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OCEANOGRAPHIC DATABASES AT THE APPLIED PHYSICS LABORATORY

The Environmental Databases Project at the Applied Physics Laboratory holds a wide variety of environmental data sets. These data sets are used in planning sea tests and analyzing post-test environmental data, conducting modeling and simulation efforts, and for examining historic trends. Most uses of the data involve fusion of several data sets. The databases have proved to be a valuable resource in the environmental research ongoing at the Laboratory. Oceanographic data have been collected and compiled into databases for the last several hundred years. Today, the International Council of Scientific Unions sponsors the World Data Centers, which are responsible for the exchange of oceanic information. In the United States, the National Ocean Data Center operates World Data Center-A. The United States also has two additional data centers: the National Climatic Data Center and the National Geophysical Data Center.

INTRODUCTION

The Applied Physics Laboratory has a well-established record as a leader in oceanographic research and development for the U.S. Navy. In 1970, the Laboratory received the Navy's Master Oceanographic Observation Data Set (MOODS) to provide quick responses to queries about the ocean environment in support of sea test planning. Since then, the Environmental Databases Project (EDP) of the Submarine Technology Department (STD) has enlarged the Laboratory's oceanographic database holdings. These databases have become a unique resource sustaining many aspects of the oceanic research carried out by STD. To accommodate new areas of interest for the U.S. Navy, the databases have been expanded to include shallow-water and meteorological data. The EDP has provided data to other APL departments over the past three years.

Oceanographic data records have been maintained since the early days of history. The earliest such records were made by the Greek geographer Strabo (63 B.C. to 24 A.D.) on tides and depth soundings down to 2 km. Data were collected in the United States by Benjamin Franklin, in his role as Postmaster General, on arrivals and departures of ships en route to and from England. His collection of data provided the information used to produce the first chart of the Gulf Stream in 1786. The nineteenth century saw great advances in oceanographic data collection, since information was needed for the laying of transoceanic cables. Data were collected on temperature, depth, and bottom types as was information on any biota that might damage the cables. The British *Challenger* expedition (1872-1876), sponsored by the Royal Society, can be considered the beginning of modern ocean science. A team of scientists made physical, chemical, and biological measurements in the Atlantic, Pacific, and "southern" oceans. It took nineteen years to organize and edit the collected data.[1]

OCEANOGRAPHIC DATABASES

Since the ocean has historically provided trading routes for nations, most countries with an ocean coast are involved in collecting oceanographic data to understand the processes that can enhance trade. Much of the data collected for trade information have provided the foundation for modern oceanographic databases. Following the *Challenger* expedition, more effort has gone into basic ocean science research. A worldwide effort coordinated through the World Data Centers is under way to collect, maintain, and exchange oceanic data.

World Data Centers

The three World Data Centers are designated WDC-A (Washington, D.C., U.S.A.), WDC-B (Moscow, Russia), and WDC-D (Tianjin, People's Republic of China). They are part of the World Data Center System instituted in 1957 to provide a mechanism for data exchange during the International Geophysical Year. The World Data Center System operates under guidelines issued by the International Council of Scientific Unions (ICSU). Every two to three years the Committee on International Oceanographic Data and Information Exchange publishes an updated version of the *Intergovernmental Oceanographic Handbook,* which outlines the history of data exchange, provides guidelines for the structure and responsibilities of the Intergovernmental Oceanographic Commission (IOC) Committee on International Oceanographic Data Exchange (IODE), and reports activities of the Committee. Likewise, the IOC publishes revised IODE manuals that list the world, regional, and special data centers. The IOC also

offers guidance on the data exchanged internationally and the procedures for exchange.[2]

U.S. Data Centers

The United States acquires foreign data primarily through the World Data Center System by direct bilateral exchanges with other countries. The WDC–A center is operated by the National Ocean Data Center (NODC) under the auspices of the U.S. National Academy of Sciences. The NODC is the U.S. national facility established to acquire, process, store, and disseminate global oceanographic data. Management of the National Oceanic and Atmospheric Administration (NOAA) Central Library (Washington, D.C.) and its regional libraries in Miami, Florida, and Seattle, Washington, is also provided by NODC. The Central Library coordinates the NOAA Library and Information Network consisting of more than thirty member libraries, information centers, and special collections within NOAA. There are two other national data centers—the National Climatic Data Center (NCDC) in Asheville, North Carolina, and the National Geophysical Data Center in Boulder, Colorado.

The NODC's U.S. data are collected by federal, state, and local government agencies; universities and research institutions; and private industry. The Department of Defense, primarily the U.S. Navy, also contributes data to NODC.[3] Numerous university-related centers for oceanographic research exist in the United States and carry out both basic and advanced research in ocean measurements, ways to improve oceanic data collection through development of new instruments, and programs to analyze the collected data.

DATABASES IN THE SUBMARINE TECHNOLOGY DEPARTMENT

The EDP in STD's Environment Group (STE) at APL maintains the most current versions of many databases and was established to support research efforts within the Submarine Security Program. The initial databases were confined to oceanographic and atmospheric data. Over the years, other Navy programs have requested assistance for their efforts from the EDP. These programs have funded acquisition of additional hardware, software, and databases. Many of the new acquisitions have improved the EDP's capabilities for the benefit of all users.

The databases held by the EDP include the Standard Navy Databases obtained from the Naval Oceanographic Office (NAVOCEANO) located at the Stennis Space Center, Mississippi. The NAVOCEANO data encompass such diverse data sets as MOODS, the Digital Bathymetric Database (DBDB), and the Shipping Noise data set. The EDP currently holds most of the Standard Navy Databases and databases received from federal and state agencies, as well as academic institutions. In addition, the project has access to data collected during many of the STD-sponsored field tests.

Some examples of the various types of data available are discussed in the following sections.

Acoustic Databases

Among the project's holdings are two databases with information on the acoustic properties of the ocean bottom at low and high frequencies (Low-Frequency Bottom Loss and High-Frequency Bottom Loss databases, respectively) as well as sediment thickness. These databases cover most of the world's ocean floor. The Shipping Noise database contains low- and high-resolution estimated omnidirectional and horizontally directional shipping noise figures. There is no worldwide coverage for this database. A fourth acoustic database, Volume Scattering Strength, provides information on integrated column (volume) scattering strength by season, which includes diurnal and frequency-specific data and estimates of the scattering layer depth and strength within the layer.

Bathymetric and Cartographic Data

The bathymetric data held by the project are composed of three versions of the DBDB. The primary database offers global coverage on a 5-min grid (DBDB5) (Fig. 1). Data sets with 2-min (DBDB2) and 15-s (DBDB15) resolutions for selected areas of the world ocean are also available. These data are based on uncorrected acoustic measurements and referred to a velocity of 1500 m/s.

The EDP also maintains databases for plotting coastlines worldwide. The CIA-produced World Data Bank has coastlines at two resolutions: WDB I and WDB II. The WDB I resolution presents coastline data at a scale of 1:12,000,000, whereas WDB II contains coastline, river, and political boundary features at a scale of 1:3,000,000. A recent addition to the database holdings is the Defense Mapping Agency's (DMA's) *Digital Charts of the World.* This four-CD-ROM set allows hardcopy production of data for features such as topography, populated places, political/ocean boundaries, land cover, vegetation, railroads, utilities, and aeronautical information. Figure 2 shows elevation contours for the area around the Strait of Hormuz.

Biological Data

The EDP holds very limited data that relate directly to biology. Two in-house biological data sets are the Global Ecosystems Database[4] and the Global Change Database, Volume 2.[5] These two databases are part of a planned multivolume set. Both databases are intended to provide modern global- and continental-scale data needed by the global change community for environmental and ecological characterization.

Meteorological Data

The most commonly used meteorological data set available is the compiled U.S. Navy Climatic Atlases. These volumes cover the oceans of the world and contain information such as air and sea surface temperatures, dew point temperature, scalar wind speed, sea-level barometric pressure, wave height, and wind and current roses. The most recent publication is a CD-ROM that combines data

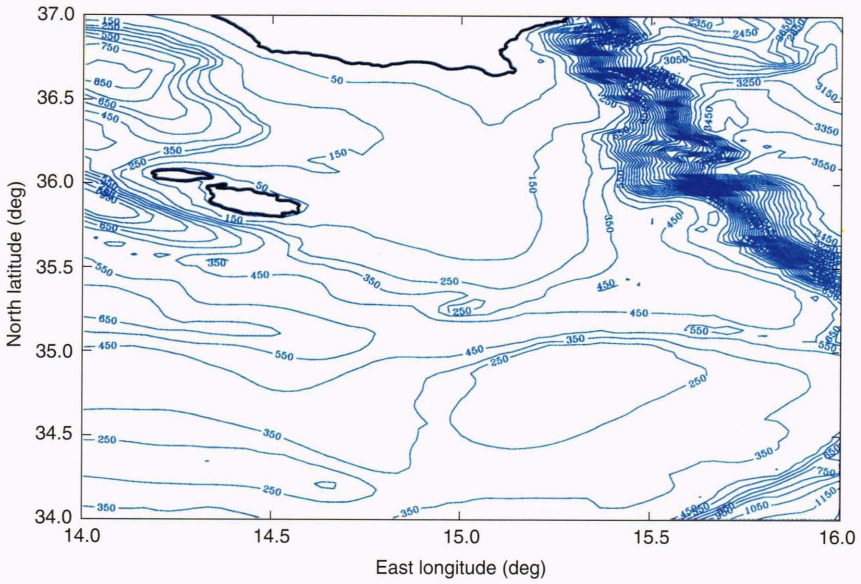

Figure 1. The Digital Bathymetric Database used to show the contours of the ocean bottom near the island of Malta in the Mediterranean Sea. (Area represented equals 180.000 nmi × 97.694 nmi; depths are in meters.)

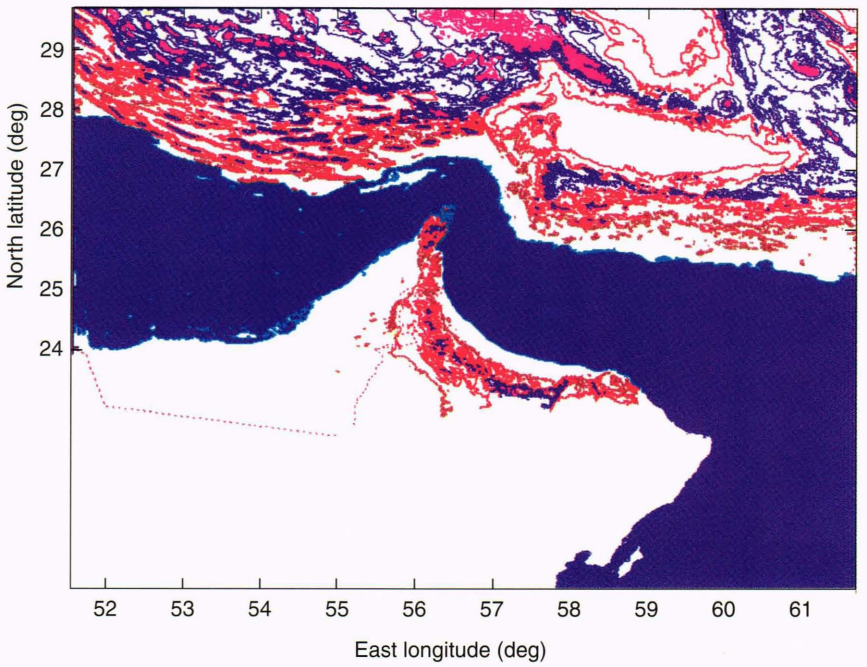

Figure 2. Map generated from the *Digital Charts of the World* database showing elevation contours of the land mass adjacent to the Strait of Hormuz. (Red represents elevations of 1000 to 3000 ft [305 to 915 m]; blue, elevations of 3000 to 7000 ft [915 to 2134 m]; and purple, elevations of 7000 to 11,000 ft [2134 to 3353 m]. The dotted line denotes international borders.)

from the collection of atlases for global coverage.[6] Not all the data in the paper volumes, however, are covered in the CD-ROM.

The DMA publishes quarterly pilot charts of data furnished by DMA and the Department of Commerce, which supply surface meteorological and current data. The pilot charts are produced primarily to provide information for commercial shipping. The EDP holds pilot charts for the Atlantic and Pacific Oceans for 1988 to the present. The project also receives and archives daily charts of the Gulf Stream produced by NOAA's Oceanographic Features Analysis Section.

The EDP has developed a Cloud Cover Database (CCDB) from archived cloud cover statistics collected and compiled by the U.S. Air Force Environmental Technical Applications Center (Fig. 3). Additional cloud cover data are available on a CD-ROM released by the NASA-Goddard Space Flight Center. The CD-ROM data are part of the International Satellite Cloud Climatology Project sponsored by ICSU, the World Meteorological Organization, and the World Climate Research Programme (WCRP). Both databases contain global monthly cloud data obtained from satellites. The EDP CCDB data are derived from the Defense Meteorological Satellite Program satellites,

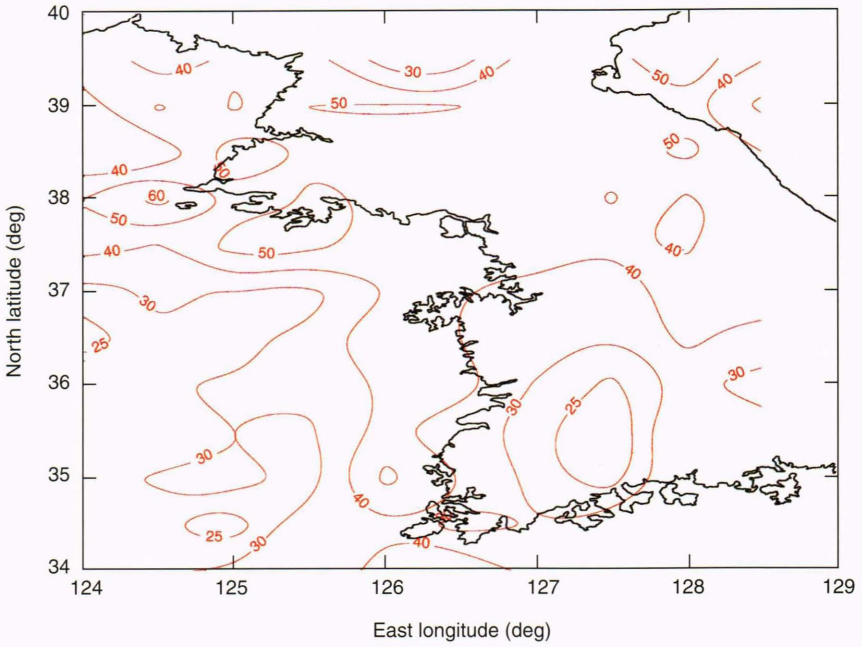

Figure 3. Plot from the Cloud Cover Database showing the percent frequency of total cloud cover equal to or greater than 5/8 at an altitude of 5000 ft for June near the Korean Peninsula and eastern Yellow Sea.

and the CD-ROM data are from the NOAA Polar Orbiting Satellites, Geostationary Operational Environmental Satellites, Geostationary Meteorological Satellites, and the METEOSAT weather satellites.[7,8] Both databases use visible and thermal infrared radiance data collected and analyzed before distribution. An additional WCRP data set held in-house is 1985 to 1986 data from the Tropical Ocean and Global Atmosphere Programme, which concentrates on tropical ocean data—both meteorological and physical.

Two databases that deal with wind are the NAVOCEANO Historical Wind Speed (HWS) and Wind and Residual Noise (WRN). The HWS database consists of archived historical marine data from the NCDC. It describes monthly wind speed at the ocean surface for the marine area between 65°S and 90°N latitude. The WRN data set describes the spectra for wind-generated noise in the Northern Hemisphere as well as the presence of transient or residual noise sources. The wind-generated noise level can be derived at specific frequencies on the basis of spectral curves.

Optical Data

Optical data sets held by the EDP include the Coastal Zone Color Scanner (CZCS) data consisting of 32 months of information collected from the NIMBUS-7 satellite (see the article by Stark in this issue). These data include near-surface measurement of the pigment contained in phytoplankton as well as the water-leaving and aerosol radiances. An additional database developed by STE from chlorophyll and diffuse attenuation (K_d) statistics obtained from academic institutions provides data to a depth of 200 m. The Monthly Mean Distributions of Satellite-Derived Sea Surface Temperature and Pigment Concentration database contains additional water optical clarity data.

Physical Data

The primary physical oceanographic database accessed by STE staff to fill oceanographic data requests is MOODS. This data set provides measured temperature and salinity profiles as well as calculated sound velocity profiles worldwide (Figs. 4A, B, and C). The data are measured by many devices, such as thermometers, reversing thermometers, bathythermographs, expendable bathythermographs, and conductivity-temperature-salinity instruments. Measurements are made from surface ships or aircraft, and, because of instrument limitations, almost none of the data extend to the ocean floor. Information making up the data set was collected by many sources as early as 1901. The database is updated continuously by NAVOCEANO; the EDP receives an updated version annually.

The Generalized Digital Environmental Model, produced by NAVOCEANO, is another commonly used physical oceanographic database. This database was produced by a four-dimensional steady-state digital model using temperature and salinity data from the MOODS data set. The data set gives seasonal data to the ocean bottom for temperature, salinity, the sound velocity profile, bottom depth, and sea surface temperature.

The NODC has publicly released a CD-ROM data set that offers worldwide temperature and salinity data. Much of these data are included in MOODS; however, MOODS is not available to researchers outside of the Department of Defense.

Other Databases

Several other databases held by the EDP do not fit into any of the previously listed categories. These include data on geomagnetics, seismic activity, and historical temporal shipping. These databases generally have worldwide coverage.

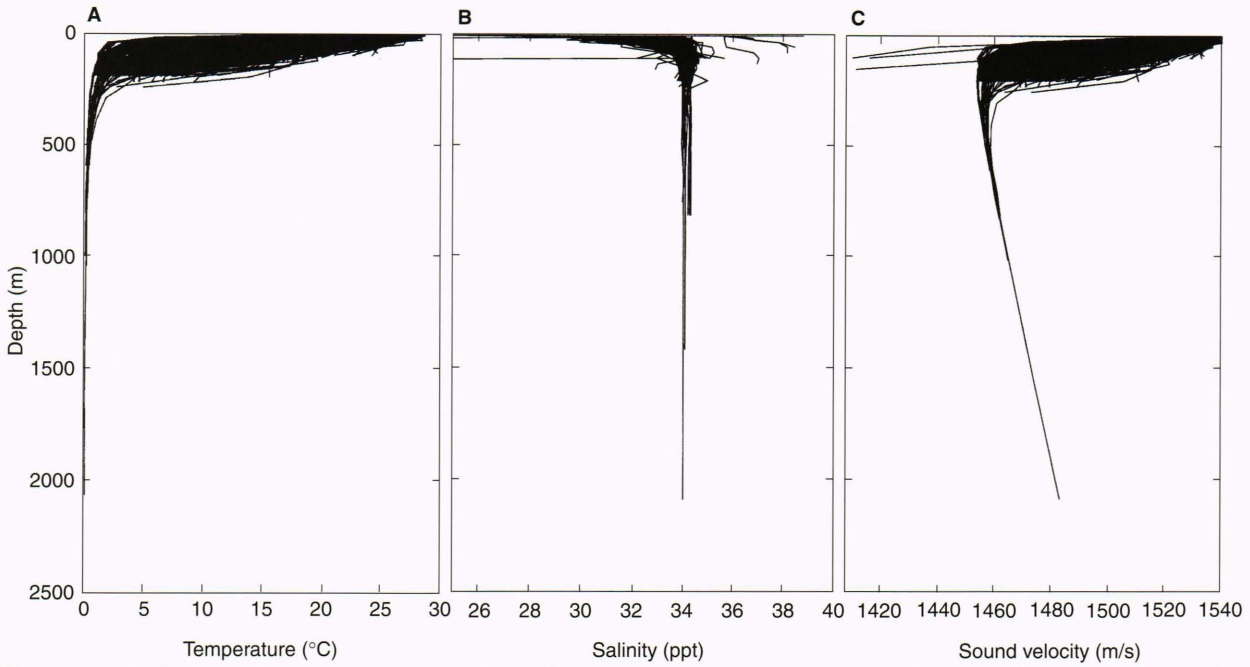

Figure 4. Plots showing various oceanographic profiles for September in the western Sea of Japan (34° to 39° N latitude, 127.5° to 131.0° E longitude) from the Master Oceanographic Observation Data Set (MOODS). **A.** Temperature. **B.** Salinity. **C.** Sound velocity. (ppt = parts per thousand.)

The EDP also holds several data sets from surveys and STD field tests. These data are archived but have not been organized into databases. Working for the Submarine Security Program, STE participated with NAVOCEANO and the Naval Research Laboratory—Stennis Space Center in planning a series of ocean survey programs. The Ocean Measurement Program and the Fixed Site Measurement Program at NAVOCEANO have provided STE with the data from the surveys. In addition, the EDP holds data collected during STD-sponsored field experiments.

Additional databases may be accessed via computer modem. The APL staff has access to the Navy Oceanogaphic Data Distribution System, which primarily provides meteorological data worldwide. These data are updated twice daily and show model predictions and a comparison of model predictions and measured data. Centers such as the Jet Propulsion Laboratory in California maintain many oceanographic and meteorologic databases. Once an account is established with an organization, a user can dial in via computer modem and download the appropriate data. Access to catalogs, listings of holdings, and access information are available worldwide through INTERNET.

FACILITIES AND CAPABILITIES DATABASE

The EDP houses its data in the Environmental Database Computing Facility (EDCF) designed to support the STE staff. The majority of the databases are accessible through an unclassified computer system, which also functions as the operating system for the STE computer network that serves VAXstations, IBM-compatible personal computers, an Apple Macintosh computer, and various output devices. A dedicated VAXstation is used for the classified databases system. Further capabilities of the EDCF include general purpose computer software development employing Fortran and Interactive Data Language, high-resolution graphics using color displays and printers, rapid retrieval of environmental data, and flexibility of output formats and media.

The unclassifed databases are housed on a Digital Equipment Corporation (DEC) MicroVAX 3500 boot node virtual memory operating system (VMS) with a 400-MB disk drive, two 1-GB disk drives, four 1-GB small computer system interface disk drives, a magnetic tape drive, a 9-track tape drive, and an Exabyte tape drive. Two X-Windows terminals and individual personal computers on the STE network are used to access the data. The paper or viewgraph output is produced in black and white or in color using a 4-color wax-transfer process. A DEC VAXstation 3100 boot node VMS with one 3.5-in. floppy disk drive, a TK50 magnetic tape drive, a 500-MB erasable optical disk drive, a 9-track tape drive, and an Exabyte tape drive houses the classified databases. Both color and black and white hardcopy and viewgraphs can be produced.

The capability and productivity of the EDCF will be increased in 1994 by implementing a database management software package on the unclassified system, installing an additional VAX3500 CPU, and upgrading the network hardware connections. Access capability will be added to the databases from Sun workstations.

DATABASE USES

The numerous databases available to researchers are used in many ways. The most basic application is for analysis to show historical trends. This form of data analysis is currently being employed to investigate the possibility of global warming caused by the pollutants of

the modern world. At APL, the databases have been put to a wide variety of uses—primarily by the staff of the Submarine Security Program.

Initially, the databases were accessed by STD Project Managers to assist in planning sea tests. Sea tests usually have very specific oceanographic feature requirements such as ocean fronts, temperature variations, or current conditions. The databases allow oceanographers to look at historical information and choose the most appropriate time and/or location to conduct the test. In recent years, the uses for the databases have expanded greatly. Additionally, post-test analysis allows researchers to compare historical data with environmental data collected during the field experiment. The information derived in this way can facilitate analysis when comparing actual and expected test results.

A large effort by the Navy is devoted to producing three-dimensional environmental data fields to assess and predict the performance of operational Navy systems.[9] These data fields are assembled from large databases such as MOODS. To add a more realistic effect to these data fields, real-time environmental data are now being merged into the historical data fields. The data must be combined in such a way as to avoid a discontinuity between real-time and historical data, and the validity of the data must not be compromised. This approach will allow modelers to provide accurate predictions from current data. This use of real-time data could have a dramatic effect on model results if the research were directed toward the Pacific Ocean area influenced by El Niño conditions. El Niño dramatically changes the temperature of the water in the coastal regions of South America but does not occur annually.

Most data requests received by the EDP require overlaying data from several sources. Figure 5 is a graphic representation of cloaking depth (i.e., the difference between the depth to which a measured amount of light penetrates and the ocean bottom) for the winter around the Korean Peninsula as derived from three databases: CZCS (optical clarity), DBDB5 (bathymetry), and WDB I

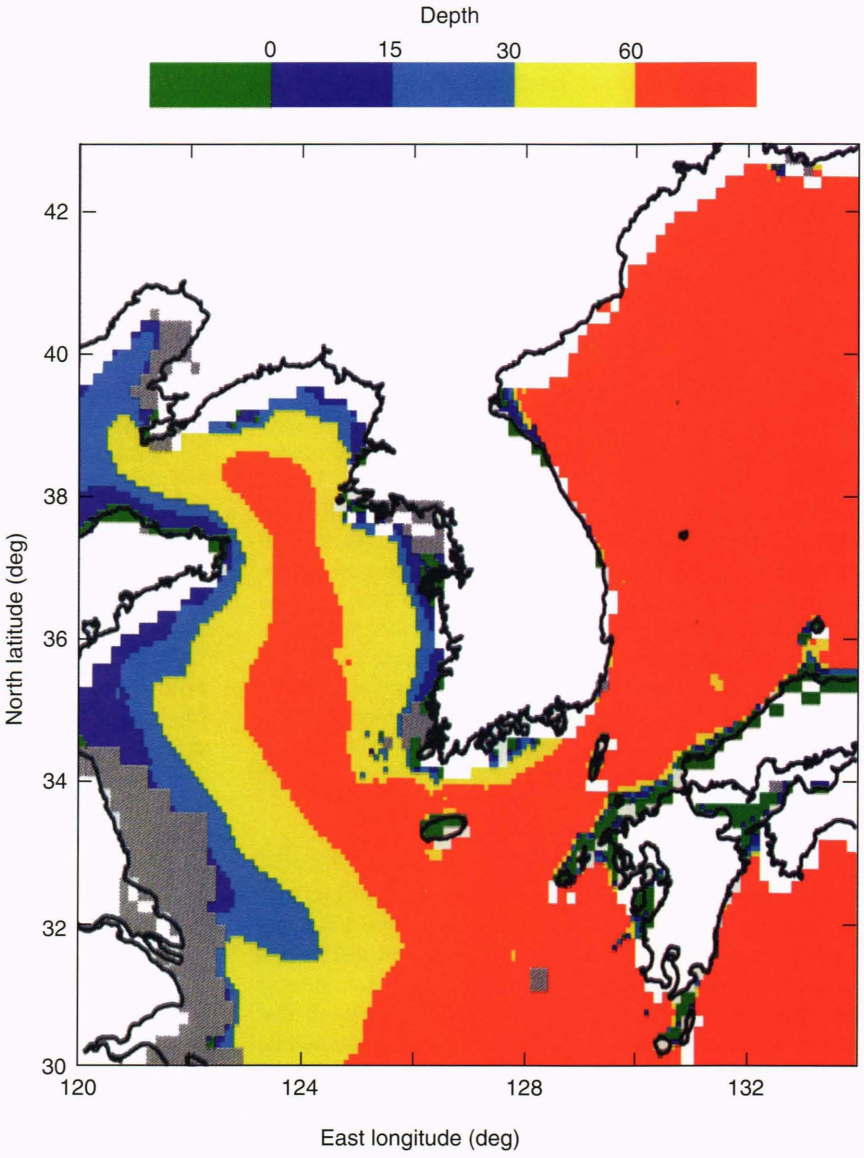

Figure 5. Combined data from the Coastal Zone Color Scanner, Digital Bathymetric Database, and World Data Bank to produce the "cloaking depth" for the winter ($1K_d$ [diffuse attenuation] depth [m]) in the area around the Korean Peninsula.

(cartography). The most common graphic representation using CCDB is the overlaying of cloud cover and cartography data. Much of this work has been in support of requests from APL's Fleet Systems Department. The *Digitized Charts of the World*, produced by DMA, enables detailed maps of land areas to be produced. Features such as roads (dual highways and single-lane to roads under construction), civilian and military airports, railroads, elevation contours, and vegetation are among the wide-ranging options. These types of maps have been used to support studies and war games by APL's Naval Warfare Analysis Department.

The increased interest in coastal oceanography prompted the use of the bathymetric databases and cartographic data to produce the map shown in Figure 6. This type of data representation illustrates areas of interest to the shallow-water research community.

The use and inclusion of real-time environmental data for modeling and simulation were discussed earlier. During field experiments, however, it is highly desirable to have the real-time data available for immediate analysis. The analysis allows test plans to be altered while they are still being formulated to assure the best conditions for success. Temperature data are collected using U.S. Navy P-3 aircraft (see the article by Grempler in this issue). These data are merged with historical best fit data for the area surveyed to extend measurement values to the bottom of the ocean. These near real-time data products are available to modelers and test participants. All the collected data are compiled into data libraries that will become part of the oceanographic databases.

SUMMARY

The use of oceanographic databases has expanded greatly at APL over the past three years. As the Navy has extended its interest from the deep ocean to include shallow water regions, the demand for additional data has increased. No longer are data requests strictly for a plot of ocean temperature. Today the requests can be as diverse as a map showing the land area from 100 km inland to 100 km offshore with appropriate elevation and bathymetry contours, calculation of the slope of the land and beach area, type of vegetation encountered, and the optical clarity of the water and cloud cover on a seasonal basis. The challenge to the EDP is to locate appropriate data, ensure that the data are of the best quality, and process these data in a timely fashion. In addition, the project is continually working on ways to integrate databases and to display them graphically in the most informative way.

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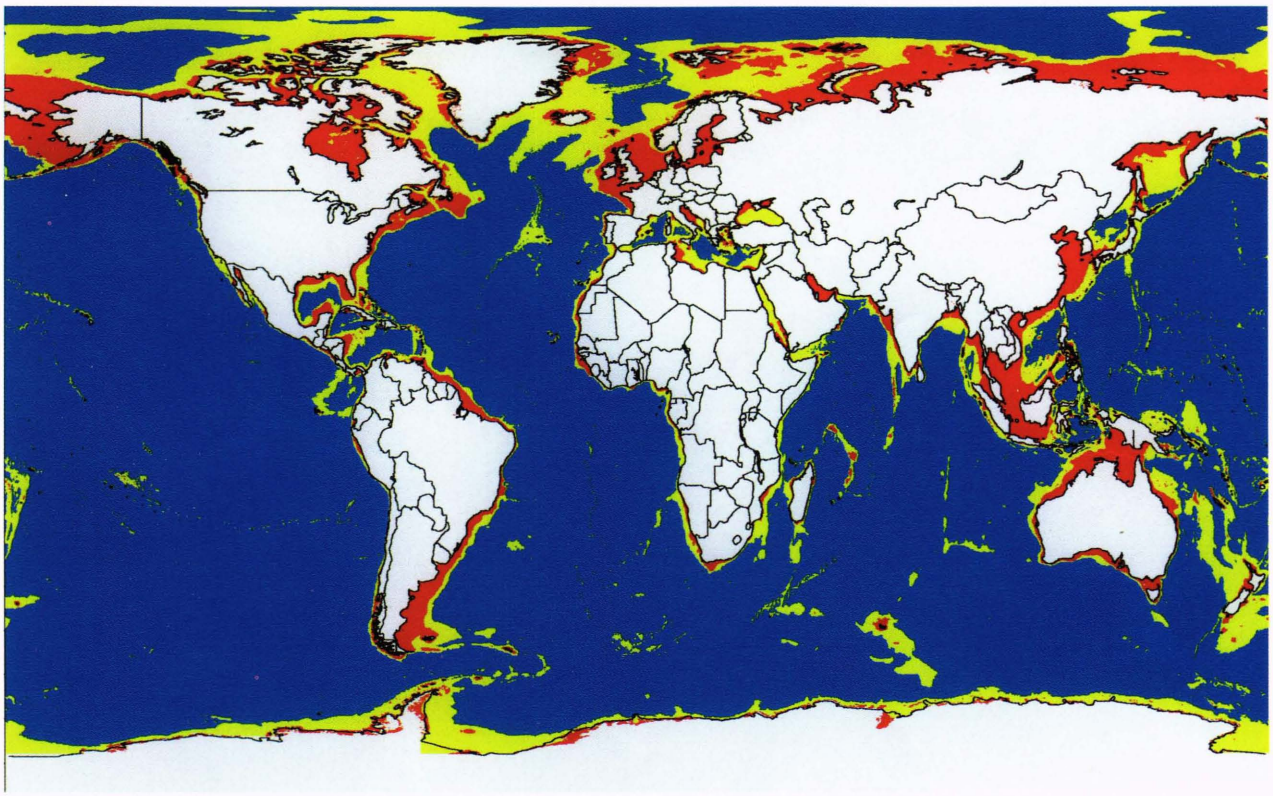

Figure 6. Worldwide map using the World Data Bank and Digital Bathymetric Database to plot the coastal (0 to 200 m, red) and shallow (200 to 2400 m, yellow) regions of the ocean.

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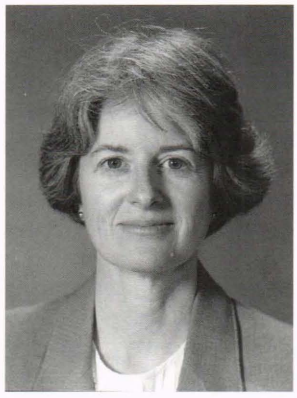

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