MATE

MARINE ADVANCED TECHNOLOGY EDUCATION CENTER

www.marinetech.org

Operational Marine Forecasters

Contents

NOPP National Oceanographic Partnership Program

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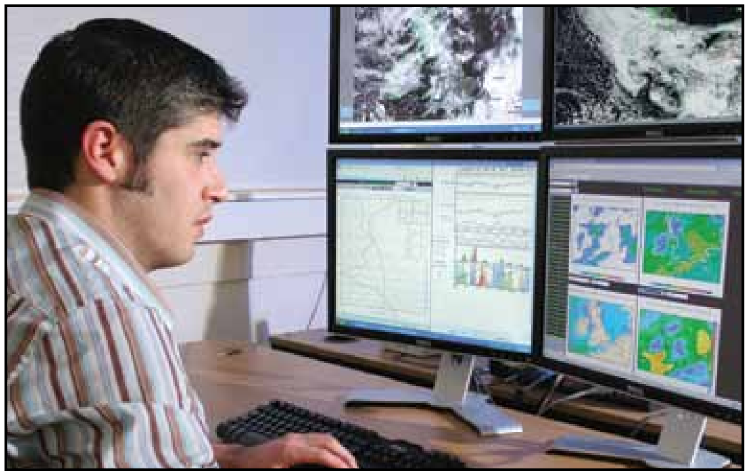
Operational Marine Forecasters and the Importance of Marine Forecasting



Shejun Fan, Fugro / GEOS

A marine forecaster at Fugro GEOS, Inc. prepares a forecast for a client conducting operations in the North Sea..

Operational marine forecasters produce forecasts of the marine environment that help people operate more effectively and safely in and near the ocean. These forecasts predict many aspects of the marine environment, including winds and waves at the ocean surface, ocean temperature, currents, tides, surf, sea ice, the propagation of sound through the ocean, the locations of fish and marine mammals, harmful algal blooms, coastal flooding, and the movement of oil spills.

Marine forecasters apply ocean and atmospheric science, knowledge, and skills to produce predictions about the state of the ocean and marine atmosphere. Operational marine forecasters deliver forecasts and recommendations about operating in the marine environment on a real-time, continuous, and/or on-demand basis. The environment for which they are making their forecasts includes the open and coastal ocean, bays, estuaries, large lakes, and the interfaces of these water bodies with the land and the atmosphere.

Some of the earliest marine forecasts were of the tides, waves, and currents. These early forecasts were based on careful observations and the recognition of the sequence of events by which the ocean changes. For example, early ocean forecasters recognized that they could use the lunar cycle to predict the time of the month at which the highest high tides and lowest low tides would occur. Others studied ships' logs and learned to predict where and when storms at sea, big waves, and strong currents were most likely to be encountered.

Today, marine forecasters rely on an ever increasing number of observations to help them understand ocean patterns and processes, and on models run on computers to predict how the ocean will change over time and space. The forecast models use equations to describe our scientific understanding of ocean processes — for example, the processes by which the sun warms the ocean, winds cause waves, ocean circulations make good feeding grounds for fish, and earthquakes generate tsunamis. Data from observing systems around the globe are used to produce comprehensive analyses of global, regional, and local marine conditions, and to provide data that is used by ocean forecast models. These data are collected by sensors mounted on a variety of platforms, including ships, buoys, satellites, drifters, ocean gliders and the sea floor.

Many ocean forecast models are very similar to the models used in atmospheric forecasting, and many ocean forecasts look similar to weather forecasts. For example, forecasts of ocean temperatures and

(continued on page 19)

Introduction to MATE's Knowledge and Skill Guidelines

The process of developing a competent ocean workforce that is well prepared for employment requires collaborating with a wide range of people and organizations. One of the major tasks of the Marine Advanced Technology Education (MATE) Center is to identify and define marine technical occupations and the abilities that men and women need in order to perform well in these occupations. The major product that results from this work is a set of occupational Knowledge and Skill Guidelines (KSGs) for technical marine occupations. These guidelines describe what workers need to know and be able to do in order to perform their jobs well and they are different for each occupation. The KSGs developed by the MATE Center include those for marine technicians, remotely operated vehicle (ROV) technicians, hydrographic survey technicians, aquarists, aquaculture technicians, oceanographic instrumentation technicians, and operational marine forecasters. All the KSGs developed by the MATE Center can be found at www.marinetech.org/marineworkforce, or printed copies can be requested from the MATE Center.

—Deidre Sullivan, MATE Center Director

About the MATE Center

The Marine Advanced Technology Education (MATE) Center is a national partnership of organizations working to improve marine technical education and in this way help to prepare America's future workforce for ocean-related occupations. Headquartered at Monterey Peninsula College (MPC) in Monterey, California, the MATE Center has been funded as a National Science Foundation (NSF) Advanced Technological Education (ATE) Center of Excellence since 1997. The MATE Center works with community colleges, high schools, universities, research institutions, professional societies, working professionals, and employers to facilitate the development of courses and programs based on occupational knowledge and skill guidelines. In this way, the Center is working to create a flexible education system that meets the needs of students, working professionals, employers, and educators, and that promotes direct interactions between these groups. The Center is also working to increase the awareness of ocean-related careers and to provide students, educators, workers, and employers with up-to-date information to assist them in making informed choices concerning their education and future directions.

The Importance of Marine Technology

The ocean economy is large and diverse, accounting for twenty percent of the U.S. economy and supporting one in six jobs in the country. Marine technology plays a vital role in supporting the ocean economy, including national security, transportation, energy, telecommunications, recreation and tourism, fisheries and aquaculture, search and recovery, environmental management, and research. These economic sectors are diverse, but the technology supporting them has many similarities, including the use of: electronics for power, controls, and miniaturization in a remote, harsh environment; in situ and remote data collection systems to monitor the environment; advanced computing systems for analyzing and displaying data; and modeling and forecasting systems to simulate and predict environmental conditions. The need for highly qualified professionals with advanced technical knowledge and skills to design, build, operate, and maintain marine technical systems has never been greater. A concerted effort is required to ensure that the U.S. workforce is prepared for an economy that is increasingly dependent on ocean activities and the technologies that make these activities feasible.

MATE Strategy for Improving the Marine Technical Workforce

PRODUCTS	DESCRIPTION
Needs identification ↓	List of critical workforce needs from employer surveys
Occupational definitions ↓	Employer recognized occupational categories
Occupational knowledge and skill guidelines ↓	Employee identified knowledge and skills for specific occupations
Competencies ↓	Knowledge and skills grouped by subject area
Instructional materials and services ↓	Competency-based assessments, modules, courses, faculty development workshops, competitions, and internships
Educational programs ↓	Degree and certificate programs aligned with workforce needs
Career management programs	Job placement programs, professional development courses

Knowledge and Skill Guidelines for Operational Marine Forecasters

Introduction


Steve Anderson, NWS / NOAA

Forecaster Christine Riley prepares a forecast of marine conditions off the coast of California at the National Weather Service Forecast Office in Monterey, California.

On 17-18 September 2009, the Marine Advanced Technology Education (MATE) Center hosted a workshop to define the occupational parameters associated with the operational marine forecaster (OMF) occupation. The workshop panel (on right) combined their individual expertise with results from a pre-workshop survey of 131 operational forecasters (and their supervisors) to develop an occupational definition and to outline the job functions and tasks for OMFs. They also outlined the typical customers for operational marine forecasts. The workshop panel characterized the occupation by identifying the most common job titles, salary ranges, educational backgrounds, basic and advanced coursework, personal characteristics, and general knowledge, skills, and abilities necessary to succeed in the field. The panelists also described the work environment of OMFs by identifying the tools typically used by OMFs, along with the professional societies, conferences, and publications that are relevant to OMFs. Expected future developments in the OMF occupation were also identified. Finally, the workshop panel summarized the knowledge and skills related to three primary oceanic forecast areas: ocean circulation, seawater properties, and surface waves. The knowledge and skills for a fourth area, coastal sea level, were added by the workshop organizers after the workshop, using the knowledge and skills template developed at the workshop. Sixty-four responses to the workshop findings were obtained by a post-workshop survey of a wide range of OMFs and their supervisors. The major results of the workshop and post-workshop survey are summarized below.

Occupational Definition

Operational marine forecasters (OMFs) produce real-time, continuous, and on-demand products and services that describe and predict the state of the marine environment to support timely decision-making. The marine environment includes the open and coastal ocean, estuaries, large lakes, and their interfaces with the land and the atmosphere.

Overview of Operational Marine Forecasters

OMFs have the very challenging job of predicting the future of a very complex, interactive, and constantly changing marine environment. Everyday observations of the ocean reveal how much ocean temperature, waves, currents, and tides can change over the course of hours, days, and seasons. These and other ocean changes are the result of interactions between the ocean, atmosphere, and land --- and between Earth, the moon, and the sun. OMFs need to understand the basic science of these interactions and the changes they produce in ocean conditions. They also need to be able to work with a wide range of data and data analysis tools that describe the interactions, as well as models that predict the resulting changes. OMFs are also becoming increasingly more responsible for understanding and responding to the needs of their customers, so that their forecasts and recommendations are as relevant and useful to their customers as possible.

Workshop Participants:

Workshop Organizers: **Tom Murphree, Leslie Rosenfeld, Deidre Sullivan, and Shawn R. Smith**

Workshop Facilitator: **Tom Murphree**

Workshop Recorder: **Jill Zande**

Panel Members:

Steve Anderson
Arete Associates, Inc.

Warren Blier
National Oceanic and Atmospheric Administration (NOAA) / National Weather Service (NWS)

Dominic DiMaggio
U.S. Navy / Naval Oceanography Antisubmarine Warfare Center (NOAC)

Shejun Fan
Fugro, Inc. / Global Environmental and Ocean Sciences

John Farrara
NASA / Jet Propulsion Laboratory

Ming Ji
NOAA / Ocean Prediction Center (OPC)

Scott Korschewitz
U.S. Navy / NOAC

Jeff Lorens
NOAA / NWS / Western Region Headquarters

Tom Murphree
Naval Postgraduate School

Don Murphy
U.S. Coast Guard / International Ice Patrol

Todd Rayburn
U.S. Navy / Naval Oceanographic Office (NAVO) / Ocean Prediction Department

Leslie Rosenfeld
Naval Postgraduate School

John Runyan
U.S. Navy / NAVO / Ocean Prediction Department

Shawn R. Smith
Florida State University

Dave Soroka
NOAA / NWS / Headquarters

Personal Characteristics of Operational Marine Forecasters

Successful OMFs tend to have the following characteristics:

- Aptitude for science and geography
- Ability to work in a team-oriented environment, but also individually
- Ability to seek technical advice from diverse sources
- Ability to effectively communicate orally, graphically, and in writing
  - Present forecast products at the appropriate level
  - Ask the right questions
  - Effectively listen to colleagues and customers
- Ability to network
- Ability to think critically
- Ability to develop and maintain situational awareness
- Ability to maintain focus on customer needs
- Ability to develop a broad vision (open minded; able to avoid tunnel vision)

U.S. Navy

Lt. Jeanette Sheets (center) and Aerographer's Mate 3rd Class Sapheria Myers (right) of the U.S. Navy work with a Chilean hydrographer to plan a hydrographic survey of the Bay of Concepción, Chile.

- Ability to learn from mistakes, accept criticism, and move forward despite setbacks (for example, have forward-looking mentality, not dwell on busted forecasts)
- Ability to continually acquire new knowledge and skills
- Ability to follow standard operating procedures
- Ability to multitask
- Ability to perform repetitive tasks
- Ability to prioritize
- Ability to maintain focus
- Ability to pay attention to details
- Ability to stay on schedule and meet deadlines
- Ability to handle stress
- Ability to perform shift work
- Ability to handle a rapidly changing technological environment
- Pride in, and passion for, their work

Successful OMFs tend to be:

- Organized
- Assertive
- Self-motivated, inclined to take the initiative
- Proactive
- Customer oriented
- Diplomatic
- Creative
- Patient
- Flexible
- Adaptable
- Observant
- Decisive

Occupational Titles for Operational Marine Forecasters

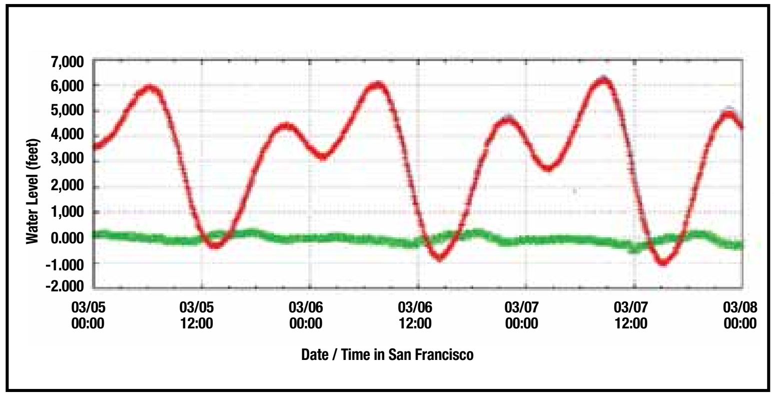
Operational marine forecasters have a range of job titles, including:

- Forecaster (for example, General, Junior, Senior, Lead, Supervisory, Marine, Ocean, Oceanographic, and Iceberg Forecaster)
- Oceanographer
- Oceanographic Duty Officer
- Meteorologist (for example, Regional / National Marine Program Meteorologist, Meteorologist in Charge, Warning Coordination Meteorologist)
- Science and Operations Officer
- Scientist / Physical Scientist
- Regional / National Marine Program Manager
- Professor
- Technician
- Data Analyst

Customers for Operational Marine Forecasters

Ocean marine forecasters support a wide range of customers, including:

- Coastal residents and organizations
- News media
- Recreational customers (for example, fishermen, surfers, beachgoers, divers, boaters)
- Commercial fishermen
- Oil and gas industry (for example, operations involving platforms, vessels and equipment)
- Shipping companies
- Salvage operators
- Dredging companies
- Towing operators (for example, towing of large rigs, barges)
- Port and harbor managers
- Coastal and ocean engineers (for example, U.S. Army Corp of Engineers)
- Bridge operators
- Survey operators (for example, charting, geodesy, seismic)
- Search and rescue organizations
- Forensic oceanographers
- Environmental/ecosystem managers (for example, managers of: marine and coastal parks, sanctuaries, protected areas; fisheries; oil spill clean-up)
- Aquaculture businesses
- Sanitation districts, dischargers
- Renewable energy planners and operators
- Ocean observing system operators
- Research community, academia
- Emergency managers
- Maritime law enforcement
- Homeland security, including marine domain awareness
- Exclusive economic zone enforcement
- Military (for example, special operations, mine warfare, antisubmarine warfare, expedtionary warfare, undersea warfare, surface and air warfare, search and rescue, small boat and glider operations, hydrographic surveying, and humanitarian operations)
- Forecasters of marine and coastal atmospheric conditions
- Forecasters of other ocean conditions (for example, sea ice and iceberg forecasters are customers for ocean circulation forecasts)
- Climate forecast customers (for example, agricultural, hydroelectric, and insurance customers)

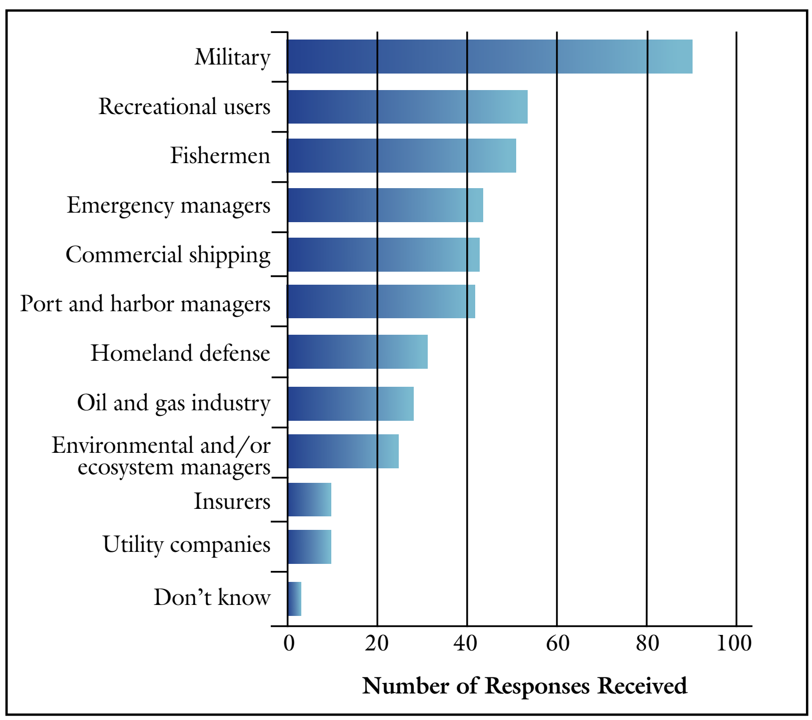


National Ocean Service / NOAA

Forecasts of sea water levels in San Francisco, California (red curve) and the difference between the forecasts and the observed water levels (green curve).

http://cruises.about.com/od/Allure-of-the-Seas/ss/Allure-of-the-Seas-cruise-ship.htm

Forecasts of the water level beneath bridges can be important in planning the movement of ships.



The types of customers for which operational marine forecasters (OMFs) provide forecasts. Based on responses received from 131 OMFs in a survey of OMFs conducted by the MATE Center.

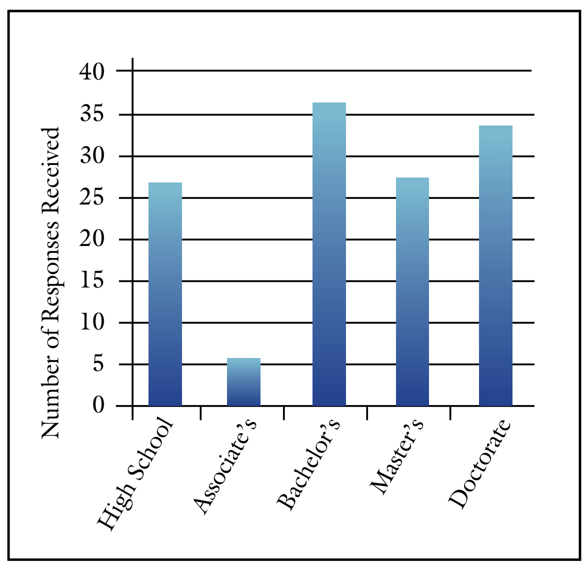
Educational Backgrounds of Operational Marine Forecasters

OMFs have a wide range of educational backgrounds. Seventy-five percent of the post-workshop survey respondents hold a master's and/or doctoral degree. But it is important to note that there are bachelor degree programs, such as the Marine and Environmental Sciences major at the U.S. Coast Guard Academy, that prepare students for entry-level marine forecasting jobs. Military service is another route into the marine forecasting profession. Over 60% of the survey respondents said they had military forecasting training. Ten percent of the survey respondents do not have a bachelor's degree, but all of these respondents had military training in marine forecasting. Some of the more common educational backgrounds that allow entry into OMF positions are shown below, with the less common of these shown in italics.

- Military meteorology and oceanogrphy schools for active duty personnel
  - Aerographer's Mate C-School
  - Basic Oceanography Accession Training (BOAT) program
- Bachelors (or equivalent)
  - Meteorology / Atmospheric Science
  - *Oceanography*
  - *Physics*
  - *Computer Science*
  - *Engineering*
  - *Geography (physical)*
  - *Mathematics*
  - *Ocean Science / Marine Science*
  - *Ecology / Environmental Science*
- Masters
  - Meteorology / Atmospheric Science
  - Oceanography
  - *Physics*
  - *Computer Science*
  - *Engineering*
  - *Geography (physical)*
  - *Mathematics*
  - *Ocean Science / Marine Science*
  - *Ecology / Environmental Science*
- Doctorate
  - Meteorology / Atmospheric Science
  - Oceanography
  - *Physics*
  - *Computer Science*
  - *Engineering (civil, ocean engineering)*
  - *Geography (physical)*
  - *Mathematics*
  - *Ocean Science / Marine Science*
  - *Ecology / Environmental Science*

Desired Basic Courses for Operational Marine Forecasters

- Calculus
- Physics (one year, calculus-based)
- Statistics
- Meteorology
  - Descriptive
  - Physical
  - Dynamic
  - Synoptic
  - Forecasting
- Oceanography
  - Descriptive
  - Physical
  - Dynamical
  - Forecasting
- Geology
- Geography (physical)
- Geographic information systems
- Cartography
- Introductory computing
- Technical writing
- Public speaking



The highest educational degrees held by operational marine forecasters (OMFs). Based on responses received from 131 OMFs in a survey of OMFs conducted by the MATE Center.

Salary Ranges for Operational Marine Forecasters

Annual salaries for OMFs vary according to educational background, work experience, and type of employer, as summarized below. Salaries tend to vary widely due to locality and cost-of-living salary adjustments. Military OMFs may also receive housing allowances and other supplemental pay, in addition to their salaries shown below.

- Entry level (bachelors degree or equivalent)
  - ♦ Industry: $40-50k
  - ♦ U.S. federal government: $30-40k (GS-5 or 7)
  - ♦ Military: $25-35k (E-5 or O-1)
- Entry level (masters degree or equivalent)
  - ♦ Industry: $50-60k
  - ♦ U.S. federal government: $40-50k (GS-9 or 11)
  - ♦ U.S. military: $35-50k (E-6 to E-9, O-3)
- Entry level (doctorate degree or equivalent)
  - ♦ Industry: $60-65k
  - ♦ U.S. federal government: $50-60k (GS-11)
- Top salaries for forecasters
  - ♦ Industry: $100k+
  - ♦ U.S. federal government: $100k+ (GS-14)
  - ♦ U.S. military: $85k+ (E-7 or O-4)

Resources Typically Used by Operational Marine Forecasters

- Observations (in-situ and remotely sensed)
- Datasets and databases (for example, observational and model output data-bases, including: reanalyses; archived, historical, and climatologcal data for winds, waves, currents, sea level, bathymetry, bottom type, sound speed, biological components, etc.)
- Hardware (for example, computers)
- Applications and software packages for generating and disseminating forecasts (for example, online and offline packages for data analyses, graphical displays, and mapping, including GIS packages, Advanced Weather Interactive Processing System (AWIPS), etc.)
- Dynamical and statistical models, output from these models, and guidance inferred from these models (for example, from circulation, wind, wave, acoustical, sea level models)
- Operational decision aids (for example, tactical decision aids)
- Literature and documentation (for example, scientific publications, documents on forecasting procedures and forecasting validation, documents on operational impacts such as survivability tables)
- Communication devices / systems (for example, satellite phones, marine radios, smartphones, classified and unclassified internet)

Relevant Conferences for Operational Marine Forecasters

- Relevant professional society meetings (see Professional Societies section)
- Customer-specific conferences (for example, conferences on maritime safety, homeland defense, military operations, offshore oil and gas operations, commercial shipping, recreational boating)
- Integrated Ocean Observing System (IOOS) meetings
- Relevant U.S. government-sponsored meetings (for example, those organized by the Geological Survey, Army Corps of Engineers, Coast Guard)

Relevant Professional Societies for Operational Marine Forecasters

- American Meteorological Society (AMS)
- American Geophysical Union (AGU)
- The Oceanography Society (TOS)
- National Weather Association (NWA)
- Marine Technology Society (MTS)
- International Maritime Organization (IMO)
- The Hydrographic Society of America (THSOA)
- American Society of Limnology and Oceanography (ASLO)

Future Developments Relevant to Operational Marine Forecasters

- Remote sensing data will become increasingly available and important.
- The spatial resolution of observational data, analyses, and model outputs will continue to increase.
- Models and model output used in forecasting will become increasingly more sophisticated and complex (for example, coupled models, ensemble model output, multi-model output).
- Stochastic forecasting methods and probabilistic forecasts will become increasingly more common.
- Forecasting will become more interdisciplinary.
- Forecasting will become more driven by customer needs.
- New variables will need to be forecast (for example, biological, ecological, optical).
- The demand for marine forecasts will continue to increase due to growing demand from existing and new customers (for example, increasing demand from existing and new alternative offshore energy customers, military customers, insurers, customers affected by climate change, etc.).
- Demand for more targeted nearshore forecasts will increase (for example, forecasts of storm surge, high surf, and tsunamis).
- Climate change is likely to alter operational marine forecasting in many ways, including:
    - ♦ Climate change will alter the background state within which forecasts are made (for example, background state for ocean temperature, sea level, waves, etc.), thereby changing forecast methods, the frequency of high priority forecasts for extreme events, the need for long range forecasts and climate projections, the types of customers for forecasts, etc.
    - ♦ Increased forecasting will be required in some areas as climate change alters customer operations within those areas (for example, increases in polar region shipping, resource exploration and development, military, and tourism operations, and longer transit seasons in the Great Lakes, as climate change alters sea and lake ice concentrations, thickness, and distributions).
    - ♦ Rising sea levels will increase the importance of coastal forecasting in low lying areas.
- Forecasting will require greater specialization.
- The range of forecast lead times and valid periods will increase (for example, more forecasts at lead times and valid periods of one week and longer).
- Data management will become more important as the amount of data used in and produced by forecasting increases.
- Operational marine forecasting will require increased collaboration (for example, among forecasting organiztions, agencies, nations).
- Decision support will become a more important and integrated part of forecasting, and will become more customized for individual customers.
- Advanced communication systems will allow forecasters to reach more customers.
- Increasingly diverse and advanced methods of communication will become more important (for example, sophisticated multimedia presentations, online social networks).
- Direct outreach by forecasters to their customers will become more important (for example, soliciting and operationally implementing customer feedback).
- The technologies that support operational marine forecasting will become increasingly complex.
- Automation of forecasting processes will increase.
- Forecasters will need more programming skills.
- Forecasters will need increased and enhanced professional development.
- Operational forecasting centers are likely to be asked to do more without corresponding increases in resources.
- Personnel turnover rates are likely to increase due to economic fluctuations.

Important Journals

- Publications of relevant professional societies (see Professional Societies section)
- Mariners Weather Log (a publication of the National Weather Service)
- United States Coast Pilot (a series of books published by the National Ocean Service / Office of Coast Survey)
- Customer-specific journals, for example Professional Mariner, The Ensign (publication of the United States Power Squadrons), Navigator, Latitude 38, Sailing, Ocean Navigator, etc.

Operational Marine Forecaster Job Function and Tasks

OMF job functions are organized into seven major categories (A-G in the table below). For each function, there are associated task areas (also shown in the table). The survey results show that OMFs spend most of their work time on job functions A and B, but that all of the functions, A-G, are important in the performance of their jobs.

Knowledge and Skill Overview Chart for Operational Marine Forecaster

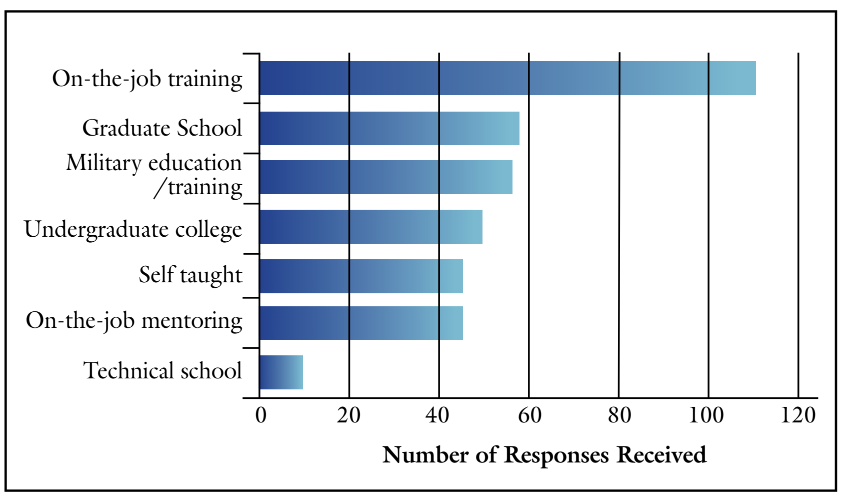
JOB FUNCTION	TASK AREAS						
A. Continuously monitor and respond to present conditions	A1 Assess present conditions to ensure timely delivery of highest priority products	A2 Guide the collection of targeted/adaptive observations	A3 Issue warnings/advisories and other special products	A4 Issue updated forecasts as conditions warrant	A5 Coordinate the generation of new or updated products	A6 Maintain appropriate watch log	
B. Prepare and disseminate forecasts	B1 Collect, organize, and evaluate data sets	B2 Diagnose past and present conditions to produce analyses and short-term forecasts	B3 Run models and analyze/interpret model guidance	B4 Use tools and techniques to produce preliminary forecasts	B5 Conduct collaborative forecast discussions	B6 Consolidate all inputs and generate final forecast products	B7 Conduct quality assurance B8 Disseminate forecast products
C. Assess forecasts	C1 Validate recent forecasts to assess confidence/uncertainty and guide ongoing forecasting	C2 Conduct long-term validation for model and other forecasting tool improvements	C3 Identify and document problems with forecasting systems and areas for improvement	C4 Solicit and document customer feedback	C5 Conduct risk analyses and risk mitigation assessments	C6 Maintain forecast assessment records and make entries into libraries of lessons learned	
D. Develop / improve forecasting processes	D1 Coordinate and collaborate with researchers and developers on methods for improving forecast processes	D2 Incorporate customer feedback into improved products and services	D3 Maintain and update forecaster manuals	D4 Design and test new forecasting techniques	D5 Implement new techniques and update standard operating procedures	D6 Test and transition relevant developments in science and technology to operations	
E. Provide decision support and improve applicability of forecasts	E1 Understand customer operations, constraints, and planning processes, establish rapport with customers	E2 Determine customer decision-making processes and needs, and how best to support them. Adapt to changing customer needs.	E3 Match forecasting capabilities with customer needs	E4 Educate customers on relevant product and service capabilities	E5 Provide probability of occurrence, confidence, and uncertainty information	E6 Provide risk assessments and risk management recommendations	E7 Make recommendations for customer planning and execution E8 Provide input to the development of decision-support tools
F. Communicate with peers, partners, customers, and the general public	F1 Design and implement improvements of forecasts and forecast delivery in collaboration with other forecasters, modelers, researchers, customers, and others	F2 Communicate effectively orally, graphically, and in writing with other forecasters, modelers, researchers, customers, and others	F3 Produce reports and develop standard operating procedures	F4 Develop education and training materials	F5 Conduct forecast briefings	F6 Conduct community outreach	
G. Participate in professional development	G1 Complete science and technology education and training courses	G2 Participate in workshops and conferences	G3 Complete leadership and management training	G4 Meet established job qualification requirements	G5 Research relevant literature, data availability, and experts	G6 Develop environmental situational awareness on scene in forecast areas of responsibility	G7 Pursue career-related advanced degrees

General Knowledge and Skills for all types of Operational Marine Forecasters

- Knowledge of, and ability to use, geospatial information, including ability to:
  - ♦ Understand and visualize spatial relationships
  - ♦ Read and produce maps, vertical cross sections, and other visual displays
- Knowledge of cartography
- Knowledge of geographical information systems (military GIS, ArcGIS, Google Earth/Ocean, etc.)
- Ability to perform oceanographic analyses:
  - ♦ Manual / subjective
  - ♦ Image
  - ♦ Geospatial
  - ♦ Statistical data
- Fundamental computer hardware and software knowledge and skills:
  - ♦ Operating systems
  - ♦ Text, numerical analysis, and graphical analysis applications
  - ♦ Database management applications
  - ♦ Computer programming languages
- Knowledge of modeling used for analyzing and forecasting oceanic and atmospheric conditions:
  - ♦ Modeling methods and model types (dynamical, numerical, statistical, etc.)
  - ♦ Model limitations and biases
  - ♦ Model inputs and outputs (model variables, spatial and temporal resolutions, etc.)
- Ability to operationally apply models of the variables being analyzed and forecasted (temperature, currents, waves, tides, coastal sea level, etc.), including:
  - ♦ Configure models and model inputs (domains, bathymetry, initial and boundary conditions, forcing, etc.)
  - ♦ Run models (simple process models, nested regional models, etc.)
  - ♦ Manipulate and assess model outputs
  - ♦ Critically evaluate conflicting information from different sources, (from observations, analyses, forecasts, etc.)
  - ♦ Apply model ouputs in the development of analyses and forecasts
- Knowledge of relevant customer operations, and customer needs for and uses of forecasts, including customer:
  - ♦ Operating concepts, planning processes, tactics, and procedures
  - ♦ Limitations (operating, financial, legal, geopolitical, etc.)
  - ♦ Desired outcomes from operations
  - ♦ Terms and units (nautical terms, technical terms, measurement units, etc.)
  - ♦ Communication and security systems
- Ability to use decision aids, and to interpret, apply, and disseminate their output (decision aids for search and rescue, survivability, oil spill trajectory, acoustic/sonar applications)
- Ability to provide relevant recommendations to customers

Relevant Advanced Courses for Operational Marine Forecasters

- Differential equations (ordinary and partial)
- Vector calculus
- Linear algebra
- Meteorology / Oceanography
  - ♦ Modeling: numerical, statistical
  - ♦ Remote sensing
  - ♦ Air-sea interaction
  - ♦ Waves
  - ♦ Tides
  - ♦ Climate, climate dynamics
- Underwater acoustics
- Marine biology
- Computer programming



The settings in which operational marine forecasters (OMFs) received their education and training in ocean forecasting. Based on responses received from 131 OMFs in a survey of OMFs conducted by the MATE Center.

Military Sealift Command / U.S. Navy

Specific Types of Marine Forecasting

OMFs forecast many different aspects of the marine environment. The following sections provide more detail about forecasting for four of these aspects: (a) ocean circulation or currents; (b) seawater properties, such as temperature and salinity; (c) surface waves; and (d) coastal sea level, including tides and storm surge. For each case, the physical processes involved, specific variables to be forecasted, typical products produced, and specialized knowledge and skills needed are listed. In the following sections, we use the term products to refer to forecaster outputs that are generated routinely or on-demand, including, for example, analyses, forecasts, warnings, recommendations, retrospective diagnostics, etc. Forecast products include deterministic and probabilistic forecasts, with a range of lead times and valid times.

Ocean Circulation Forecasting: Forecast Variables and Processes, Products, and Specific Knowledge and Skills

For this document, the term ocean circulation refers to currents of all periods and spatial scales, including tidal currents, as well as eddies, upwelling, downwelling, and internal waves, from estuaries to the open ocean.

A. Forecast Variables and Processes

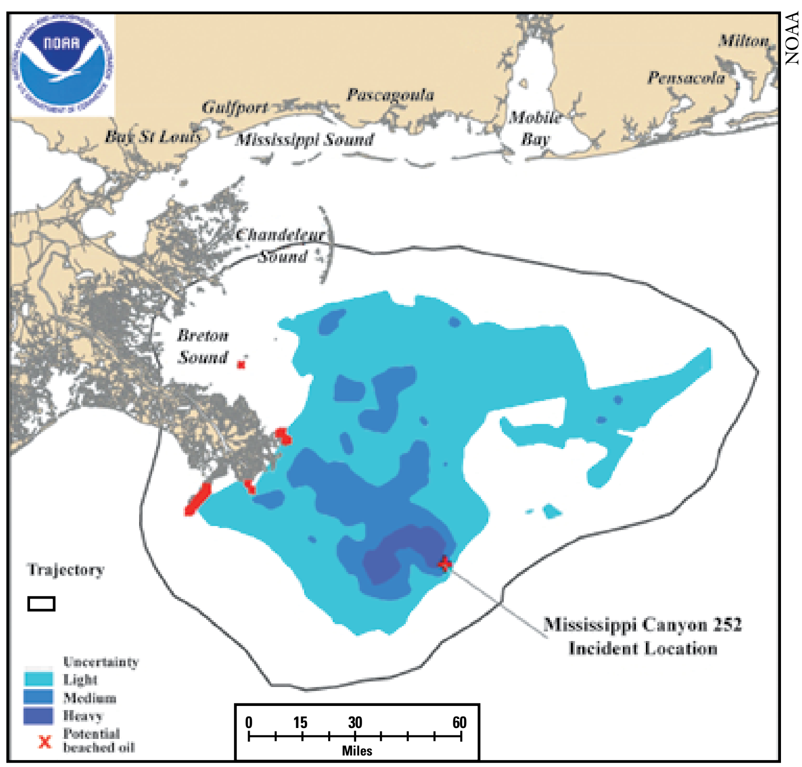
- Wind-driven currents (for example, inertial currents)
- Density-driven currents (for example, buoyant outflows)
- Tidal currents
- Eddies
- Internal, planetary, equatorial and coastally trapped waves
- Bottom flow
- Sediment transport
- Intraseasonal, interannual, decadal, and longer period variations in ocean circulation (for example, variations associated with the North Atlantic Oscillation, Arctic Oscillation, El Niño – La Niña, Pacific Decadal Oscillation, global climate change, etc.).

C. Specific Knowledge and Skills

- Advanced knowledge in oceanography and / or meteorology, including:
  - Descriptive oceanography (for example, patterns and processes in forecast area of responsibility)
  - Physics of the phenomena/ variables / processes being forecasted, (for example, physics of air-sea interaction, geostrophy, Ekman transport, tidal currents)
  - Oceanographic data analysis and data assimilation (for example, time series / spectral analyses, optimal interpolation)
  - Biological and other processes affected by circulation patterns

B. Products

- Gridded area forecasts (for example, 24 hour hindcast, 48 hour forecast, 10 day forecast, 30 day outlook)
- Feature forecasts (for example, forecasts of Gulf Stream position, Loop Current eddies)
- Climatology packages (for example, monthly, seasonal, full-year outlooks)
- Rapid response tracking and trajectory forecasts (for example, drift hindcasts and forecasts)
- Targeted and point forecasts (for example, surface currents forecast for oil spill, forecasts for individual offshore platform)
- Advisories and warnings
- Non-routine or extreme event analyses and forecasts
- Fish, marine mammal, and other biological forecasts (for example, probability of occurrence, quantity, bearing and distance), especially those based on ocean circulation variables (for example, upwelling, currents)
- Decision support products and recommendations (for example, for ship routing, search and rescue, pollution monitoring and tracking, marine mammal mitigation, military operations)



Forecast of the occurrence of oil at the ocean surface due to the Deepwater Horizon (Mississippi Canyon 252) oil spill. The forecast is for the Gulf of Mexico near New Orleans, Louisiana, on 05 May 2010. The darker blues indicate a greater concentration of oil and the red dots indicate oil at the coast.

- Knowledge of, and ability to operationally apply, ocean circulation models and their outputs. See also General Knowledge and Skills section regarding models (page 10).
- Knowledge of relevant observing systems, platforms, and sensors, including:
  - Tide gauges
  - River flow gauges
  - High frequency (HF) coastal radars
  - Ship observations
  - Expendable bathythermographs (XBT)
  - Conductivity temperature depth (CTD) sensors
  - Acoustic current profilers
  - Moored buoys
  - Coastal stations (for example, Coastal-Marine Automated Network)
  - Profiling floats
  - Drifting buoys
  - Gliders
  - Remote sensing systems (for example, altimeters, scatterometers, radiometers, passive / active microwave sensors)
  - Aircraft observations over water
  - Other atmospheric observing systems relevant to operational marine forecasting (for example, radiosondes, dropsondes)

U.S. Navy

Aerographer's Mate 3rd Class John Reed of the U.S. Navy provides forecasting support for landing craft operations.

Seawater Properties Forecasting: Forecast Variables and Processes, Products, and Specific Knowledge and Skills

For this document, the term seawater properties refers to ocean temperature, salinity, pressure, and other mass field variables, and variables derived from them, such as density and sound velocity, on all time and space scales, and from estuaries to the open ocean. We also include in this section the forecasting of sea ice concentration and thickness.

A. Forecast Variables and Processes

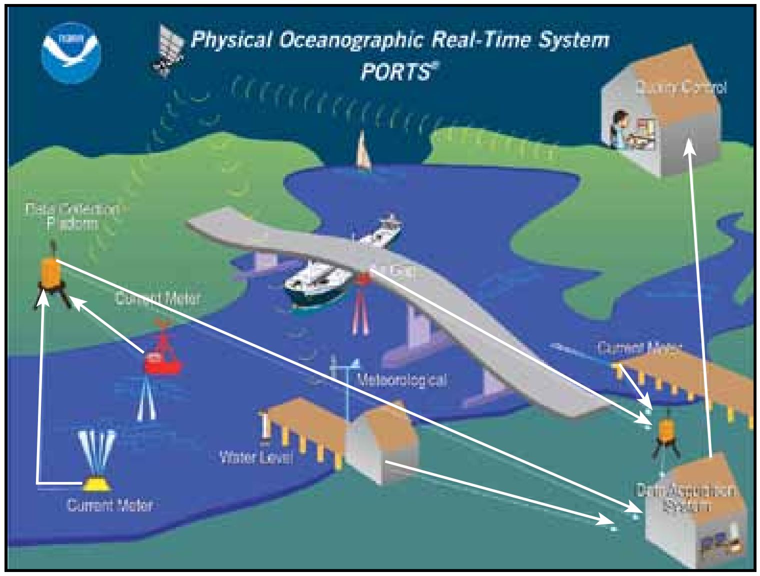
- Temperature
- Salinity
- Density
- Mixed layer depth
- Thermocline
- Fronts
- Internal waves
- Eddies / meanders
- Buoyancy plumes
- Heat and moisture fluxes
- Sea ice concentration and thickness
- Sound velocity and derived quantities (for example, sonic layer depth, deep sound channel)
- Intraseasonal, interannual, decadal, and longer period variations in seawater properties (for example, variations associated with the North Atlantic Oscillation, Arctic Oscillation, El Niño – La Niña, Pacific Decadal Oscillation, global climate change, etc.).

B. Products

- Gridded area forecasts (for example, surface and subsurface for all variables – 48 hour forecast for coastal region, 24 hour hindcast / 48 hour forecast, 72 hour global, 72 hour high-resolution regional and 72 hour nested within high-resolution regional, 10 day forecast / 30 day outlook for oil industry)
- Feature forecasts (for example, 24 to 72 hour Gulf Stream positions, Loop Current eddies)
- Climatology packages (for example, monthly,

seasonal, full-year outlooks)

- Targeted / point forecasts (for example, plume model, ice models, marine mammal tracks, survivability / endurance assessments)
- Acoustic products for military applications (for example, acoustic climatology packages, sonar performance predictions)
- Fish, marine mammal, and other biological forecasts (for example, probability of occurrence, quantity, location, especially those based on ocean mass field variables such as sea surface temperature, fronts)
- Non-routine or extreme event analyses and forecasts
- Decision support products and recommendations (for example, for ship routing, aquaculture, pollution monitoring, fisheries management, military operations)



National Ocean Service / NOAA

Operational marine forecasts depend on the collection and analysis of many types of observations. This figure shows an example of the data collection system used to produce forecasts for ports and harbors.

C. Specific Knowledge and Skills

- Advanced knowledge in oceanography and / or meteorology, including:
- Descriptive oceanography (for example, patterns and processes in forecast area of responsibility)
- Physics of the phenomena / variables / processes being forecasted, (for example, air-sea interaction, frontogenesis, water mass properties, buoyancy flux)
- Oceanographic data analysis and data assimilation (for example, time series / spectral analyses, optimal interpolation)


NAVO / U.S. Navy

Engineers prepare Naval Oceanographic Office sea gliders for collecting underwater data that will be used in developing ocean forecasts.

- Biological and other processes affected by seawater properties
- Underwater acoustics, including ability to account for the influence of static features (for example, topography, bottom type)
- Knowledge of, and ability to operationally apply, models of seawater properties and related quantities, and their outputs. See also General Knowledge and Skills section regarding models (page 10).
- Knowledge of relevant observing systems, platforms, and sensors, including:
  - Satellite altimeters, radiometers, passive / active microwave sensors
  - Drifters
  - Gliders
  - CTDs
  - XBTs
  - Moored buoys
  - Profiling floats
  - Ship observations
  - River flow gauges
  - Hydrophone arrays, sonar, sonobuoys

Surface Wave Forecasting: Forecast Variables and Processes, Products, and Specific Knowledge and Skills

For this document, the term surface waves refers to wind-driven waves, from the open ocean up to the shoreline, including breaking waves and currents related to waves (for example, rip currents, longshore currents).

A. Forecast Variables and Processes

- Wind direction, speed
- Fetch
- Sea state
- Wave height, direction, speed, period, steepness
- Wave breaking, surf
- Wave-related currents (for example, rip currents, longshore currents)
- Wave-related atmospheric phenomena (for example, sea spray, freezing spray, icing)
- Wave interactions (for example, wave–wind, wave–wave, wave–current, wave-bottom, wave-shore)
- Intraseasonal, interannual, decadal, and longer period variations in surface waves (for example, variations associated with the North Atlantic Oscillation, Arctic Oscillation, El Niño – La Niña, Pacific Decadal Oscillation, global climate change, etc.).

B. Products

- Gridded area forecasts (for example, surface waves at lead times of five days or longer)
- Sea state forecasts
- Harbor entrance analyses and forecasts (for example, forecasts for bars)
- Surf forecasts
- Freezing spray and icing forecasts
- Climatology packages (for example, monthly, seasonal, and longer-term outlooks)
- Targeted / point forecasts (for example, for hazmat support)
- Probabilistic analyses and forecasts (for example, probabilities of waves exceeding operational thresholds)
- Advisories and warnings (small craft advisories, rip current warnings)
- Non-routine or extreme event analyses and forecasts
- Optimal ship routing forecasts
- Decision support products and recommendations

C. Specific Knowledge and Skills

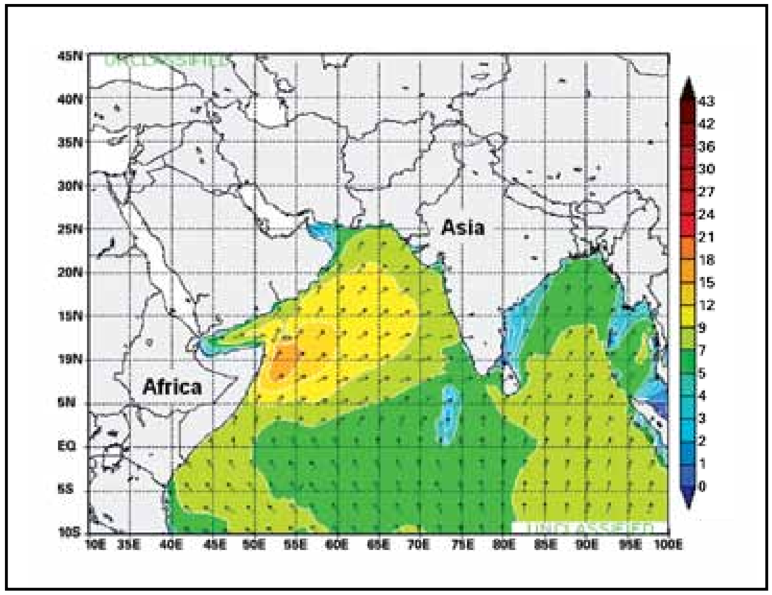
- Advanced knowledge in oceanography and / or meteorology, including:
  - ♦ Descriptive oceanography, including patterns and processes in forecast area of responsibility

http://surfspots-gps.com/big-wave-surfer-the-oceans-most-dangerous-waves

The scheduling of big wave surfing competitions relies heavily on operational marine forecasting.

- Physics of the phenomena / processes being forecasted (for example, air-sea interaction, wave processes, coastal processes)
- Oceanographic data analysis and data assimilation (for example, time series / spectral analyses, optimal interpolation)
- Bathymetry, bottom types, and coastal geomorphology in forecast area of responsibility

- Knowledge of, and ability to operationally apply, surface wave models and their outputs. See also General Knowledge and Skills section regarding models (page 10).
- Knowledge of relevant observing systems, platforms, and sensors, including:
  - Satellite altimeters, scatterometers, passive / active microwave sensors
  - Radar (for example, coastal, ship, aircraft)
  - In-situ wave sensors (for example, moored wave buoys, wave wires, bottom pressure sensors)
  - Human observing procedures (for example, from ship, shore)



FNMOC / U.S. Navy

Forecast of significant wave height (in feet) and direction of ocean surface waves in the Indian Ocean on 25 July 2011. The warmer colors indicate higher waves. The generally northeastward direction of the waves shows the effects of the Asian summer monsoon winds.

Coastal Sea Level Forecasting: Forecast Variables and Processes, Products, and Specific Knowledge and Skills

For this document, the term coastal sea level variability refers to changes in sea surface height caused by tides and atmospheric forcing (for example, storm surge)

A. Forecast Variables and Processes

- Sea level height (relative to specified datum) due to (1) astronomical tidal forcing and / or (2) atmospheric forcing (for example, storm surge)
- Extent of inland inundation (wetting / drying)
- Intraseasonal, interannual, decadal, and longer period variations in coastal sea level (for example, variations associated with the North Atlantic Oscillation, Arctic Oscillation, El Niño – La Niña, Pacific Decadal Oscillation, global climate change, etc.).

B. Products

- Tidal height for specified locations for any time period in the past or future (astronomical only)
- Times and heights of high and low water for specified locations for any time period in the past or future
- Time and height of expected maximum sea level due to meteorological and astronomical forcing
- Advisories and warnings (for example, storm surge)
- Expected extent of coastal inundation
- Harmonic constants for tidal constituents
- Co-tidal charts (showing how amplitude and phase varies over a body of water for a given tidal constituent)
- Climatology packages (for example, monthly, seasonal, full-year outlooks)
- Decision support products and recommendations

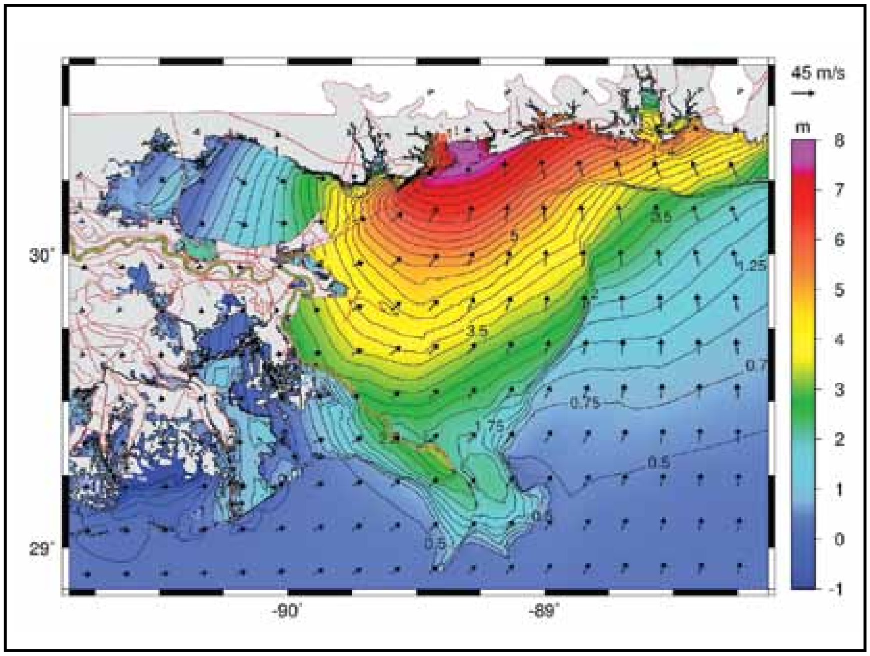
C. Specific Knowledge and Skills

- Advanced knowledge in oceanography and / or meteorology
- Descriptive oceanography, including patterns and processes in forecast area of responsibility
- Physics of the phenomena / processes

being forecasted: (for example, tides, air-sea interaction, steric effects, storm surge)

- ♦ Knowledge of patterns, processes, coastal geography, and bathymetry in forecast area of responsibility
- ♦ Fourier, spectral, harmonic, and time series analysis
- ♦ Bathymetry and coastal geomorphology in forecast area of responsibility

- Ability to perform tidal analyses and predictions
- Knowledge of, and ability to operationally apply, models of coastal sea level and their outputs (for example, harmonic tide prediction packages). See also General Knowledge and Skills section regarding models (page 10).
- Knowledge of relevant observing systems, platforms, and sensors, including:
  - ♦ Tide gauges
  - ♦ Pressure sensors
  - ♦ Human observing processes



NOAA

Forecast of the height of the storm surge (in meters) due to Hurricane Katrina. This forecast is for the surge in the coastal region near and to the east of New Orleans, Louisiana, on 29 August 2005 as Katrina was making landfall just east of New Orleans. The warmer colors indicate higher water levels and the cooler colors indicate lower water levels. The winds at the surface of the ocean (in meters per second) are shown by black arrows.

U.S. Navy

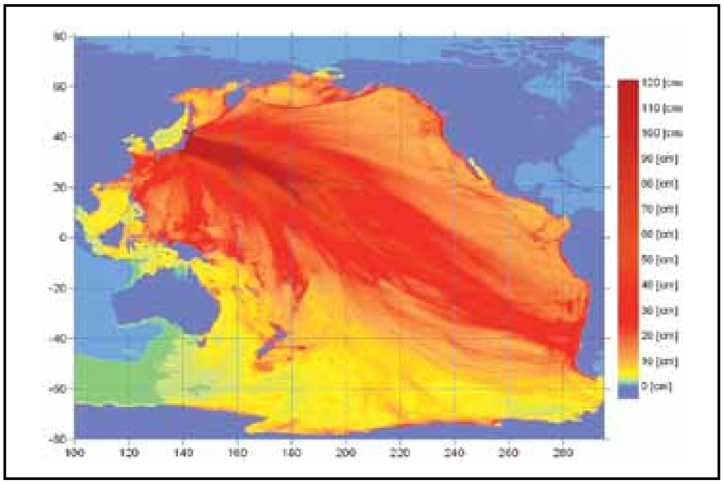
U.S. Coast Guard Boatswain's Mate 3rd Class Steven Duque (left) and Boatswain's Mate 2nd Class Adam Gunter from the U.S. Coast Guard cutter Healy participate in the collection of Arctic sea ice data to be used in improving ocean forecast models.

Other Forecasting Categories

Several other categories of operational marine forecasting were considered at the workshop, including, for example:

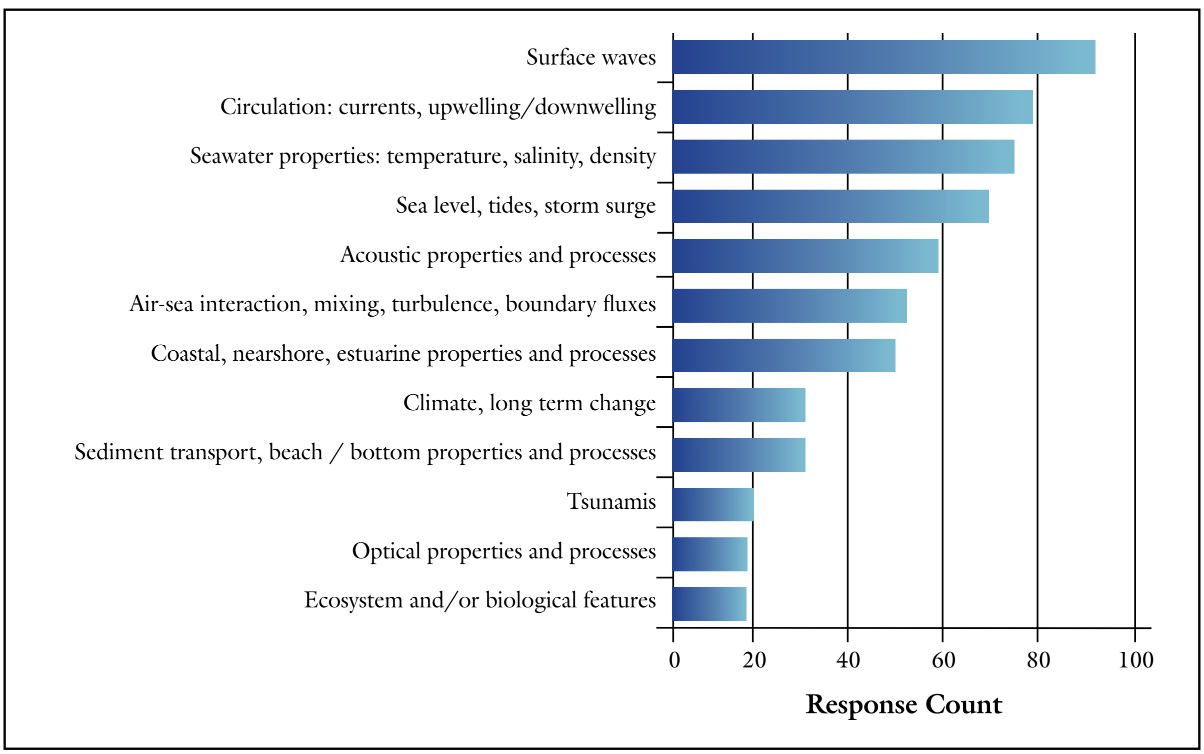
- Tsunami forecasting
- Sea ice and iceberg forecasting

These aspects of operational marine forecasting were not discussed in depth at the workshop, due to time constraints, but should be addressed in the future.

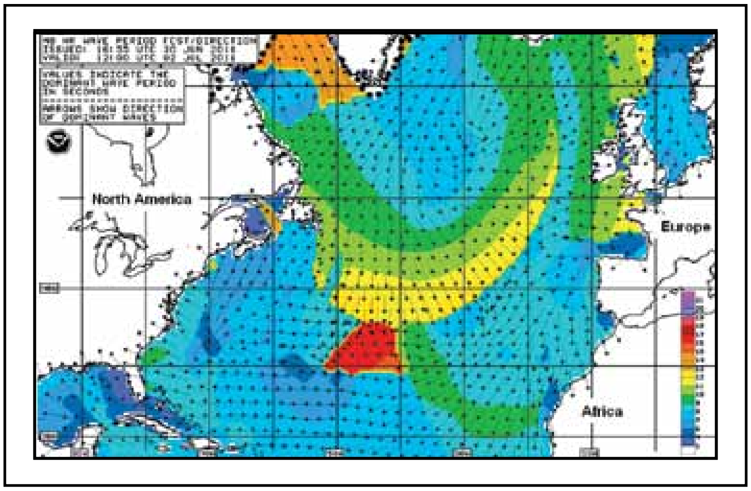


West Coast and Alaska Tsunami Warning Center / NOAA

Forecast of tsunami amplitudes (in cm) above normal sea level in the Pacific basin following the earthquake off the northeast coast of Japan on 11 March 2011. Forecast is for conditions on 11-12 March 2011, for an approximately 24 hour period following the earthquake. Near Japan, the largest amplitudes occurred within a few hours after the earthquake. Far from Japan, the largest amplitudes occurred many hours later (for example, more than 21 hours later in much of Chile). Note the relatively large amplitudes at the coasts.



The types of forecasting in which operational marine forecasters (OMFs) have operational forecasting experience. Based on responses received from 131 OMFs in a survey of OMFs conducted by the MATE Center.



Ocean Prediction Center / NOAA

Forecast of the period (in seconds) and direction of ocean surface waves in the North Atlantic on 30 July 2011. The warmer colors indicate longer periods. The arcing patterns between North America and Europe show the effects of a storm moving from west to east across the North Atlantic. Surface wave forecasts are used by many people to plan, for example, shipping routes, search and rescue operations, and surfing competitions.

U.S. Navy

Aerographer's Mate 2nd Class Joseph Lawrence and Aerographer's Mate Airman Brett Dubovecky of the U.S. Navy participate in training on forecasting ocean conditions associated with hurricanes in the North Atlantic region. Operational marine forecasters participate in many education, training, and professional development events to keep them up to date on the latest developments in ocean science, modeling, analysis and forecasting methods, and the operations of their customers.

(continued from page 1)

currents may look much like forecasts of air temperatures and winds. As with weather forecasts, ocean forecasts are used by a wide range of people for many different purposes. One of the most common uses of forecasts is to help people living and working on and near the ocean or large lakes prepare for hazardous conditions, such as high winds or rough seas so ships can steer clear. Another use is to warn coastal residents of an approaching tsunami so they can evacuate. But ocean forecasts are also used to help people know

U.S. Navy

USS Paul F. Foster operating in heavy seas. Ocean forecasts of adverse conditions are very important in minimizing the risks of operating at sea.

in advance where and when they are most likely to find the marine conditions they are seeking — such as currents that could speed up a ship's transit across the ocean, big waves for a surfing competition, or a good location for using sonar to detect an adversary's submarines.

It is important for operational marine forecasters to understand who their customers are and how they use marine forecasts. This helps forecasters make their forecasts as useful as possible, and helps customers make the best decisions as soon as possible. To improve the usefulness of their forecasts, many marine forecasters also make recommendations to their customers based on the forecasts, such as recommended shipping routes and schedules based on sea ice forecasts, warnings to fishing boat operators based on wave forecasts, or recommended coastal evacuation areas based on storm surge forecasts.

Operational marine forecasting is based on the work of many scientists, engineers, and technicians who build and design instruments, collect and analyze marine data, create and test ocean models, and develop more complete understandings of how the marine environment works. Forecasters use these data, analyses, models, and knowledge every time they issue a forecast. Forecasters also use knowledge of their

(continued on page 20)

MATE Center Focuses its Efforts in Eight Major Areas:

1. Supporting institutions interested in developing or improving ocean technology-related education programs.
2. Assessing workforce needs and developing knowledge and skill guidelines for new and emerging occupations.
3. Developing curricula in marine technology, underwater robotics, marine geospatial technology, career awareness, and ocean observing systems.
4. Offering professional development for high school, college, and university faculty that focus on a broad array of marine technologies, workplace skills, and pedagogical innovations.
5. Conducting regional and international underwater robotics (ROVs) competitions to increase students' learning experiences and build academic and employer partnerships.
6. Improving student preparation for the workplace through at-sea and shore-based technical internships.
7. Disseminating MATE products, including curricula, textbooks, occupational guidelines, competencies, and process guides (internship manuals, survey materials, etc.) both in traditional formats and electronically though the Center's web site.
8. Disseminating up-to-date, comprehensive workforce information via OceanCareers.com (www.oceancareers.com) created in partnership with the Centers for Ocean Sciences Education Excellence (COSEE).

Increasing the diversity of the ocean-related workforce is an overarching goal of the Center's work.

Jeff Lorens, National Weather Service / NOAA

A buoy for monitoring oceanic and atmospheric conditions being maintained by a U.S. Coast Guard crew. Such buoys are critical in providing data for use in operational marine forecasting. This buoy is part of a large set of buoys operated by the National Data Buoy Center / U.S. National Oceanic and Atmospheric Administration.

(continued from page 19)

customers' operations as they develop their forecasts.

So, for example, a forecaster predicting ocean surface waves in the Gulf of Mexico three days from now as a hurricane approaches will use: (a) observations that describe the present state of the winds and waves; (b) analyses that provide estimates of the present winds and waves where observations are not available; (c) models that use the data and analyses to predict the evolution of the winds and waves over the next 72 hours; (d) understanding of the physical processes that create waves; and (e) knowledge of how boat, ship, and oil rig operators working in the Gulf of Mexico can and should prepare for high waves.

Operational marine forecasters play a very important role in helping people to safely and effectively live and work in the marine environment. Their forecasts are critical in protecting lives and property, and in protecting the marine environment from harm caused by human activities (e.g., oil spills and other pollutants). As the science and technology needed for marine forecasting continues to improve, and as human activities in the marine environment intensify, operational marine forecasting will become even more important to the nation.

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Knowledge and Skill Guidelines for *Operational Marine Forecasters*

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