Educational Needs in the Changing Field of Operational Oceanography: Training the People that will Sustain Munk's 1+1=3 Scenario

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Abstract - The Rutgers University Graduate Program in Oceanography (GPO) has initiated a new Masters Degree in Oceanographic Technologies. Within the collaborative setting of the Rutgers University (R.U.) Coastal Ocean Observation Lab's (COOL) Operations Center, students will receive hands on training in the use of advanced ocean observing technologies and will participate in the year-round field activities supported by the Center. Potential Masters theses topics include improvements to the capabilities of sensors and sampling platforms, and the analysis of the observatory datasets for a wide spectrum of applications. The program was designed with input from a pair of AMS Interactive Workshops on Operational Oceanography, and with input from people working in Navy and NOAA operational centers. Graduates will directly support the sustained technology needs of the Integrated Ocean Observing System and the Ocean Observation Initiative.

I. INTRODUCTION

The world's continental shelves, the narrow ribbon between the major land masses and the deep ocean basins, cover only about 10% of the surface of the globe but account for most of the world's primary productivity and are home to most of the world's fish species. Across these continental shelves, sediments and chemicals supplied by rivers and beaches are transformed as they travel complex pathways to the deepsea. The transport pathways are influenced by forcing from the atmosphere at the surface, the deep ocean on the offshore side, freshwater inputs from the inshore side and along shelf forcing from upstream, evolving in space and time through their own internal dynamics as they interact with a variable bottom topography.

Human populations continue to grow and concentrate along the coasts. Globally human activity is increasing the atmospheric concentrations of carbon dioxide. Locally we require food, water and energy, protection from severe weather, and we produce waste. Continental shelves are affected by these increasing human pressures, responding both to the cycles and trends of global climate, and to the local needs and impacts of expanding coastal populations. Quoting the U.S. Commission on Ocean Policy, we need "sound science for wise decisions" to ensure the sustainable use of our coastal oceans for this and future generations.

II. DECISIONS ARE BASED ON PREDICTIONS

Decisions are made everyday on a range of topics and scales. Where should I go fishing today? When should I bring my ships into port? Should we build offshore windfarms to contribute to the energy grid? Where will the hurricane make landfall? Where should my growing municipality locate its outfall? How should our nation respond to rising greenhouse gases? Wise decisions are based on some type of prediction, ranging from experience-driven rules-of-thumb to complex dynamical model results. Most predictions, in turn, are based on two types of information – an observational assessment of our present state, and an understanding of the processes that will evolve that state into the future. Predictions as simple as red sky at night, sailors delight, or as complex as numerical weather forecasts that require an initial condition and a mathematical description of the laws of physics, illustrate the overarching need for both observation and understanding to make predictions. The understanding is gained through the scientific process, and science is simply the search for natural explanations based on observations. The process is iterative and is continually evolving. As our understanding increases, our need for observations may change. As our observations increase, the scientific process may add to or refine our understanding.

III. A SIMPLE EXAMPLE

The predicted trajectory of a single particle released into a gravitational field illustrates the need for observation and understanding, and how the observational requirements for improving prediction and understanding may be different but overlapping. Tossing a ball into the air, its vertical location is given by the simple equation:

$$z(t) = z_0 + v_0 t + \tfrac{1}{2} g\, t^2 \qquad (1.1)$$

where $z(t)$ is the location at any time t, z_0 and v_0 are the initial location and velocity, and g is the acceleration of gravity. We derived this simple equation in high school through our understanding of physics, namely Newton's famous $F=ma$ relation, the knowledge that the gravitation force is the constant mg, and then integrating this equation twice to produce the two constants of integration, z_0 and v_0. The results of the detailed observation and analysis of many trajectories of many objects, once understood by scientists like Galileo and Newton, can now be applied to any ball we toss in the air today. Since we know the acceleration of gravity, we can predict the location of any ball for all time if we simply observe its initial location and velocity. Changing either the initial position or velocity will also change the trajectory, so the initial condition must be observed every time we want to make a prediction. Through our understanding of the process, our observational data has been reduced to the cirtical pieces of information that is required for prediction, and therefore an efficient observation network can now be designed.

But because our model is not perfect (we neglected the small contribution of other forces like air drag), and because our initial condition is not perfect (our measurement tools may be imprecise or we could have read them incorrectly), our predicted trajectory will drift with time when compared to the actual trajectory. We can compensate for the drift by again observing the ball along its trajectory, and restarting the prediction. With enough observations of the differences between the predicted and actual trajectories, we may eventually deduce that the air drag is proportional to the square of the velocity. Increasing the complexity of the model by adding in the effects of air drag will then likely result in a slower drift between the predicted and actual trajectories, increasing the time between the required restarts. The observations provide feedback to improve the understanding, and the improved understanding be used to make the observation network more efficient. But no matter how simple or complex the model, you can't use it for predictions unless you know the initial state. Similarly, no matter how many observations you make, the best you can do is persist the trend if you don't understand the evolutionary processes. Predictions therefore require both current observations (efficiently acquired based on understanding), and scientific understanding (developed over time by interpreting observations).

IV. PREDICTION IN THE COASTAL OCEAN

Expanding this notion to the coastal zone, how do we make predictions if we are to eventually make wise decisions? Ideally we will need regular updates of the initial location and velocity of the full ocean of particles in a 3-dimensional volume, we will need physical models that allow the trajectories of all these particles to evolve in time in response to the different types of forcing, and we will need coupled models from other disciplines to account for their transformations along the way. But coastal circulation typically exhibits an energetic mesoscale and submesoscale responding to rapid changes in boundary forcing as well as the internal dynamics of fronts, eddies, plumes, and intrusions embedded within a wide spectrum of coastal trapped waves, inertial waves, tides, internal and surface waves, Langmuir circulations, and turbulent boundary layers. A coastal ocean that varies rapidly in space and time on so many scales presents us with a sampling conundrum for traditional shipboard or mooring based approaches. Walter Munk [1], looking back on the last 100 years of oceanography, characterized this time period as the "century of undersampling". Although we seek to sample the full 3-dimensional spatial structure of the ocean as it evolves in time, ships can only remain at sea for short periods, and moorings are fixed in space. In the early years, our understanding of oceanography was biased by our limited observational trajectories through space-time.

The undersampling problem in oceanography can only be addressed through advances in technology. The first great technological advance was in remote sensing. Satellites provided the first synoptic views of the spatial structure of the world ocean and how it evolved in time. Passive imagers provided sea surface temperature and chlorophyll distribution maps that showed us the location of different water masses and their thermal structure. Active altimeters provided estimates of the sea surface height, that, when turned into geostrophic velocities, told us where the particles were going. But remote sensing typically only gives us a picture of the ocean surface. The second great technological advance will be in sampling the subsurface. Munk [1] noted that acoustic tomography gave us a blurry view of the subsurface spatial structure, and this could be tightened in different location with thousands of drifting profilers. By combining the surface remote sensing with the in situ spatial datasets, the strengths of one observational technology compensated for the weaknesses of the other. The resulting picture of the ocean was better than could be achieved by either technology alone – what Munk [1] termed the classic "1+1=3" scenario. This approach gives us the blueprint for achieving a well sampled ocean by combining surface remote sensing with spatially distributed in situ subsurface data. When will the ocean be considered well-sampled? When the errors in the prediction models for whatever purpose they are applied are no longer dominated by the errors in the initial condition. In a well sampled ocean, the causes of the forecast errors are at minimum equally distributed between the initial condition, the model formulation, and the model forcing.

But Munk's [1] application of the 1+1=3 scenario was to the deep ocean. How do we apply this same scenario to coastal seas where satellite Ocean color maps are complicated by the complicated optics of coastal waters, satellite altimetry is complicated by tides that are now larger than the geostrophic height variations, tomography is complicated by bottom interactions, and subsurface floats tend to quickly drift out of the more compact regions of interest. Again, the problem will be solved by new observational technologies, including sensors, platforms and communication systems that are deployed in clusters now known as coastal observatories. Unlike the deep ocean, where, for example, a single altimeter on a satellite with a single processing algorithm can provide global coverage, coastal observing technologies often must be designed, deployed, and their data sets analyzed, differently within each region. Their installation and sustained operation will require a distributed network of people with both the technical expertise and an understanding of oceanography to operate the systems in an effective and efficient manner. Many of these people do not yet exist, and must be trained starting now if they are to be available as the coastal observation network buildout continues. In this paper, the origins of the academic coastal observatories are briefly traced, steps to define the requirements for this new type of oceanographer are reviewed, and an emerging program to educate these oceanographers is described.

V. ADVANCES IN TECHNOLOGY

Many academic coastal ocean observatories trace their origins back to the early 1990's [2]. During this decade, a range of new technologies were developed for more cost-effective observation of the coastal ocean. For example, acoustic Doppler current profilers were dropping in price from the $60,000 range to the $20,000 range, making multiple profilers standard equipment in every oceanographer's toolkit. New optical sensors were becoming available that for the first time were making biological oceanographic datasets nearly as attainable as physical [3]. Scientists were beginning to acquire these new technologies and deploy them on sustainable platforms, initiating long-term data collection programs. Surface buoys powered by batteries and solar cells were being deployed by academic groups for long time series in both deep and shallow water. Seafloor observatories for long-time series were being established using self-contained sensor packages powered by batteries. On-board data storage was augmented with satellite communications and line-of-sight radio modems to enable real time transmission of surface data subsets [4], while submarine cables were installed or converted from telephone service to provide both power and two-way high-bandwidth communications to the seafloor observatories [5]. Datasets delivered to shore in real-time were soon distributed through the developing World Wide Web, enabling broader use both within the scientific community and beyond.

As the time series stations were being established, means to acquire spatial datasets in the coastal ocean were developing in parallel. Satellite tracking stations to collect local direct broadcast imagery spread through the scientific community in the early 1990's, rapidly expanding data availability and the breadth of scientific applications. Extending the use of 1 km square pixel AVHRR satellite imagery from the deep ocean to coastal waters was a demonstrated vital component of coastal ocean studies as early as 1993. Demonstrations of coastal applications for satellite ocean color imagery in dreaded Case II waters followed soon after. HF Radar for coastal surface current mapping, the coastal equivalent of deepwater satellite altimetry, experienced a similar rapid expansion in the 1990's. Permanent HF radar stations were established on beaches throughout the nation, and clusters of multi-institutional operator networks began to form [6, 7]. Beneath these surface maps, new ways to spatially sample the subsurface were being developed. Undulating ship-towed platforms equipped with sensors and real-time data displays on both ocean-class ships and small coastal research vessels were developed during, and were in common use by the end of, this decade [4]. Simultaneously, autonomous underwater vehicles began driving or gliding through coastal waters, conducting their first test flights and science missions [8, 9]. Again, the now ubiquitous World Wide Web simplified distribution to a broader community [10].

VI. THE DEVELOPMENT OF COASTAL COLLABORATORIES

Technology was enabling scientists to change the way they, and others, observed the sea. Much of the above technology development work was individually sponsored by the core research agencies of NSF, ONR, NOAA and NASA. In the late 1990's, the newly formed National Ocean Partnership Program (NOPP) began funding a series of integrated coastal observatory and forecasting experiments. Academic, government and industry groups partnered to develop and demonstrate through collaborative research projects the advantages of combining the rapidly expanding coastal observation networks with data assimilative models. The projects demonstrated the added value of combining remote sensing surface with spatial subsurface data in real time to produce an ensemble of forecasts [11] that in turn provided adaptive sampling feedback to research fleets [12]. The projects often required "radical collocation", that of moving all participants and assets to a central and often isolated location for the collaboration to occur [13]. The first demonstrations of these collaboratory concepts were presented to the community at a NOPP-sponsored special session of an AGU meeting in early 1999. The projects demonstrated that teams of scientists working together to leverage the capabilities of the different observing sensors, platforms and models could address a new class of coastal science problems not tractable by a single scientist working in isolation with a single observing technology. As the scientific results of these studies were published, it was observed that the papers had more multiple authors, and that multiple agencies were often acknowledged for support [14].

During the summer of 1999 in Solomons, MD, a community wide workshop on the Challenges and Promise of Designing and Implementing and Ocean Observing System for U.S. Coastal Waters. The state of the art based on the existing coastal ocean observatories was reviewed. The relatively isolated observatory efforts were already demonstrating the utility of long-term real-time coastal ocean observation networks where they existed. The rationale for the wider deployment of even larger network of coastal observatories was the promise of (1) safe and efficient navigation and marine operations, (2) efficient oil and hazardous material spill trajectory prediction and clean up, (3) monitoring, predicting and mitigating coastal hazards, (4) military operations, (5) search and rescue, (6) prediction of harmful algal blooms, hypoxic conditions, and other ecosystem or water quality phenomena, and (7) scientific research. Comparisons with the present incarnation of the seven national needs IOOS will serve (www.Ocean.US) indicates that, except for the still controversial deletion of scientific research, the promise of long-term real-time coastal observing networks identified in 1999 is about the same today. Implementation of the networks over larger areas was a growing possibility through advances in enabling technologies that include the rapid expansion of sensors, systems and platforms, the availability of real-time communications to bring the data to shore in real-time, and the universal acceptance of the World Wide Web as a broader dissemination network for data and products. Challenges included long-term operations, instrument calibration, biofouling, and power constraints, and data management. Among the recommendations were long-term support for long-term measurements, training a new generation of support staff to operate the networks, and national coordination for linking and standardizing. It is the second recommendation here where it is first observed that in addition to traditional oceanographers, a new type of oceanographer, one trained in the sustained operation of advanced observing technologies, was going to be needed in the near future. The observatory operators would have to work together as part of a network with the goal of sustained and continuous operations in support of research and applications. Specialists familiar with individual sensors and systems, the data processing, the assimilation of the data into models, and interpretation of the results leading to a better understanding of the present and predicted state of the coastal ocean were required. To ensure their integration, the goal was not engineers or technicians without oceanographic experience as operators, but oceanographers able to operate systems together and understand the desired endpoint.

VII. DEFINING THE NEED FOR OPERATIONAL OCEANOGRAPHY

The transition from short term experiments to sustained operations of research observatories that also served other applications prompted numerous articles and responses that peaked in the literature the following year (ex. [17, 18, 19, 20, 21, 22]). For the academics, sustained real-time observations for coastal research was a new field, requiring a new type of operational oceanographer. Both the Navy and NOAA, however, already had longstanding traditions in operational oceanography, numbering over 3000 people in the Navy and over 1000 in NOAA. But some of these articles also noted that the role of Naval operational oceanography was continuing a shift to a littoral focus. At the same time, senior personnel from Naval operations centers acknowledged that their greatest challenge in operational oceanography was keeping up with the rapid advances, which at that time included satellite data and dynamical forecast models. Ph.D. graduates capable of keeping up were found to be interested in R&D, not operations, and existing Masters graduates were found to be in other areas outside of oceanography. The operational centers found themselves spending time providing oceanographic training to Masters students from other disciplines. The new need for practically trained oceanographers was likened to a more mature meteorological paradigm. In meteorology, some students still pursue Ph.D.s that lead to research careers, while others pursue Bachelors and Masters degrees to find equally satisfying employment opportunities, often in weather forecasting applications that still benefit both science and society. To fill this growing need, NAVOCEANO considered sponsoring graduate traineeships at top oceanography institutions for Masters degrees, with the possibility of summer employment at NAVO.

Several universities have responded to this need for technical training of Masters level students in a collaborative environment. Academic, government and industry-wide discussions were fostered through two interactive workshops in Operational Oceanography hosted by Prof. Christopher Mooers at meetings of the American Meteorological Society (AMS) in 2000 and 2001. In the first meeting, the Rutgers group presented their initial plans for a Masters degree supporting personnel training for operational oceanography. Additional feedback was obtained through telephone and email contacts with personnel working at operational centers. Results were presented and the proposed program again vetted at the second interactive workshop in 2001.

Results of these discussions and workshops indicated that every subdiscipline of oceanography - physics, chemistry, biology and geology - was already developing the need for Masters students with a strong technical expertise in engineering or computer science related activities. Rather than an engineer or computer science major with an introduction to marine science course on their transcript, the balance was being tipped in the other direction. Oceanographers with technical experience in engineering or computer science was the missing segment of the training spectrum. It also was clearly recognized that oceanography is increasingly interdisciplinary. While students developed their technical skills within their traditional subdiscipline, they also should be exposed to the broader interdisciplinary aspects of oceanography through participation in some of the oceanography core courses in physics, chemistry, biology and geology. Descriptive and dynamical physical oceanography was seen as necessary for all, with the additional exposure to ocean acoustics recommended from Navy groups.

One of the most important criteria identified for future success was the development of personal communication skills, both written and oral. In this regard, writing and defending a Masters thesis was considered essential, a surprise result of the discussions and surveys. Going into the discovery process, it was expected that the Masters without thesis option available at some universities would be preferred since it guaranteed graduation on a fixed time schedule. It is widely recognized that some Masters theses inevitably will take longer to finish than others. But cutting off work on a Masters thesis based on an artificially imposed time table for completion has the potential to be as harmful as allowing for indefinite extensions. The overwhelming consensus was for completing the full Masters thesis processes, despite the uncertainty and additional time this potentially adds to graduation schedules.

Additional desirable experience included field experience in the collection of data, computer programming skills so new analyses could be performed, familiarity with numerical analysis libraries such as Numerical Recipes or Matlab to aid program development, data analysis for time series and spectra, the ability to manipulate large databases, GIS experience for placing the data in a temporal and spatial context, statistics for estimating data errors and limitations, descriptive and dynamical oceanography for interpreting the often physical data, and applied ocean modeling that focused on the interpretation of model results, not model development. The ability to relate ones existing knowledge and new observations of the ocean to numerical model output was the key result.

VIII. DEVELOPMENT OF THE EDUCATIONAL PROGRAM

The above process provided valuable guidance to the Rutgers group developing the new Masters degree in Oceanographic Technologies. The purpose of the new degree is to provide oceanography Masters-level students with background training and hands-on experience in a modern integrated and sustained research observatory. The objective is to provide the training necessary so that they would find employment within the rapidly expanding network of research and applied observatories currently being constructed. Rutgers' existing Graduate Program in Oceanography, initially focused more towards Ph.D. students, already had a less often used Masters degree option that was fully consistent with the community-defined needs of this new program. As with all GPO Masters students, the new Oceanographic Technologies Masters students would be required to complete 24 course credits, 6 research credits, and defend a Masters thesis (Table 1). Since most semester-long courses are 3 credits, a typical course load would be 2-3 courses per semester. Of the 24 course credits, 9 must be derived from a list of approved core courses that include the required physical oceanography plus two of biological or chemical oceanography, marine geology, and earth system history. This requirement must be met by all GPO students, Ph.D. or Masters. Three additional courses are designed to directly provide classroom training for later hands-on thesis work. Coastal Ocean Observing Systems provides an introduction to specific sensors and platforms used in the observatory, Ocean Data Analysis provides the background theory and practice of observatory data analysis, and Numerical Modeling I provides the background required for running ocean forecast models. Most students will likely take all three of these courses. The remaining credits can be obtained through other advanced graduate oceanography courses, or background courses in engineering or computer science. All of the new courses required for the program have now been developed and test-taught at least once. A dedicated room has been refurbished as a teaching lab through competitive internal teaching development funds provided by Rutgers' Cook College.

Duration of the program is 2-3 years, depending on the time required for the Masters thesis. The expected minimum is 3 summers and 2 academic years, with one or two semester extensions as required for completion of the thesis and its defense. Table 2 illustrates two sample course schedules, one with an emphasis on modeling, and the other with a semester internship at a forecast center. An important feature of the program is participation in summer research programs. During the first summer, students will participate in a series of short training courses, including a software tools lab that introduces Matlab and Web-based programming, a presentation/writing lab that introduces students to how to give a talk and how to write a scientific paper, and a team building course. Also during this summer, first year students will assist second year students in their thesis research. Third year students, now focused on their actual thesis writing, will provide sagely advice on how not to mess up. The hands-on teaching paradigm of watch one, do one, teach one is in place here.

Responding to the need for experienced operators for the rapidly expanding network of coastal ocean observatories, the initial focus will be training Masters level students in the operation and use of modern sustained ocean sampling technologies. Students will have numerous hands-on training opportunities in the collaborative environment of the Rutgers University (R.U) Coastal Ocean Observation Lab's (COOL) Operations Center (Figure 1), and will be direct participants in the ongoing field research activities of the collaboratory. The Operations Center is the central control room for Rutgers' advanced observing technologies, including L-Band and X-Band satellite receivers for tracking the international constellation of satellites, a triple nested HF radar network for current mapping, wave monitoring and vessel tracking, a fleet of autonomous underwater gliders, and a seafloor cabled observatory. The technologies are maintained and continuously upgraded through NOPP-style partnerships with the manufactures, including SeaSpace, CODAR Ocean Sensors, Webb Research Corporation and WETSAT.

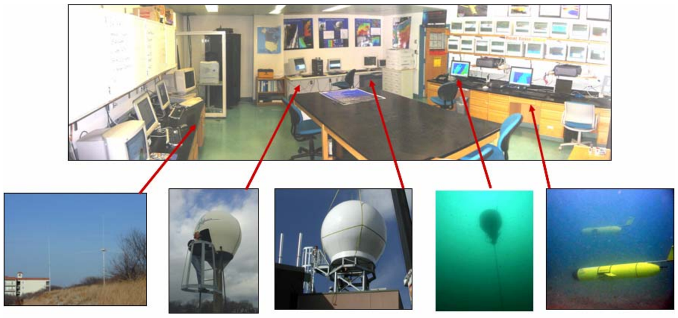

Figure 1: The R.U. COOL Operations Center includes the control room for Rutgers sustained ocean observing technologies supporting collaborative oceanographic research, education and applications on a year round basis.

For this new program to be most effective, it would be best to have a small cohort of 3-6 students start at the same time each year. Interacting as peers, they will learn from each other in a team oriented environment. We also desire students that will complement existing and expanding research programs. This will enable us to leverage multiple hands-on training opportunities in focus areas with a high possibility of employment after completion. With these two goals in mind, we see immediate needs for training students in both High Frequency (HF) Radar and Autonomous Underwater Glider operations and applications. Both of these technologies and their applications are rapidly expanding but are people limited. Applications for both technologies benefit from data sharing with each other in a collaborative environment.

Masters students interested in HF Radar will work directly with the Rutgers HF Radar team. The HF Radar focused students will directly contribute to Rutgers ongoing collaborations with NOAA and the Coast Guard to establish a National HF Radar network, and will have numerous opportunities to work with one of the radar manufacturers through Rutgers long-standing partnership with CODAR Ocean Sensors. Recent Federal and State efforts will soon establish well over 100 radar units around the U.S., with the Ocean.US Surface Current Mapping Initiative (SCMI) [23] recommendation being 2 operators for every cluster of 5 radars to sustain operations. While a variety of skill levels are required, experience has shown that a few highly trained operators can support a much larger group of less experienced operators. The recent Radiowave Operators Working Group (ROWG) and Quality Assurance Real Time Ocean Data (QARTOD) meetings identified several topics that could be addressed as potential Masters theses. External thesis committee members could be invited from the NOAA and Coast Guard HF Radar community.

Masters students interested in Autonomous Underwater Gliders will work with the Rutgers Glider team. Students will directly contribute to ONR funded efforts to use gliders in scientific studies and to deploy gliders with the fleet. They will be able to work directly with Webb Research Corporation, one of the glider manufacturers, and will participate in the developing NOPP-style Glider Consortium. With Glider production of all types in the process of spinning up, our greatest limitation is quickly shifting to the lack of trained personnel to participate in the numerous field exercises available to us. Beyond the developing research fleets, the operational Navy expects to gear up by purchasing up to 20 Gliders a year for several years. Masters thesis topics range from the integration of new sensors or the improvement of existing sensor algorithms to the scientific analysis of data collected during Navy exercises. External thesis committee members could include professors from the Naval Academy or civilian scientists working in the Naval Research Labs.

IX. SUPPORT FOR TRANING

New Jersey generously supports several students in the Graduate Program in Oceanography. These State fellowships are usually dedicated to incoming Ph.D. students to cover their first three years, carrying them through their qualifying exam and thesis proposal stage. After this, the Ph.D. students are typically picked up on research grants. Competition at the Ph.D. level for the limited state and grant support is sufficient to fully fill the available positions and limit Ph.D. admissions. Thus an alternative funding stream must be developed for Oceanographic Technology Masters students. Annual costs for a three-year fellowship run about $50,000 to $60,000 per year depending on the number of credit hours taken. The budget also includes limited funds for travel to conferences, experiment sites or to meet with external advisors, computer expenses and office expenses. Although students can always pay their own way through graduate school, fellowship support will be sought from federal agencies.

As development of this new Masters program was proceeding at Rutgers, a similar program in Operational Oceanography was evolving in parallel at the University of Bergen, Norway. Bergen-based partners include the Nansen Environmental and Remote Sensing Center, the Institute for Marine Research, the Mohn-Sverdrup Center for Global Ocean Studies and Operational Oceanography, and Aanderaa Instruments. Scientists from the two programs have visited each others institutions, have participated in each other’s curriculum planning meetings for program development, and have begun sharing course concepts. The strongest international collaboration is expected to be through shared students. The G. Unger Vetlesen Foundation, known for its support of both oceanographic research and U.S/Norwegian collaborations, recently approved funding for Rutgers’ first Vetlesen Fellowship in Oceanographic Technologies. A full three-year Masters student fellowship will be awarded through Rutgers regular competitive 2005-2006 admissions cycle for a summer 2006 start. A student will be sought that is especially interested in our growing collaborations with European science partners. A likely external thesis committee member for this student will be a professor invited from the University of Bergen Operational Oceanography program.

X. CONCLUSIONS

The field of oceanography and the tools oceanographers use are maturing, prompting more collaborative and interdisciplinary science. As this process continues, policy decisions on the safe and sustainable use of our coastal oceans will increasingly depend on scientific knowledge of the environment to improve its prediction and our understanding of the downstream consequences. Improved predictions for decision making requires sustained observations to continuously update the present state of the environment, and continued scientific research to improve our understanding of the processes that control how that environment will evolve in the future. Universities already are very good at producing research oceanographers. As the field matures, additional effort will be required to train the new technology proficient operational oceanographers to sustain these efforts. Several universities have designed and have even started these programs, but still lack the federal investments to ensure we are prepared for the now eminent growth of the field of ocean observing.

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Table 1: Sample Course Requirements

Purpose:
Provide masters-level students in marine science hands-on training in a sustained coastal ocean research observatory.

Duration:
3 summers, 2-3 academic years

Requirements:
24 course credits, 6 research credits, Masters Thesis defense.
Course credits consist of 9 background core course credits, 6 or 9 operational core course credits, and 6 or 9 of the optional course credits for a total of 24 course credits.

U.S. Academic Partners:
California Polytechnic University, CA
Mote Marine Laboratory, FL

Courses:
Course Requirements:
24 credits (8 courses) of classwork, 6 credits of research

Background Core Courses (9 credits – 3 courses)
Physical Oceanography (PO) – IMCS Faculty
Biological Oceanography (BO) – IMCS Faculty
Chemical Oceanography (CO) – IMCS Faculty
Marine Geology (MG) – Geology Faculty
Earth System History (ESH) - Paul Falkowski

Operational Core Courses (6 or 9 credits – 2 or 3 courses)
Coastal Ocean Observing Systems (COOS) – Scott Glenn & Robert Chant
Ocean Data Analysis (ODA) – Robert Chant & John Wilkin
Numerical Modeling I (NM-I) – Dale Haidvogel

Optional Courses (6 or 9 credits – 2 or 3 courses)
Coastal Ocean & Estuarine Dynamics (COED) – John Wilkin & Dale Haidvogel
Remote Sensing (RS) – Jim Miller & Scott Glenn; Jenifer Francis & Dana Veron
Waves, Current & Sediment Transport (WCST) – Scott Glenn
Numerical Modeling II (NM-II) – Dale Haidvogel
Microbial Dynamics (MD) – Oscar Schofield
Large Scale Dynamics (LSD) – Dale Haidvogel
Radiative Transfer (RT) – Dana Veron
Others – As approved by advisor

Table 2: Sample Course Schedule

Sample Schedule A is a typical two academic year, three summer session, schedule illustrated here with a modeling concentration. Sample Schedule B is an adjusted schedule to allow for a semester internship at a remote site. Academic year 3 is reserved for finishing the masters thesis if required.

	Sample Schedule A with Modeling Concentration	Sample Schedule B with Semester Internship
Summer 1	Research Experience	Research Experience
	Software Tools Lab	Software Tools Lab
	Presentation/Writing Lab	Presentation/Writing Lab
	Team Building Lab	Team Building Lab
Academic Year 1 - Fall	Physical Oceanography	Physical Oceanography
	Coastal Ocean Observing Systems	Coastal Ocean Observing Systems
		Biological Oceanography
Academic Year 2 - Spring	Chemical Oceanography	Chemical Oceanography
	Coastal Ocean Modeling	Ocean Data Analysis
		Option 1
Summer 2	Research Project	Research Project
Academic Year 2 - Fall	Biological Oceanography	Research - Internship
	Option - Numerical Modeling I	Research - Internship
	Research - Lab	
Academic Year 2 - Spring	Ocean Data Analysis	Coastal Ocean Modeling
	Option - Numerical Modeling II	Option 2
	Research - Lab	
Summer 3	Thesis Defense Target	Thesis Defense Target
Academic Year 3 - Fall	Thesis (If required)	Thesis (If required)
Academic Year 3 - Spring	Thesis (If required)	Thesis (If required)

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