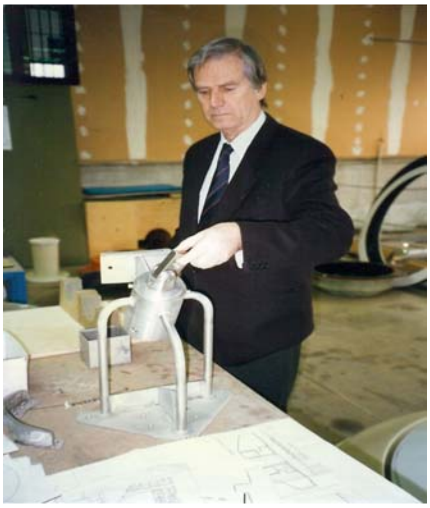

Figure 2: *Federico de Strobel inspecting a Barny component during development at the facility of the local builder Proteco Sub.*

Figure 3: *Lavinio Gualdesi (left) solves the problem of recovery line tangling by putting the line in a stretchy bag. Giancarlo Bartoli of Proteco Sub is at right. Photo taken on NURC's former workboat, MANNING.*

Housed within each Barny is an RDI "Workhorse" ADCP to record currents at many levels in the water column, a pressure gauge to measure sea surface height, and two acoustic release/transponders, each controlling a fully independent recovery and acoustic location function (Figure 4). Guiding these choices was the desire for extreme reliability to minimize the potential for loss of equipment and data. Affordability was essential so that enough Barnys could be fielded to make a useful array. In practical terms, cost of the Barny housing was not to exceed the combined value of the on-board instruments.

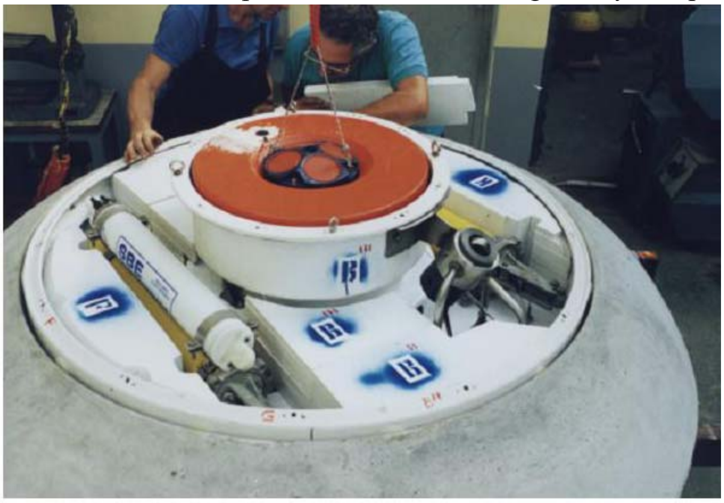

Figure 4: *Barny interior showing: two acoustic transponder/releases (yellow cylinders, barely visible), pressure/temperature gauge (white cylinder), pop-up recovery float (orange cylinder), and in the centre, an ADCP with upward-looking acoustic transducers. The irregularly shaped white pieces are a jigsaw puzzle of flotation material.*

Keys to Barny reliability are a reinforced concrete base to absorb impacts, a smooth profile so that trawl gear can slide over the top, multiple independent recovery modes, and a policy of making and evaluating incremental improvements. Mobility was achieved by providing each Barny with a stackable rack for shipping and storage, allowing up to twelve Barnys to be stacked three-high in a standard 40 ft shipping container together with launch/recovery equipment, and spare parts - all the equipment needed for a major field program.

Figure 5: *Barny prototype being launched for testing near NURC.*

Figure 5 shows a prototype Barny in launch configuration. The silver coloured canister monitors the depth, pitch and roll of the package during lowering until it is confirmed to be sitting level on the bottom. The acoustic launch release (vertical yellow cylinder) is then activated and all the launch hard-ware is brought back on board. A more complete Barny description is given in Perkins, et al. (2000).

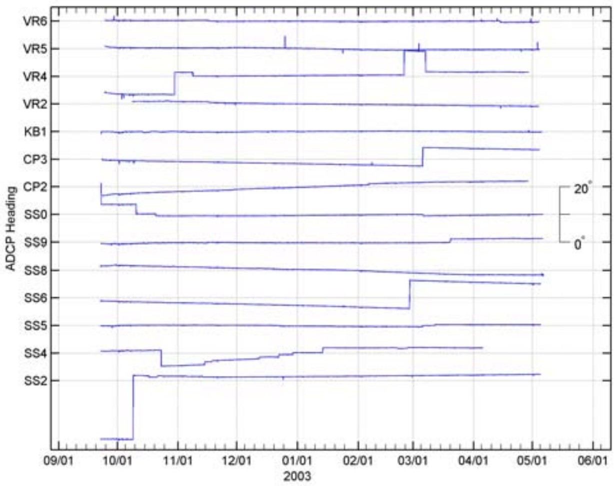

Figure 6: *Barny trawler hits are indicated by abrupt changes in ADCP compass heading vs. time for 14 Barnys deployed in the Adriatic Sea during 2002-2003. Traces are offset by 10^0 for clarity (see scale at right). Labels on left axis are NRL site identifiers. See Figure 12 for mooring locations.*

Figure 7: *Barny recovered from a muddy site near the Po River outflow. Although filled with mud, it functioned normally.*

By far the greatest hazard to a Barny while it is collecting data comes from fishing trawlers. After the instrument is recovered, trawler hits are easily recognized by the marks they leave. Hits are also evident as abrupt changes in the compass heading of the ADCP, one of the parameters it records. The intensity of fishing in the Adriatic Sea and the ability of Barnys to withstand it are clearly brought out in Figure 6, showing the compass heading vs. time for the 14 instruments used in the ACE program (reviewed below). Collectively these instruments survived 33 trawl strikes without loss of data and one instrument alone in a favored fishing spot was struck 11 times. Mud also presents a risk. Although it has not been found to prevent functioning of the instrument (Figure 7), extremely soft mud can interfere with recovery. Biofouling is controlled with antifouling paint.

2.2 Data Assimilation

A program for variational data assimilation was written for NRL by Keith Thompson of Dalhousie University in Halifax. This approach, which is well known and well documented (Griffin and Thompson, 1996; Pistek et al., 1998; Book, et al., 2004), is implemented through a numerical model that is driven by tidal-frequency data within the model domain. Here we give a very brief sketch of the procedure because it provides such outstanding tidal predictions from a mix of Barny and other data. The reader wanting more technical depth can find it in the three works just cited.

Output from the model consists of amplitudes and phases of surface elevation and barotropic (depth averaged) current for each tidal frequency and at each model grid point. The underlying model equations are the traditional linearized, vertically averaged shallow-water equations of motion. These gridded arrays of tidal amplitude and phase constitute a tidal data base that can be used to calculate barotropic tidal height and current for any time, past or future and, through spatial interpolation of the output, to any position in the model domain. The assimilation technique finds boundary values for the model that minimize the squared difference between model output and data input (the cost function). It therefore eliminates the need for externally imposed boundary conditions, which are required for conventional models but are often difficult to obtain and verify. One may therefore think of assimilation as a dynamically correct data interpolator.

In most coastal regions of the world, tidal velocity data is scarce, usually owing to the difficulty of maintaining moorings for long-periods under a constant threat of damage by fishing activities. Thus, Barny's data collection strengths are ideally suited to address this important gap, and data from Barnys provide important tidal information needed for better assimilation and tidal modeling away from the coasts. Normal pre-assimilation data processing strongly discriminates against anything that is not a barotropic tide: vertically averaging the measured currents discriminates against baroclinic (depth dependent) processes such as internal tides, and least-squares tidal analysis of the vertically averaged data further discriminates by requiring phase stability over records that are often several months long. Moreover, current data has been found to provide a stronger constraint on the model than does surface height so that a modest number of Barnys can resolve the tides over a substantial area, as is documented in the program descriptions that follow.

Our confidence in the barotropic equations, the data assimilation model, and the tidally analyzed data itself has come to be very high. In a successful assimilation, the residual error between model and data is small. This close agreement remains even when portions of the available input data are withheld from the assimilation. As an added bonus, assimilation has been found to be an excellent indicator of data quality; in the few occasions where assimilation of data from some measurement site has led to a large model-data mismatch, we have found the problem to lie with data processing errors.

3
Programs and Results

Descriptions of six programs that made essential use of Barnys, and sometimes data assimilation, make up the remainder of this paper, with emphasis on principal scientific findings and publications. Each program has resulted in a dataset that is much richer than can be described here. For example, currents from a Barny deployment typically consist of measurements at many depth levels from top to bottom once per hour for several months and so will have useful information on many scales, whereas here they are shown averaged over depth and time to give an estimate of the mean current and are represented in a figure as a single vector.

Within each project, we have tried to work closely with others active in the same areas and have greatly benefited by doing so. These were usually professional scientists working in their home waters and were regional experts. We regret that their efforts cannot be treated more fully here.

The programs are presented below in temporal order and identified by geographic area. Most of them involve NURC/NRL cooperation in the form of a Joint Research Program (JRP), participation by personnel from both institutions, and use of the NURC vessel NRV ALLIANCE. NRL project names, being broadly descriptive, are given in parenthesis.

3.1 Korea/Tsushima Strait (LINKS - Linkage of Asian Marginal Seas).

This was the first major Barny application, during which a line of six instruments was deployed across each end of the Strait for eleven months in 1999-2000. These were the first successful long-term mooring sections made in the heavily fished Strait. Work was coordinated with Korean oceanographers and with an ONR-sponsored program in the adjacent Japan/East Sea. A summary of the oceanography of this region has been given by Chang, et al., 2004. Here we note three findings from the Barny measurements. (See Perkins, et al., 2000; Jacobs, et al., 2001; Teague, et al., 2002.).

A well known mean current flows north eastward through the Strait into the Japan/East Sea as seen in Figure 8. We estimate its average annual transport as 2.7 Sv. through the well placed southern mooring line and found that the current split caused by Tsushima Is. persists for more than 60 km from the NE tip of the Island as seen on the northern line.

Current variations over intervals of 2 to 4 days have transport comparable to the mean (Teague, et al., 2002). The variations are caused by changes in atmospheric surface pressure over the Japan/East Sea, (Lyu, et al., 2002,). In the response to this atmospheric "pumping", the mass of water in the straits leading into and out of the Japan/east Sea, dominated by that in Korea/Tsushima Strait, plays a major role. In this sense the response is Helmholtz-like, although in this case there is no resonance.

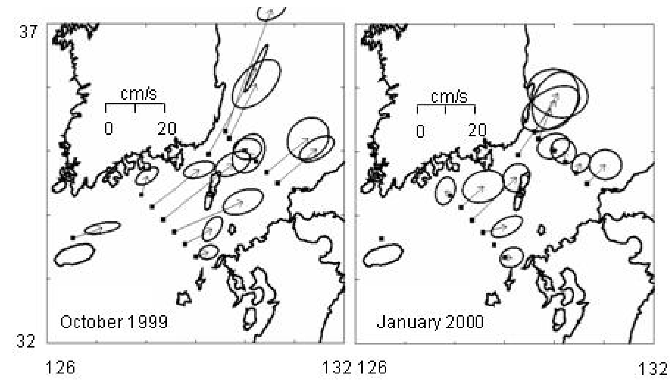

Figure 8: *Mooring locations and currents in Korea/Tsushima Strait during LINKS. Vectors originating at each mooring site give mean current averaged vertically and over the month of October 1999, when currents were strongest, and January 2000, when they were weakest. A standard-deviation ellipse at the tip of each vector indicates non-tidal variability.*

Assimilated into a regional model for the 8 largest tidal constituents was a very large collection of tidal observations, including the Barny measurements, coastal tidal heights, and satellite altimeter heights, the altimetric heights having been shown to give good estimates of tidal height in shallow water (Teague, et al., 2000). The model domain is identified as region 1 in Figure 9. RMS model-data differences averaged over all Barny sites were 1.2 cm/s for u and v current components and 0.9 cm for surface height (Book, et al., 2004).

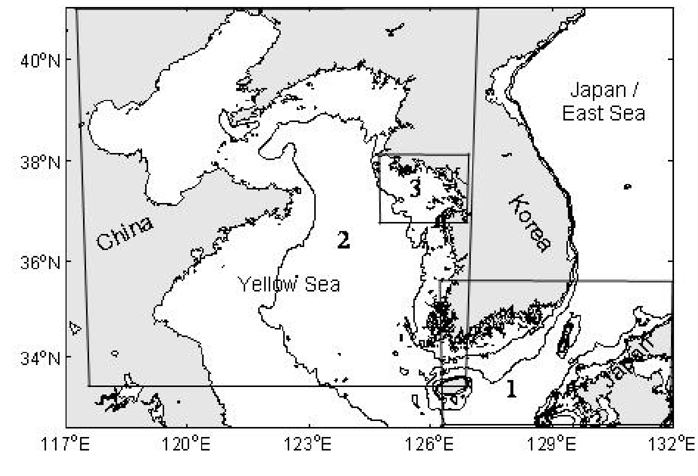

Figure 9: *Domains of Asian assimilative tide models: 1 - Korea/Tsushima Strait; 2 - Yellow Sea; 3 - Gyunggi Bay. Bathymetric contours are shown at 50 and 100 m.*

3.2 Yellow Sea and Gyunggi Bay (High Resolution Coastal Currents).

Tides in the Yellow Sea are among the world's highest, with tidal ranges at some locations of over eight meters measured peak-to-peak during springs. Objectives of this program were to produce descriptions of the tides in the Yellow Sea and in Gyunggi Bay, regions 2 and 3 respectively in Figure 9. The project was a joint effort between NRL and the Korean Ocean Research and Development Institute (KORDI), with funding support from the Korean government and from the US Navy through its ONR-NICOP program and through the Naval Oceanographic Office. An especially valuable component of the collaboration has been the Barny-based ADCP data collected by KORDI in Gyunggi Bay (Figure 10), which includes the approaches to Seoul and Inchon, Korea.

Figure 10: *Barny recovery in Gyunggi Bay by Kyung-Il Chang (right) of KORDI.*

An assimilative tide model for the Yellow Sea (Figure 9, region 2) was first constructed, making use of coastal tide stations, satellite altimetric data, and the few other current and pelagic tide measurements that were available. Our intention was to create a tide model for the whole Yellow Sea that would be of interest in its own right and would merge seamlessly with a more detailed Gyunggi Bay model. However, the Yellow Sea model proved to be of limited accuracy because of inadequacies in the available bathymetric data bases. The two models agreed well with each other, not surprisingly, only in regions where the bathymetry was sufficiently smooth to be well resolved in the coarser, large-scale model. Performance of the large-scale model was also disappointing in its northern (Bohai Bay) and eastern (Chinese coast) regions where there are considerable uncertainties in bathymetry. A uniformly valid tide model of the Yellow Sea will require a more detailed and accurate bathymetric data base than was available to us.

Gyunggi Bay (Figure 9, region 3) is characterized by extremely strong tides, shallow water and extensive tidal flats. It also has a highly irregular coastline, which has been extensively modified by ongoing land-reclamation projects especially east of longitude 126 E. We consider it to be one of the more challenging areas in the world for tidal predictions. Assimilated into this model were: 27 Topex-Poseidon altimeter sites, 8 IHO coastal tidal stations, 1 ADCP from the US Naval Oceanographic Office, and 3 KORDI-run Barny deployments. All data was reduced to amplitudes and phases for each site for the four dominant tidal constituents, M_2, S_2, O_1, and K_1. The resulting tidal coefficients were used to synthesize month-long, tides-only time series for assimilation. A few bathymetric data bases were evaluated by running the assimilation model for each one and ranking them according to which gave the best model-data fit. The winner was the US National Imagery and Mapping Agency (NIMA) Digital Nautical Chart soundings. The coastline was updated using Korean maps. Tidal flats in the north and northeast were removed from the model domain by providing an open model boundary just seaward of them so that optimum boundary conditions there could be determined by the assimilation procedure itself. This useful technique is not available to non-assimilative models. Accuracy of the resulting Gyunggi Bay tide model is typically under 10 cm for surface height and from 10 to 15 cm/s for current.

3.3 North Adriatic Sea (ACE - Adriatic Current Experiment).

The area was chosen to explore response of this shallow sea to the sudden, intense winds that occur repeatedly in the area during winter. These are of two main types: bora, which blow towards the southwest from the mountains of Croatia, and scirocco, which blow northeastward up the axis of the Adriatic. As a result of cooperation between several US institutions, NURC and the national laboratories of Italy, Croatia and Slovenia, a large and diverse array of instruments were concentrated in the area mostly north of Ancona, Italy during the winter of 2002-2003. Here we focus on the array of 14 Barnys deployed at that time by NRL and NURC through a JRP (Figure 11). Intense bottom trawling in the area, combined with past geopolitical tensions, have previously prevented large deployments of moored current meters.

Figure 11: *Headed for the Adriatic Sea and the ACE program, the ALLIANCE afterdeck is bestrewn with 14 Barnys*.

During the winter of 2002 - 2003, seven bora and two scirocco occurred (Lee, et al., 2005; Book, et al., 2007). Currents at all Barny sites resulting from the bora of Jan. 9, 2003, which may be taken as representative, are shown in the lower-right panel of Figure 12. Outflow from the N Adriatic is generally concentrated along the coast near Ancona but is strengthened during bora by a factor of two to four (compare the bora panel to the upper panels of Figure 12). A similar statement can be made for sirocco-driven currents during the two storms that were observed (e.g., see the lower-left panel of Figure 12 for the Nov. 16, 2002 sirocco).

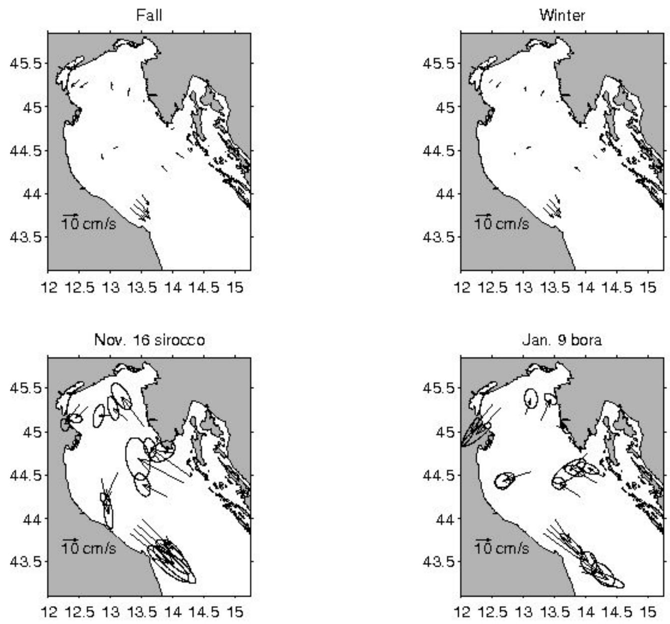

Figure 12: *NRL and NURC mooring locations and example currents in the Northern Adriatic during ACE. Mean currents observed for fall, winter, a day with strong scirocco wind, and a day with strong bora wind. A velocity-scale vector is drawn in the bottom left of each panel. The ellipses drawn on the scirocco and bora panels are the two-standard-deviation ellipses centred at the mean flow values.*

The Adriatic is one of those regions in the Mediterranean where tides are significant. They are the subject of continuing investigation. All Barnys were recovered safely despite experiencing many trawler hits and a very soft muddy bottom at some sites (Figures 6, 7, and 13).

3.4 Northern Gulf of Mexico (SEED - Slope to Shelf Energetics and Exchange Dynamics).

An array of thirteen ADCPs and other instruments was deployed across the shelf break south of the Mississippi coast from May 2004 to May 2005 (Figure 14). The six shallowest moorings, three at 60 m depth and three at 90 m depth, were Barnys. The seven deepest moorings included RDI "Long-Ranger" ADCPs in buoyancy spheres that covered the upper 500 m of the water column. These high-resolution measurements were planned to better understand the mechanisms that transfer properties across the shelf slope.

Figure 13: *With all ACE Barnys recovered and secured on deck, ALLIANCE heads for La Spezia. A tired scientist (Henry Perkins) is still recovering.*

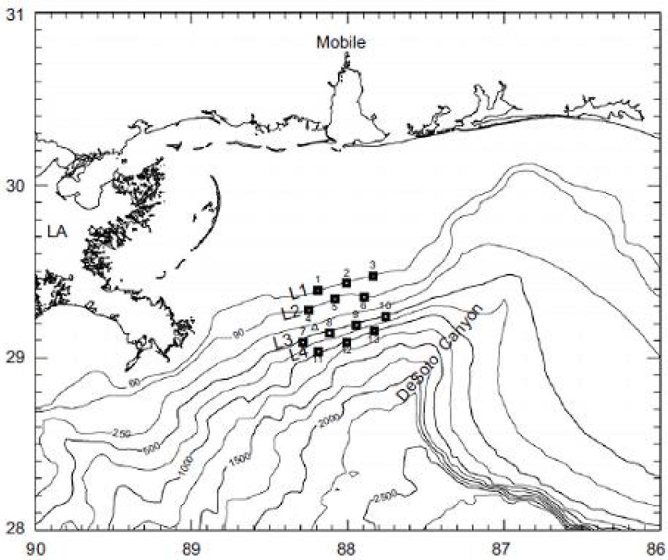

Figure 14: *Mooring array in the SEED program, in place from May 2004 to May 2005. The six shallowest sites were occupied by Barnys, the remainder by "Long Ranger" ADCPs that covered the upper 500 m of the water column. Bathymetric contours are at 60, 90 and 250 m and every 250 m thereafter.*

During SEED, currents were found to be driven by both local and remote winds, by cyclonic eddies associated with the Gulf of Mexico Loop Current extension, and Loop Current rings, by smaller eddies associated with the cyclonic eddies, by frontal meanders or streamers associated with the eddies, and by tropical storms (Teague, et al., 2006; Carnes, et al., 2008). Currents at the shelf edge were characterized and related to the integrated wind-stress curl. Large scale circulation features could be determined from the first two empirical orthogonal function (EOF) modes, which accounted for 83% of the variance and were strongly related to the integrated wind stress.

Passage of Hurricane Ivan directly over the SEED array provided what may well be the best data set of currents under a major hurricane ever gathered. This encounter resulted in: the highest wave ever measured (Wang, et al., 2005); determination of the air-sea momentum exchange by instruments on the sea floor (Jarosz et al., 2007); and large bottom scour on the outer shelf (Teague, et al., 2007).

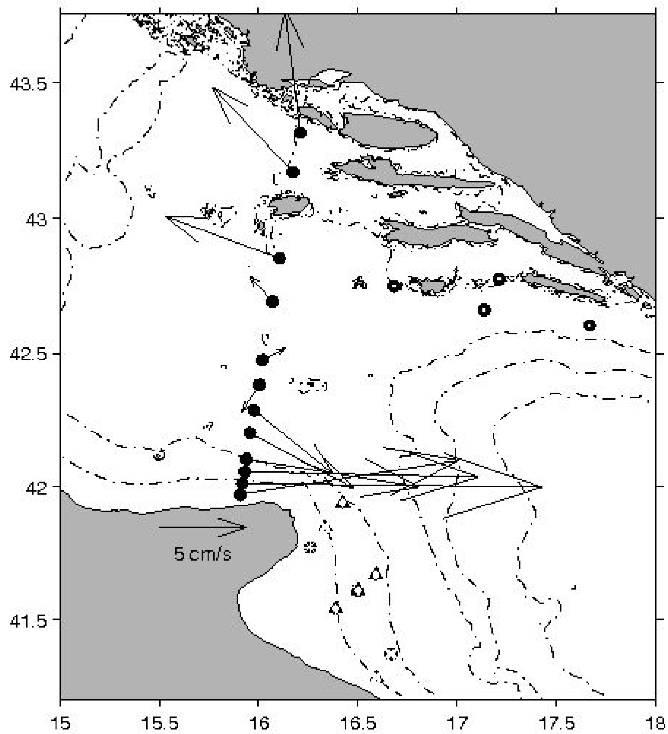

Figure 15: *DART major mooring sites. The line of 12 Barnys running north from Cape Gargano to the Croatian coast (solid circles) was maintained from October 23, 2005 to September 15, 2006. Mean, depth-averaged currents for this time period are shown with arrows with a velocity scale plotted over Cape Gargano, Italy. Two moorings failed early and the means are over shorter periods. Other symbols show the locations of Barnys or other moorings from NRL, NURC, and collaborating Croatian institutions that were deployed at various times for shorter periods over the 11 month experiment.*

3.5 Central Adriatic Sea (DART - Dynamics of the Adriatic in Real Time).

During 2005-6, NRL in collaboration with NURC and several international partners, undertook a study to evaluate monitoring and prediction capabilities for vigorous, swiftly-evolving fronts and eddies in a topographically controlled coastal environment. (Book, et al., 2008). The Palagruža Sill and Cape Gargano area of the central Adriatic Sea were chosen as the focus areas for DART because they exhibit strong isobath curvature and divergence associated with sharp topographic changes and because the West Adriatic Current frontal system produces instabilities in this region (Burrage, et al., 2009). A major part of the NRL component of DART was deployment of a line of 12 Barnys from October 2005 through September 2006 (11 months). The moorings ran along the Palagruža Sill from the north shore of Cape Gargano, Italy to the Croatian Island of Šolta (43.42°N, 16.25°E) and extended into the channels between nearby Croatian islands (Figure 15). Also collected were drifter data, towed Conductivity, Temperature and Depth (CTD) measurements, turbulence profile measurements, numerous standard CTD casts, remotely sensed temperature, optics, and roughness. In addition, high-resolution atmospheric and ocean models, and wave models were run to realize various research goals (Dykes et al., 2009; Martin, et al., 2009).

The program has provided the first direct measurements of exchange at the along-axis shelf break of the Adriatic, and illuminates mechanisms for exchange (e.g., Vilibić, et al., 2009). Analysis is ongoing.

3.6 Turkish Straits (EPOS - Exchange Processes in Ocean Straits).

Eight Barnys were deployed in pairs at the ends of the Dardanelles/Çanakkale Straits and Bosporus/Istanbul Straits in September 2008 (Figure 16). They were recovered and the Dardanelles/Çanakkale moorings were redeployed in February 2009, to be recovered for the final time in October 2009. This work, a collaboration between NRL, NURC and Turkish institutions, was planned to determine the two-layer exchange processes between the Aegean and Black Seas.

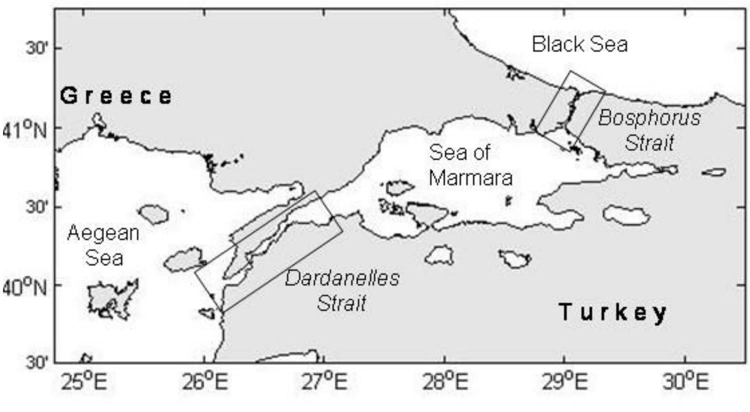

Figure 16: *Eight EPOS Barny moorings in the Turkish Straits; two at each end of the Dardanelles Strait and two more at each end of the Bosphorus Strait.*

Historical and recent studies have shown that straits can have a strong impact on the large-scale thermohaline circulation of the ocean. Knowledge of the exchange dynamics in straits is also critical to comprehend and predict the circulation in the basins connected by these straits. Past studies have shown that the exchange flow in straits can vary on a variety of temporal and spatial scales. An important temporal scale requiring more research is the synoptic time scale with periods between a few days and a few months. Synoptic variability is very energetic in both open and coastal oceans; however, our understanding of synoptic fluctuations in straits is still limited. Hence, the long term goal of this project is to understand synoptic variability and its significance to exchange dynamics in ocean straits.

Analysis of these measurements will address the following issues: seasonal variability of the exchange flow; importance of synoptic time-scale variability of the exchange; influence of mixing and topographic effects on flow and stratification in the two straits; and the appropriate minimum physics that must be represented in analytical and numerical models to accurately predict the observed exchange dynamics. Figure 17 symbolizes the ongoing nature of this program.

Figure 17: *A much used Barny is recovered off Istanbul during a scheduled EPOS servicing operation in February 2009. Measurements will continue in the Dardanelles/Çanakkale until October, 2009.*

4
Conclusions

Development and application of the Barny TRBM was made possible by close cooperation between NURC and NRL. The high level of performance of the Barnys, their high degree of mobility and overall reliability, enables them to be deployed in arrays of moderate spatial extent in much of the world's ocean shallows. A high probability that the instruments and data will be recovered allows arrays to be planned and deployed with little concern that the overall experimental plan will be disrupted by losses of equipment or data. Effectiveness of this approach has been demonstrated in several widely separated, dissimilar regions, some of which are extremely heavily fished.

Assimilation of tidal current and surface height data permits description of the tides over extensive areas with accuracy limited primarily by uncertainties in bathymetry. Barny-based measurements, coastal tide station data, tidal surface heights from satellite altimetry, historical current moorings, and pelagic tide gauges, none of which need be contemporaneous, can be simultaneously assimilated into a model of the linearized, barotropic shallow water equations. The resulting database of gridded tidal coefficients will satisfy two essential requirements: first, it will by its construction satisfy the barotropic tidal equations and second, it will be in close agreement with the tidal data throughout the model domain. In each case where adequate oceanographic and bathymetric data were available, the resulting description of the barotropic tide is highly accurate.

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Title

The Barny Program: fourteen Years of NURC-NRL collaboration

Abstract

Shallow ocean environments, with their rapid variability, short spatial scales and often intense fishing, pose a special challenge for physical oceanographic study. Since 1995, a series of collaborative programs between NURC and the US Naval Research Laboratory (NRL) have addressed this issue. That effort has resulted in an improved capability for measurement and interpretation in water depths to 200 m, on spatial scales from hundreds of meters to hundreds of km, and on temporal scales from tidal to annual. Here we report on two aspects of this work: first, the technologies which have enabled progress in data collection and interpretation; and second, a summary of six major field programs, conducted mostly through a series of Joint Research Programs between NURC and NRL, in which those technologies have been brought to bear. Taken altogether, an effective, highly mobile and affordable approach for studying ocean shallows is demonstrated.

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