J2.5 COMET® MARINE AND COASTAL METEOROLOGY MODULES

Kevin K. Fuell*, Doug Wesley, Alan J. Bol
UCAR/COMET, Boulder, Colorado

1. INTRODUCTION

Since 1990, the Cooperative Program for Operational Meteorology, Education and Training (COMET) has been conducting residence courses and delivering distance learning materials to support the integration of science into the operational forecast process. With NOAA's National Weather Service (NWS) as its core sponsor, the COMET Program has produced web-based training on many aspects of weather forecasting, including hydrology, aviation, fire weather, convective storms, numerical weather prediction, winter weather, and satellite meteorology.

In the mid-1990's the COMET Program produced its first marine meteorology module. The focus of this material was primarily on offshore (deep water) forecast issues affecting the commercial and recreational mariner. In 2003 the COMET Program began updating this material with new advances in modeling and remote sensing as well as making the content web-based. In late 2003 the NWS also requested a series of modules on forecasting rip currents (Fuell 2005). These modules coincide with the launch of the a national rip current program, and they prepare forecasters to provide a rip current hazard level forecast for coastal recreation areas.

Other sponsors, such as the United States Navy, were interested in atmospheric processes that are unique to the coastal environment. In 2001 the Navy tasked COMET to develop training on mesoscale phenomenon affecting the coastal atmosphere. A set of foundation topics are used as stand-alone training modules that support specific training on coastal mesoscale phenomena. The foundation topics cover, for example, the operational definition of mesoscale phenomena, how computer models handle mesoscale processes, interactions with topography, thermally-forced circulations, and principles of convection. These support more specific modules on coastal processes such as coastal jets, dynamically forced fog, cold air damming, and coastally trapped wind reversals. These modules were developed in conjunction with experts at the Naval Post-graduate School (NPS) and are intended for an audience at the undergraduate level. All of these modules can be found at http://meted.ucar.edu.

*Corresponding author address: Kevin Fuell, UCAR/COMET, P.O. Box 3000, Boulder, CO 80507-3000; email: fuell@ucar.edu

2. MARINE – WIND AND WAVE SERIES

A basic skill for a coastal or naval operational forecaster is to be able to forecast wave height and period in nearshore and offshore waters. The original COMET Marine Meteorology module addressed this topic, but was in need of revision to include new advances in modeling and remote sensing. A "Wind and Wave" series of web-based modules began production in 2003.

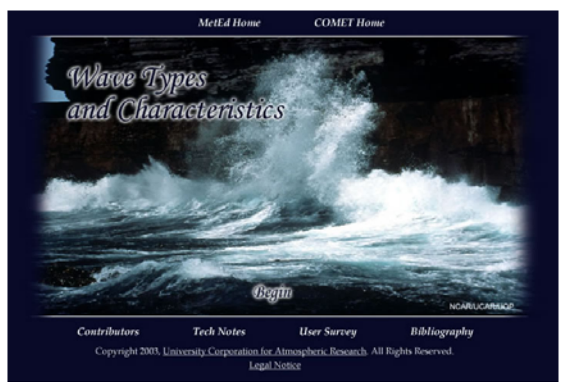

Figure 1. Splash screen to the first module in wind and wave series.

The audience is intended to be forecasters with little to no operational experience in the coastal marine environment. The updated sections on remote sensing and modeling of open ocean conditions may even be useful for veteran marine forecasters. These modules are developed using expertise from experienced NWS staff, private industry, and the university community. They incorporate user interactions, audio, 3-D graphics and animations, operational data products, and test questions. The first three modules in the series start with the basics of wave types and characteristics, followed by understanding wave generation, and then examining wave propagation and dispersion. The concepts from these three modules are then practically applied in a scenario-based module on true sea state forecasting. Because the wind is the driving force of wave growth, the marine boundary layer and its associated winds are examined in a separate module. Lastly, shallow water wave processes are examined as the wave generation and wave propagation modules are mostly applicable to deep water waves. The following sections briefly discuss each of the modules within the series

2.1 *Wave Types and Characteristics*

The basic characteristics of wave height, period, and length are presented in the first module of the series (Figure 1). Wave types ranging from wind waves, tides and seiches are introduced as well as the more rare pressure-induced and tsunami waves. The basic physical, mathematical, and statistical traits of waves are discussed, along with how they change once waves become swell. This material serves as a building block to subsequent modules.

2.2 *Wave Life Cycle I: Generation*

The second module in the series covers the first phase of the wave life cycle: generation. It examines how wind creates waves and the relationships between wind speed, wind duration, and fetch length during generation. These three factors are key to predicting wave height and what will limit wave growth. Two new topics are covered extensively in this module: wave growth due to dynamic fetch (Figure 2), and remote sensing of over-water winds using satellite-based scatterometry (Figure 3). The dynamic fetch content was created with help from forecasters of the Meteorological Service of Canada (MSC), another of COMET's sponsors. Waves generated within a dynamic fetch can become much larger than expected as they remain, or

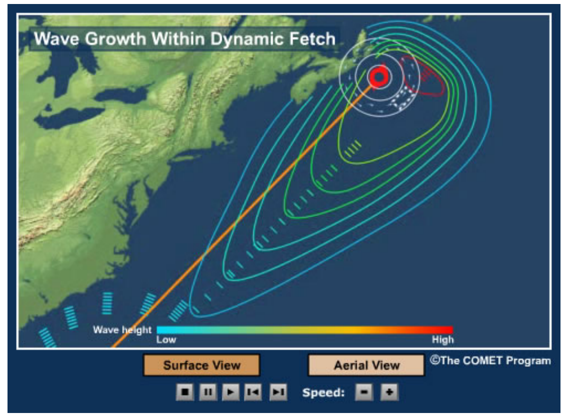

Figure 2. Still shot from the dynamic fetch conceptual animation.

are "trapped," in the fetch for a relatively long duration. A forecast that does not include the effects of dynamic fetch could grossly underestimate the wave heights a mariner may encounter.

The second new topic in the module is scatterometry. This discusses how the observations of over-water winds are made using active microwave sensing. The ability to detect winds over the open water where observations are few and far between makes scatterometry an indispensable tool for any marine forecaster. The strengths and weaknesses of this technique are also presented.

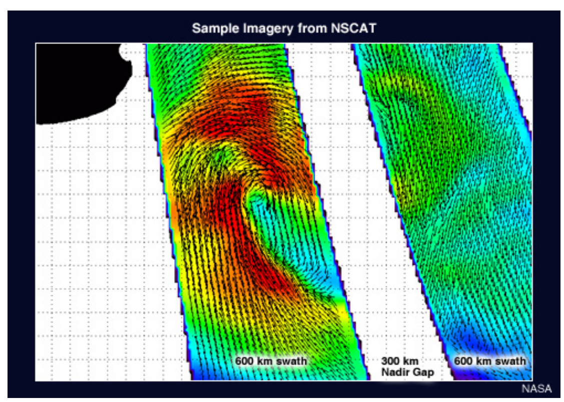

Figure 3. Example of scatterometry wind data.

2.3 *Wave Life Cycle I: Propagation and Dispersion*

The third module in the series examines what happens to the waves after they leave the generation area and begin moving toward a distant coast line. Conceptual animations help the user easily visualize what happens to the wave height and period during these processes (Figure 4). Exercises allow the user to practice manually forecasting the arrival time of distant swell while also presenting the basics of how a wave model would keep track of waves generated and propagating in all directions.

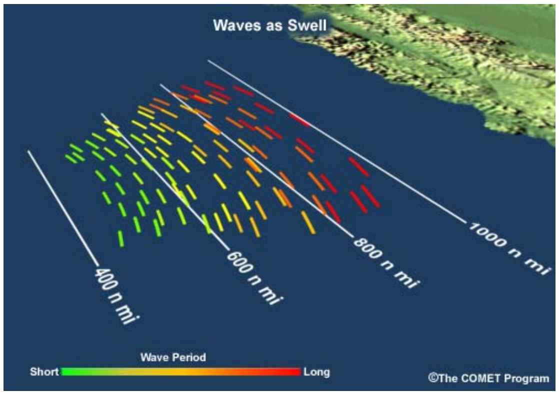

Figure 4. Still shot from the animation of waves propagating toward the coast.

2.4 *True Sea State Forecasting*

Having been introduced to basic wave characteristics and the processes of wave generation, propagation and dispersion, the learner can now apply this knowledge to make a true sea state forecast. In the fourth module, a scenario-based approach highlights the advances in wave modeling and presents the learner with multiple exercises on how to use model output, satellite-based wind observations, and in-situ observations in the forecast process. These exercises simulate the decisions that a marine forecaster makes during day-to-day operations.

2.5 *Marine Boundary Layer*

While the initial training modules concentrate on wave forecasting, they frequently remind the learner that an accurate surface wind forecast is critical for both the forecaster and the numerical model. To reinforce the importance of wind forecasting in the accurate prediction of sea state conditions, a separate module will be published by Spring of 2006. This module will help the forecaster understand the atmospheric processes within the marine boundary layer (MBL) and how these processes develop and modify the surface winds. A basic review of the pressure verses wind relationship leads to more advanced discussions of unbalanced flows including the isallobaric component of the wind. The module then examines the vertical structure of the MBL and how this relates to the surface wind. In particular, the effects on the MBL winds due to stable and unstable atmospheric conditions within the layer are presented. Finally, consideration is given to the impact of coastal terrain, severe convection, and tropical storms on MBL winds.

2.6 *Shallow Water Wave Processes*

Much of the previously described training on waves pertains to those considered to be in deep water. As a wave gets closer to the coast it becomes a shallow water wave and many of its characteristics begin to change as it starts to interact with the bathymetry. The processes that cause these changes, such as shoaling (Figure 5), are presented in this module. Eventually, the wave reaches the nearshore environment and wave breaking occurs. The module discusses why waves break, how to forecast breaking wave height, and how to determine the breaker run up on the beach. In addition, special cases of shallow water wave processes are discussed. These include wave current interactions in river and harbor bars, basin resonance, and tsunamis. Richard Koehler of the NWS Forecast Training Decision Branch at COMET has developed a short information module on tsunamis in light of the December 26, 2004 event. This 15-minute presentation is accessible on COMET's meted website and some of its content will be used within the shallow water wave module, to be published by early 2006.

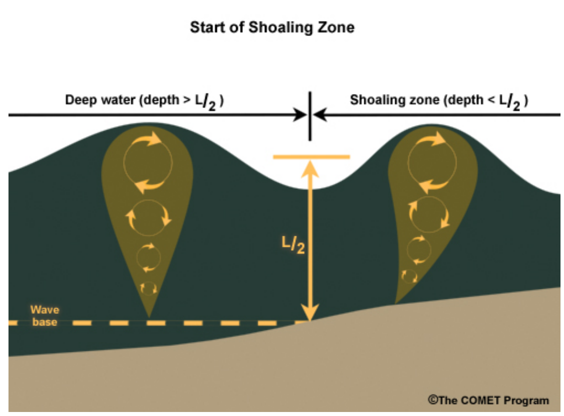

Figure 5. Shoaling process as wave leaves deep water.

3. RIP CURRENT SERIES

The United States Lifesaving Association (USLA) estimates 80% of surf zone rescues and 100 fatalities can be attributed to rip currents annually. The NWS reported that rip currents were the second largest annual cause of weather related deaths in the U.S. from 1994-2003.

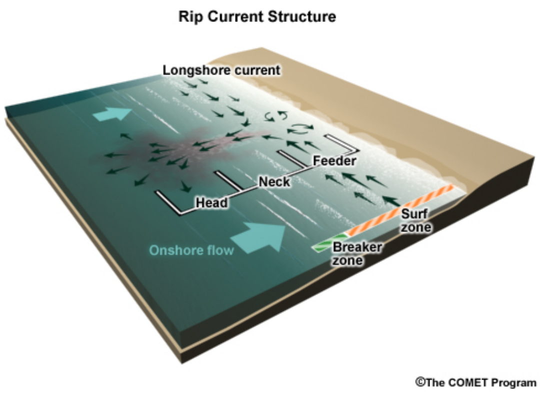

Figure 6. Three-dimensional conceptual graphic of the rip current as part of the nearshore environment.

This prompted the NWS to create a national rip current program and to begin issuing rip current hazard level forecasts in a new seasonal product called the Surf Zone Forecast (SRF). Formal rip current forecasting training began development in late 2003 to educate forecasters on this new product as well the advances in wave modeling, output products from these models, and buoy observations of waves. The main objectives of this training are:

- To present the basic hazard of rip currents and explain how the USLA and NOAA SeaGrant partner with the NWS to protect the public.
- To provide an understanding of the physical oceanography processes that occur in the nearshore environment and to show rip currents as just one of these processes
- To demonstrate the use of sparse wave observations in conjunction with wave model spectral output to forecast the likelihood of rip current development.
- To examine the regional differences in rip current events between the areas of the U.S. West Coast, East and Gulf Coasts, and the Great Lakes using case studies.

The following is a brief description of each module in the rip current training series.

3.1 *NWS Mission and Partnerships*

This 20 minute webcast from Tim Schott of the NWS Marine and Coastal Services Branch presents basic rip current concepts, standards for rip current terminology, and the NWS rip current program objectives. The section on the Rip Current Task Force covers the agreement between the USLA, Sea Grant, and NWS to create a partnership for public outreach, consistent communications regarding rip currents, and knowledge transfer from the research to the operational community. The intended audience consists of forecasters, but this material may be especially useful to those in management.

3.2 *Nearshore Fundamentals*

The second module in the series discusses the nearshore environment and its circulation. The subject matter expert is Dr. Chung-Sheng Wu from the NWS / Office of Science and Technology. This self-paced web module shows rip currents as a natural part of the nearshore circulation and it discusses rip current characteristics in detail. It provides the knowledge needed to understand various aspects of the nearshore circulation and surf zone such as non-uniform breaking wave heights that lead to wave set-up (Figure 7),

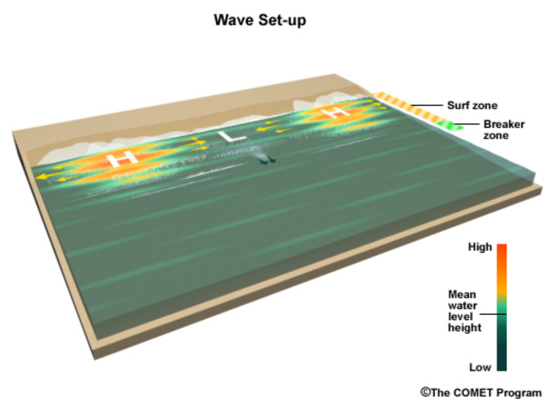

Figure 7. Areas of high (H) and low (L) water level with start of rip current as flow converges.

the longshore current, variable and fixed bathymetry, multi-spectrum waves, as well as the slope of the beach.

While an overall picture of the nearshore environment is presented, the main objective is to understand how aspects of the local nearshore environment affect rip current development and strength and how to apply this knowledge when considering information presented to the public.

3.3 *Rip Current Forecasting*

With the background knowledge of the nearshore marine environment, the focus of the rip current training turns to forecasting these events. In this module subject matter experts from the NWS Wilmington, North Carolina and Miami, Florida weather forecast offices (WFOs) introduce forecasters to wave spectrum analysis where observations by buoys and model predictions of wave energy (Figure 8) are analyzed to assess and forecast the threat of rip currents. The NOAA WaveWatch III is the primary model used in the training.

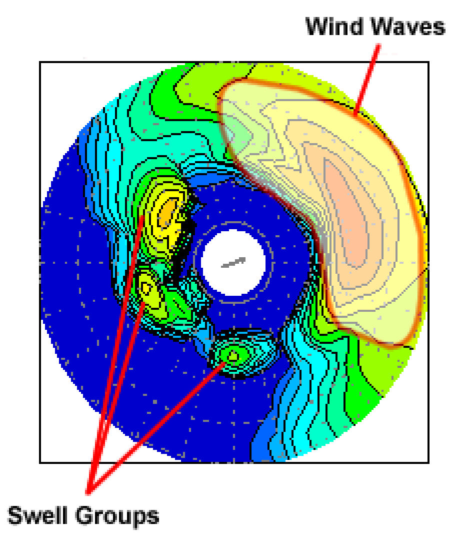

Figure 8. Polar plots of wave energy density from the NOAA WaveWatch III.

3.4 *Rip Current Regionalized Case Studies*

The fourth part in the rip current series uses case studies from several regions of the U.S. to reinforce what has been learned in the first three parts of the series. While the physics of a rip current may be the same, the climatologic influences that develop rip currents may be regionally dependent. Likewise, bathymetric characteristics differ across regions. This module engages the learner to apply the knowledge and skills gained from earlier parts of the series in practical exercises while demonstrating the regional differences in rip current forcing.

4. MESOSCALE PRIMER MODULES ON COASTAL METEOROLOGY

As part of COMET's Mesosale Primer (see http://meted.ucar.edu/mesoprim.index.htm and Fig. 9), several modules address forecaster training needs regarding coastal meteorology. Examples are West Coast Fog, Dynamically-forced Fog, Coastally Trapped Wind Reversals, Cold Air Damming, Coastal Jets and Sea Breezes. These training modules contain material that is primarily aimed for the university undergraduate. Each module contains a real forecasting scenario, scientific content relating to forecasting these phenomena, case examples, interactive questions as the content and examples proceed, and a quiz.

Fig. 9 Web interface for the Mesoscale Primer series.

As an example, we now demonstrate the components of the Coastally Trapped Wind Reversals (CTWR module and Fig. 10).

4.1 *Coastally Trapped Wind Reversals*

The lesson begins with a Naval forecasting scenario centered off of Southern California (Fig. 11).

Fig. 10 Web menu page for the forecasting scenario.

This scenario mimics a forecasting challenge that deals with a common persistent problem off the southern California coast: fog. This challenge is complicated by a model forecast of Visual Flight Rule (VFR) conditions with Northwesterly flow at and near the coast. The model forecast timing of deteriorating conditions busts as a CTWR makes its way northward through the central California coast (Fig. 12), while simultaneously a major Naval carrier/flight mission is trying to conduct operations near the coast. The carrier is moving northward, essentially following the surge, unfortunately.

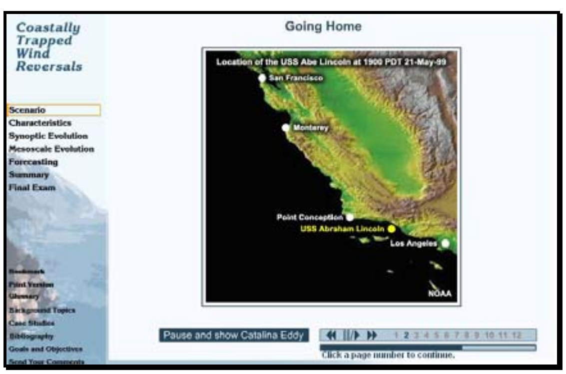

Fig 11 The CTWR forecasting scenario, with the relevant geography of the area illustrated.

The second section of the module describes the characteristics of CTWRs, including climatology (with maps showing international areas prone to the occurrences) and their signature on common meteorological measurements. The next section describes the synoptic evolution of these features.

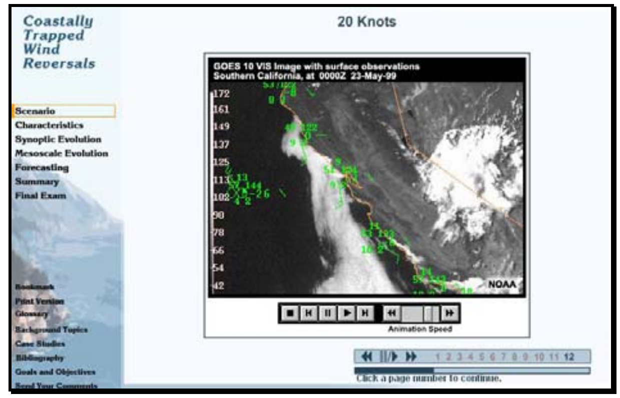

Fig. 12 Visible satellite imagery along with surface observations during the unpredicted surge.

Synoptic aspects include initial conditions and surface, 850 mb, and 500 mb conditions (Fig. 13).

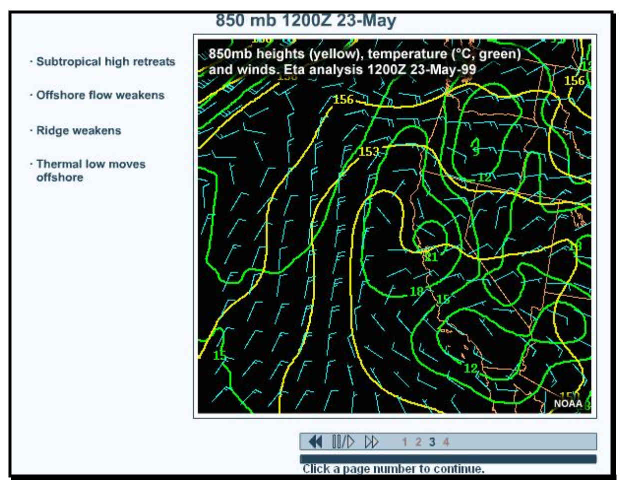

Fig. 13 Observed 850 mb fields during the CTWR of 23 May 1999.

Then, mesoscale observations and conceptual models of the CTWR are discussed, based on historical research conducted off the California coast (Fig. 14).

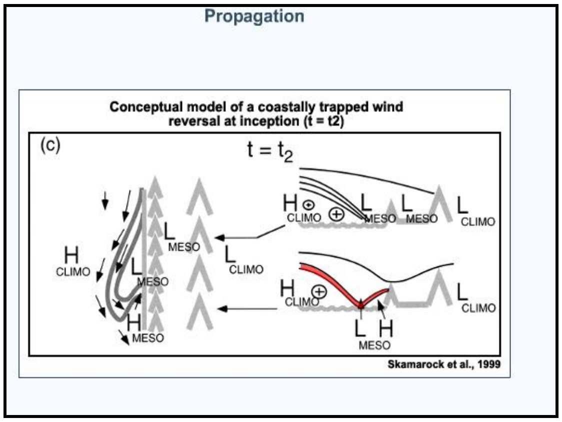

Fig. 14 Mesoscale features in the conceptual model of the CTWR; the stage shown corresponds to the time when the CTWR begins to propagate northward.

The final section of the CTWRs module discusses some forecasting aspects of these events, emphasizing operational models and surface/satellite observations. For example, here is a table presented in this section:

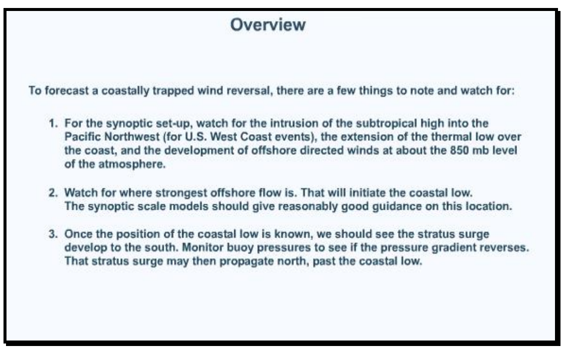

Table 1: Overview of forecasting rules-of-thumb for CTWRs

Fig. 15 shows one interactive exercise from the section on Forecasting CTWRs.

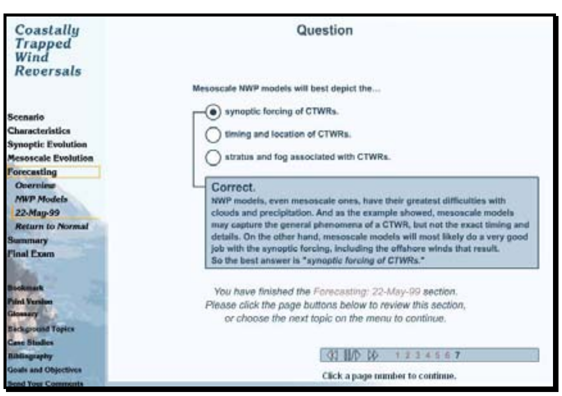

Fig. 15: Example of a module interactive exercise, from the section on Forecasting CTWRs.

A final exam containing 25 multiple-choice questions is included as the final module section. Fig. 16 shows an example.

Fig. 16 Question 20 of the 25-question exam included at the end of the module.

5. SUMMARY

This paper has presented an overview of the marine and coastal meteorology modules in the COMET Program, including the Marine Wind & Wave, Rip Current, and Mesoscale Primer series. The goal of the marine effort is to develop a distance learning marine course using many of the self-paced modules discussed in this paper along with several case-based teletraining sessions led by an instructor. For the Mesoprimer, the Coastally Trapped Wind Reversals lesson was chosen as the showcase Web module in this manuscript. Future modules on (a) Landfalling Fronts and Cyclones and (b) North Wall Effect are currently in development. At this time, the plan is for subsequent efforts in the Mesoprimer to increase coverage of oceanographic topics, including currents and tides.

6. ACKNOWLEDGEMENTS

This paper was funded by cooperative agreement NA17WD2383 from the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. The COMET Program is primarily funded by the NWS, with additional funding from NMOC, AFWA, NESDIS, NPOESS, MSC, and NSF. Graphic artists Steve Deyo and Heidi Godsil provide graphical support for the modules.

7. REFERENCES

COMET, 2005: Marine Meteorology http://meted.ucar.edu/topics_marine.php

COMET, 2005: Mesoscale Meteorology modules. See http://meted.ucar.edu/mesoprim.index.htm

COMET, 2005: Coastal Meteorology modules. See http://meted.ucar.edu/topics_coastwx.php

Fuell, K.K., K. Olson, T. Schott, 2005: Rip Current Training for Coastal Forecasters. Preprints AMS Forum: Living in the Coastal Zone, AMS, J1.5