DIGITAL OCEAN MAPPING OF THE PACIFIC EEZ

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ABSTRACT

This paper describes the recent ocean mapping research conducted at the Pacific Mapping Program (PMP). Three-dimensional bathymetric maps and side-scan sonar image mosaics were generated. Data integration has been a strong point of PMP's research. This includes the generation of integrated maps of bathymetric data and side-scan sonar images, correction of pixel locations of side-scan sonar images by using bathymetric data acquired separately, and the improvement of bathymetric data by shape from shading technique. Research efforts have been made in developing a Marine Geographical Information System.

INTRODUCTION

The Pacific Mapping Program (PMP) was established at the College of Engineering, University of Hawaii, in 1990. It is a joint effort in ocean mapping of the Pacific Islands EEZ supported by the United States Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), and the University of Hawaii.

The overall goal of the PMP is to facilitate the exploration and development of the resources of the EEZ of the Pacific Islands. The program will serve as a local repository for EEZ information and data in the Pacific Region. In addition, the PMP organizes training programs and workshops on ocean mapping for Hawaii and U.S. territorial islands in the Pacific. The University of Hawaii offers graduate students throughout the Pacific Basin certificate and/or graduate degree programs in ocean mapping.

Since 1990, the PMP has been concentrating its ocean mapping research efforts on data base generation, bathymetric data and side-scan sonar image processing, data integration, seafloor surface modeling, and marine GIS applications. The following sections describe the research work conducted at the PMP.

OCEAN MAPPING DATA PROCESSING

A system for ocean mapping data processing is set up at the PMP and is in full operation. Data sets of the Pacific Islands EEZ are provided by government agencies, institutions, and the private sector. The data processed are mostly bathymetric data, side-scan sonar images, gravity as well as magnetic data. They are processed, displayed, and analyzed for different application purposes.
Hardware and Software Configuration

Figures 1 and 2 depict the hardware and software configuration of the system at the PMP for digital ocean mapping. A SUN SPARC II, a VAX 3200 workstation, and two IBM compatible 386 PCs, running UNIX, VMS, and MS-DOS operating systems, respectively, cover platforms used by most commercial and public domain software packages for ocean mapping. An Ethernet connection between these computers and a link to Internet enable data communication within PMP and with outside hosts.

Figure 1. Hardware configuration

Actually, Figure 2 shows an integrated ocean mapping system at the PMP. At the user interface level, data are filtered so that input file formats are compatible with those used by the system. A user interface on the VAX system has been developed. Software applications can be selected from a user friendly task-oriented menu system. Thus, this integrated system approaches system transparency to users. Integrated software packages include commercial and public domain applications for general image processing, GIS, sonar image processing, bathymetric data processing, cartographic processing, modeling, and animation. The PMP has developed software for user interfaces, data integration, shape from shading processing, pixel relocation of sonar images, etc. The integrated system provides a software environment where data sets can be processed and integrated in a unique environment.
Data Processing

Multi-Beam data are available in the forms of full resolution data ("unthinned" points with coordinates of longitude, latitude, and depth) and grid data (grid points generated from full resolution data or thinned data). These data cover relatively large areas and have been used to generate bathymetric maps, digital seafloor data bases for navigation of under water vehicles, and three-dimensional maps for planning of seafloor explorations.

In many areas there are no Multi-Beam data available. Bathymetric data acquired by single sounding systems from different cruises can be used to generate grids, contour lines, etc. Depth points along track lines are sometimes dense and sometimes sparse depending on the sounding systems used and survey strategies. The overall data distribution of bathymetric points are usually very sparse. Gridded data provide a digital seafloor model with mostly interpolated grid points, while a TIN (Triangulated Irregular Network) preserves the originality of the input data. An improved seafloor model can be achieved by shape from shading using side-scan sonar images (Li and Pai, 1991).

Side-scan sonar images are processed to produce sonar image mosaics and integrated maps of sonar images and bathymetric data. MIPS (Mini Image Processing System), enhanced by the USGS, is used for preprocessing, geometric and radiometric...
processing and mosaicking. The USGS standard procedure for digital sonar mosaicking has been adopted in order to produce sonar image mosaics with the same quality of USGS's sonar image mosaic atlas series. Additional correction of pixel locations of sonar images are applied where bathymetric data are available (Li, 1992b).

DATA INTEGRATION

Generation of Integrated Maps

In many applications different data sets presented in one map may be more useful than maps generated from individual data sets. We can create an integrated map of the side-scan sonar images and bathymetric data of an area using a colored mosaic of side-scan sonar images as map background and bathymetric data to generate contour lines. If classes of seafloor bottom material were identified and presented in different colors on the map, it would be very helpful for marine mining applications.

Draping a side-scan sonar image over a digital seafloor model can be accomplished by using many commercial and public domain software systems. This technique certainly helps obtain an intuitive three-dimensional view of the seafloor and interpret image features which could be impossible without viewing the images threedimensionally. More sophisticated three-dimensional display and modeling of the seafloor surface can be realized by applying appropriate data structures and animation systems.

Shape from Shading

One of the benefits of data integration is to enhance the quality of data sets involved. If bathymetric data are acquired at the same time as sonar images, the technique of corregistration can be used to locate pixel positions of sonar images according to seafloor topography from the bathymetric data. Since pixel positions of sonar images are usually calculated with an assumption that the seafloor surface be flat in profiles across track lines this may cause shifts of pixels in the direction perpendicular to track lines (Chavez, 1986; Reed and Hussong, 1989). Bathymetric data acquired in different cruises may be applied to correct pixel locations of sonar images by data integration (Li, 1992b). Thus, the geometry of the sonar images is strengthened by integrating existing bathymetric information.

Inversely, the geometric information of seafloor surfaces can also be derived from sonar images to enhance bathymetric data. Shape from shading is one of the methods which generates shape models (first derivatives or slopes) of object surfaces by the analysis of gray values (shading) of images. Application of this technique to underwater sonar images enables a conversion of recorded strengths of reflected sonar signals from seafloor surfaces to seafloor slopes which can be transformed to seafloor depths given depths of a boundary in the mapping area (Li and Pai, 1991).

MARINE GEOGRAPHICAL INFORMATION SYSTEM

Geographical Information Systems (GIS) are the primary applications using geographical spatial data. Thematic data can be represented in various layers designed in a unique reference system for efficient data base management, inquiring, analysis, and display. In comparison to a "land based" GIS, a Marine Geographical Information
System (MGIS) is different in a) data and data acquisition systems involved, b) data processing techniques, and c) applications. Efforts have been made at the PMP to develop a MGIS. Since most existing GIS systems are not designed for marine purposes, existing software systems have been integrated to provide the necessary functionalities needed in an MGIS.

Layer Design in GIS vs. MGIS

Bathymetric data are usually used as the basic layer to provide seafloor topography for other thematic layers, such as side-scan sonar images, gravity, magnetic data, and cable routes, etc. There are very few cultural objects on the seafloor. Therefore, features such as address geocoding and building representations are seldom used in an MGIS. Instead, a track line layer of cruises is very important for data analysis and interpretation. For instance, a track line layer may help geologists figure out the geometry between the sonar image acquisition system and the seafloor surface mapped, and thus interpret sonar images easily.

Data Structures

In a MGIS, three-dimensional data structures are often used instead of the two-dimensional line features such as roads, rivers and others in a land-based GIS. TIN data structures can be used to network discrete data points and reserve the originality of the data set. Many processing and analysis functions are available on the TIN structure (ARC/INFO, 1991). However, a grid provides more efficient raster type spatial operations. For spatial modeling and many three-dimensional dynamic engineering applications, octree is a powerful data structure (Samet, 1990; Li, 1992a). It supports compact data storage, efficient Boolean operations, and fast data searching.

Construction of data structures representing regularly shaped objects, which often appear in ocean engineering applications, can be achieved by applying boundary representation (B-rep) and Constructive Solid Geometry (CSG) (Li, 1992a). A successful integration of these data structures will lead to a powerful MGIS.

Dynamic Modeling and Animation

Three-dimensional bathymetric maps provide an efficient way of seafloor visualization. Furthermore, draping sonar images on a digital seafloor model is beneficial for three-dimensional visualization and image interpretation. However, in many cases we need sophisticated three-dimensional dynamic modeling and visualization in order to support applications such as GIS/GPS based real-time navigations, underwater vehicle simulations, and other ocean engineering applications. Successful applications depend on a) a successful selection of three-dimensional data structures to optimize the balance between the data base compactness and operation efficiency, b) corregistration of ocean-related data sets involved, and (c) high performance computers and advanced visualizing systems. Systems fulfilling all three requirements need to be researched.
CONCLUDING REMARKS

In comparison to the land surface of the earth, the seafloor surface has still too much to survey. Ocean mapping will greatly support the increasing extension of human activities from shallow water to deep water areas, and provide first hand data for EEZ exploration, global change monitoring, research in ocean related sciences and others.

Efficient and economic ocean mapping can be achieved by strategic systematic mapping using state-of-the-art systems and utilization of available historical data which may be acquired by different institutes using different systems. This requires methods for assessing, processing, and integration of data with different qualities and densities of data distribution. Hardware and software advances in computer graphics provide the possibility of real time ocean related application systems using ocean mapping data. A Marine Geographical Information Systems will be a powerful link between ocean mapping and other disciplines. With a MGIS, the time consuming procedures of conventional ocean mapping would be no longer necessary. Diverse GIS capabilities such data enquiry, spatial modeling, spatial analysis, three-dimensional display, etc. make ocean mapping data more valuable to end users.

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REFERENCES


EEZ MAPPING IN CANADA: ADVANCES IN SHALLOW WATER SURVEYING

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ABSTRACT

To meet its needs for coastal and continental shelf surveying, Canada is currently employing a variety of acoustic swath mapping tools capable of working in relatively shallow water. These systems (Navitronics, shipboard and DOLPHIN-mounted EM-100 and EM-1000s) present significantly higher artifact and data volume problems than their corresponding deep-water counterparts.

The operational philosophy behind the deployment of these swath systems reflects the individual system capabilities and the needs of the primary user groups (marine transport and fisheries). Data post-processing and management require that data quality problems (which vary from system to system) be well understood. A "Hydrographic Ground Truthing" experiment is being undertaken, looking at the relative data quality provided by the three acoustic systems currently employed.

INTRODUCTION

Exploration and conservation of EEZ resources have been, and will continue to be, primarily focussed on the continental shelf. Canada, with the longest coastline and one of the largest continental shelves in the world, has critical economic, environmental and strategic interests in more precisely mapping and understanding the vast area of its EEZ.

Although there is a slowly increasing trend towards working in deeper water, the majority of man's interaction with the seabed remains focussed in the waters of the continental shelf and particularly the coastal zone. Only recently have shallow-water acoustic swath systems, capable of providing hydrographic-quality topography and quantitative echo strength data become available. Such systems tend to have a swath width that decreases with water depth and as a result, surveying in shallow water requires a much greater expenditure of ship time. Shallow water systems, nevertheless provide a much greater spatial resolution than their deep-water counterparts resulting in a larger data volume management problem.

Canada, with an unusually large proportion of its EEZ in water depths less than 200 m (the continental shelves, the Artic Island passages and the Great Lakes) has
acquired a number of acoustic swath survey system to address the problem of
maximising the efficiency of both collection and processing of seabed information.

In order to optimise the existing knowledge-base within Canada, alliances have
been formed between government departments, universities and private industries. Two
examples of these alliances are the Canadian Ocean Mapping System (COMS) and the
NSERC Industrial Chair in Ocean Mapping (Hughes Clarke, et al., 1992). Both these
alliances directly address the problems of large-area shallow-water surveying.

In this paper we outline the operational philosophy used for surveying within
Canadian waters, the problems associated with this approach and provide examples of
the type and quality of data available through implementation of this philosophy.

OPERATIONAL PHILOSOPHY

Multibeam or multitransducer sounders provide the ability to produce high-
density narrow-beam sounding without the excessive use of shiptime that would be
required with single-beam sounders. Such sounders are usually deployed in such a way
that 100+/-% coverage of the seafloor is obtained. Thus the line spacing will reflect the
swath width (usually 80 or 90% of the system coverage).

Because the line spacing required in shallow water is one or more orders of
magnitude smaller than that employed in deep water, it is not feasible to undertake a
systematic regional coverage program. Priorities, driven by human use and abuse
patterns, must first be delineated and those regions of highest priorities given
precedence.

The largest users of the Canadian shallow water EEZ are marine transport and
the fisheries. As a result safety of navigation (hydrographic quality bathymetry) and
surficial seabed lithology (fisheries habitats) are of prime concern.

The choice of acoustic swath system depends upon both the water depth and the
operational logistics inherent in the survey location. As a result, shallow water acoustic
swath surveying in Canada can be divided into three operational regimes (Figure 1).

Water Depths of 2-15m in Dockside or Estuarine Environments

The system employed for shallowest water is the 200 kHz Navitronics boom
sounding system (Burke and Forbes, 1984). As configured on CSS F.G. Smith (Figure 2a),
the total swath is 45 m with a total of 36 transducers (there are 14 other Navitronics
installations in Canada of which the Smith is the largest). Each beam has a width of 7
degrees (to -3dB points). The Navitronics currently only provides depth information. In
water depths greater than 20 m with a beam spacing of 1.4 m the beams overlap. The
survey speed of the vessel with booms extended is only about 3 knots and thus the areal
extent of coverage is limited. Because the soundings are all based on vertical travel paths,
the systems is insensitive to refraction caused by the horizontal stratification in the water
column that is so common in coastal and estuarine environments. The principal
limitation of the Navitronics system currently is the ambiguity in distinguishing mid
water returns (very common at 200kHz) and the true seabed.
Figure 1. Operational philosophy behind the deployment of acoustic swath systems in Canada.

Figure 2a. CSS F.G. Smith with Navitronics boom system deployed.
The Middle and Outer Continental Shelf

The middle and outer shelf operations are undertaken using the Simrad EM100 system currently installed on the CSS Matthew (51 m) and until this year, the CSS Lauzier (nm). The EM100 provides 2.4 times water depth up to 150 m, thereafter the swath width reduces to 1.7 times water depth.

Since the beginning of this year the EM100 is also available from the robotic vehicle DOLPHIN. DOLPHIN (Deep-Ocean Logging Platform with Hydrographic Instrumentation and Navigation) is an 7.0 m long diesel powered torpedo-shaped semi-submersible (Figure 2b) which can be controlled through a UHF radio link (Dinn, et al., 1987). As part of the Canadian Ocean Mapping System (COMS, Peyton, 1992b), the DOLPHIN's were fitted with a modified EM100 multibeam sounder and deployed using differential Global Positioning System (DGPS) by Geo-Resources Inc. of Newfoundland (Peyton, 1992a).

Figure 2b. DOLPHIN and handling system

The DOLPHIN represents an economic method of deploying high resolution multibeam sounders from either a shore station (Figure 3a) or from a mother vessel (Figures 3b,c) in contrast to the cost of purchase and installation of hull-mounted multibeam sounders which cannot be deployed from ships of opportunity. The maximum economy of using a DOLPHIN occurs when two or more DOLPHINS are deployed at once and either the mother vessel has her own swath system (Figure 3b) or is fully utilised
Figure 2c. NSC Frederick G. Creed SWATH vessel underway

Figure 3. Operational Modes for the COMS DOLPHIN/EM100 System.

a. Shore based deployment (with or without ancillary 10 m survey launch).

b. Deployment in parallel with mother vessel.

c. Deployment independent of mother vessel.
doing other concurrent activities (e.g., bottom sampling or submersible support (Figure 3c)). Using the UHF radio link currently implemented in COMS, the DOLPHINS can work up to a maximum range of 5 km from the shorestation/mother vessel and can run a series of survey lines without direct operator interaction.

The DOLPHINs can operate while collecting hydrographic quality data in higher seastates (up to Seastate 6) than surface vessels configured with the same sounder (Peyton, 1992b). Thus the DOLPHINs are ideally suited for outer continental shelf operations which would otherwise require ocean-going vessels.

Limitations to using the DOLPHIN include operating in areas of high shipping activity and the recovery of the system. To circumvent the first limitation, operations can be conducted by installing the DOLPHIN/EM100 data logging gear on a small 10 m long survey launch. A custom shipboard mounted crane (Figure 2b) has been developed to minimise the second limitation and has been field tested in sea states up to 4 with successful launch and recoveries (Peyton, 1992b). The DOLPHIN has fuel and lubrication for a 24 hour period (at 10 knots) and the recycling time for recovery, fueling, lubrication and redeployment is on the order of 3 hours. Thus a DOLPHIN may be maintained in an operational state for 90 percent of an operation.

**Water Depths Greater than 15 m and Within 3 hours Steam of a Port**

Until recently, hydrographic surveys carried out in the inner continental shelf (10-50 m) were conducted primarily using single beam echo sounders. The recent development of the EM1000 multibeam sounder by Simrad, has provided an efficient means of collecting very wide swath (7.5 times the water depth) hydrographic quality data.

The EM1000 can be employed with as little as 5 m below the transducer. This system is currently deployed on the SWATH vessel NSC Frederick G. Creed (Figure 2c) and is routinely operated at survey speeds of 16 knots. While the EM1000 is capable of operating to 800 m, the size and berthing of the Creed currently restrict its activities to daily operations. For this reason, the Creed is utilised in coastal and inner shelf environments only.

**DATA PROCESSING**

In order to handle high volumes of swath bathymetric data, a custom designed commercial software package has been developed for the Canadian Hydrographic Service jointly by the University of New Brunswick and Universal Systems Limited of Fredericton, NB. This system, called HIPS (Hydrographic Information Processing System), relies on the statistical outlier approach developed by Ware, et al. (1991), and incorporates navigational editing and interactive sounding cleaning to produce a tidally-corrected sounding set with a minimum of artifacts. The system then takes the cleaned sounding data into a GIS environment for chart production. The HIPS currently handles Navitronics data, EM100 and EM1000 data and is generic in design so that it can handle any single beam or multibeam data set.

In addition to sounding data both the EM100 and the EM1000 produce information on the strength of the seafloor echo. This data can provide information on seafloor type which in not visible in the bathymetric data. A new processing package has been developed at UNB to provide digital mosaics of the sidescan imagery that is available.
from the EM100-1000 series (see Figure 4). For the EM-100, a single amplitude is provided for each of the 32 beams, but for the new EM1000 a calibrated amplitude time series (samples at 0.2 ms intervals) is provided for each of 60 beams totaling up to 4k bytes of data per ping. In order to compile each of the beam amplitude traces into a single sidescan-equivalent (but topographically corrected) image requires a dedicated post-processing toolkit. Recent EM-1000 operations show that is is feasible to both clean the bathymetry and create and digitally mosaic the sidescan data at the same rate as data acquisition, even in the shallowest water depths with ping rates up to 1/4 seconds.

HYDROGRAPHIC GROUND TRUTHING EXPERIMENT

The Hydrographic Ground Truthing Experiment (Wells, et al., 1992) is a three-year strategic grant program, funded by the Canadian National Science and Engineering Research Council (NSERC) which examines the quality and data content of shallow water acoustic swath-map systems. The first phase of this experiment has recently been completed. It involved the acquisition of acoustic swath and subbottom data in both intertidal and subtidal environments in the Bay of Fundy (maximum tidal ranges of 15 m (50 ft)) for comparison to ground truth data collected in the form of aerial photography, CASI imagery, terrestrial topographic surveys, bottom photography and bottom sampling.

While the data has only been recently acquired several new directions appear promising. By independently logging the received echo trace signals for each of the beams within the Navitronics systems, it is apparent that there is the ability to distinguish both in-water echos such as fish or kelp (which show up as a major problem at 200 kHz) and the seabed type from the seabed echo. This would provide a greater degree of confidence in the hydrographic quality of the soundings and a new dimension for seabed classification concurrent with the hydrographic survey.

The Simrad EM1000 swath sounder was deployed for the first time and several capabilities and limitations emerged. The system has a minimum depth capability at approximately 5 m beneath the keel (equivalent to 8 m on the Creed) and this appears to be substrate dependent with improved capability on hard substrates. Offshore in water depths in excess of 25 m the systems performs optimally. Acoustic data was collected from the SWATH vessel at speeds of up to 18 knots. The only apparent degradation in the data was the increased distance alongtrack between soundings.

Because of the remarkably wide swath, the EM1000 system is very sensitive to time lags and/or horizontal accelerations not resolved by the ship motion sensor which produce noticeable roll artifacts in the data. In coastal and especially estuarine waters, the shallow angle of beam forming makes the system extremely sensitive to refraction caused by changes in sound speed in the upper few metres of the water column. Thus the hydrographic quality of the data can be compromised by imperfect knowledge of ship motion and water column structure.

The sidescan imagery from the EM1000 defines sediment boundaries which have no bathymetric expression and thus provides additional useful information. Sediment bedforms with wavelengths as short as 4 m are resolvable in water depths of 80 m. The EM1000 imagery has two advantages over a conventional sidescan: it is corrected for bottom topography; and it is calibrated so that a seafloor type will return the same echo independent of water depth (there is still a grazing angle effect in the data).
Figure 4. Example EM1000 data from Minas Channel, Nova Scotia. This data was acquired by the NSC Frederick G. Creed at 16 knots. The image is made up of 12 parallel swaths. The first image (A) shows the sidescan data acquired (loud echoes are bright) and the second image (B) shows the sun illuminated topography (illuminated from 190°). Note that the bedrock outcrop is both visible in the sidescan as a change in backscatter, and also resolved by the bathymetry. Water depth varies between 20 and 140m.
CONCLUSIONS

In summary, the choice of acoustic swath system in shallow water depends on the water depth range, the requirements of the survey and the logistics of the operation. Acquisition of high density sounding and echo trace data cannot proceed without adequate data processing. In order to retain the high vertical resolution (decimetres) and detailed horizontal spatial resolution (1-10 m) provided by these new swath systems, the full data content must be maintained. Software, developed in parallel with the acquisition of swath systems in Canada, has attempted to maintain the full integrity of the data.

Continued advances in the capability of shallow water systems will provide end users with the required detailed hydrographic and geologic knowledge of the continental shelf and coastal zone which has previously been unavailable. Such detailed knowledge of the continental shelf and coastal zone is necessary if Canada is to manage effectively its huge Exclusive Economic Zone.

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REFERENCES


BOTTOM CLASSIFICATION USING MULTIBEAM SONAR SYSTEMS

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ABSTRACT

Experimental studies in different regions of the oceans have shown that sound backscatter is determined by the parameters of the sediment only (not relief) at frequencies below 2.5 KHz. At frequencies above 2.5 KHz, both bottom sediment composition and bottom relief play significant roles. A method is presented in this paper to predict backscatter strength from core sample data so that multibeam sonar backscatter data can be used together with synthetic core sample data to both determine sediment boundaries and to determine appropriate weighting functions for interpolation of geological data parameters between core sample locations.

Acoustic Classification

The scattering of sound by the bottom in the "backward" direction has been described theoretically (Brekhovshikikh & Lysanov, 1982). Modern data are expressed in terms of "backscatter strength S", defined as:

\[ S = \frac{\text{Iscat} A}{I_{\text{inc}}} \text{ in } \text{1/m}^2 \]

where:

- Iscat = intensity of sound back-scattered from area A
- A = acoustic spot size on the bottom in m²
- \( e^{*}\text{pulse width}/2*\text{cos(\theta_0)}) * 2*\text{depth*sin (beamwidth/2)} \)
- I_{\text{inc}} = incident sound intensity at the bottom in uPa/\text{m}

Experimental studies in different regions of the oceans have shown that sound backscatter is determined by the parameters of the sediment only (not relief) at frequencies below 2.5 KHz. At frequencies above 2.5 KHz, both bottom sediment composition and bottom relief play significant roles.

Backscatter can be considered as a superposition of 3 independent curves. The first curve is dependent on sediment composition only, the second curve is dependent on small scale bottom relief roughness, and the third curve is dependent on large scale bottom roughness.

While sediment sound speed is obtainable from core sample geology, roughness and interface roughness between sub-bottom sediment layers are not.

Thus, core sample data yields a family of backscatter curves dependent on bottom roughness. When the bottom is perfectly flat, then the family of curves reduces to a single "smooth bottom" backscatter curve.
For a totally smooth bottom, backscatter effects are due to sediment composition only. Table 1 shows backscatter strength as a function of sediment composition. The texture, density, and sound speed data in the table are from (Hamilton, 1980) and (Hamilton, 1974). The first curve which models the effects of sediment only is defined by the Mackenzie equation (Mackenzie, 1961). The curve shape is given by:

\[
\text{Mackenzie} = b_2 * \cos(\text{grazing}) ** a \quad \text{in dB/m}^2
\]

\[
S_\text{B} = 10**((\text{Mackenzie}/10.) \quad \text{in m}^2
\]

where:

- \(a = \log10(b_1/b_2)/\log10(\cos(89.99))\)
- \(b_1 = 10*\log10((Z_2-Z_1)/(Z_2+Z_1)) + \text{diffusivity}\)
- \(b_2 = -46. + 1.95*\text{lgs} -(\text{lgs}-10)^*\text{brtl}\) calcarceous
- \(b_2 = -46. + 2.00*\text{lgs} -(\text{lgs}-10)^*\text{brtl}\) slope/shelf/hill
- \(b_2 = -47. + 2.05*\text{lgs} -(\text{lgs}-10)^*\text{brtl}\) diatom
- \(\text{lgs} = \log2(\text{grain size um})\)
- \(\text{brtl} = \text{grain size sdev} / \text{grain size}\)
- \(\text{grazing} = \text{bottom grazing angle in degrees}\)
- \(Z_i = \text{ci}*\text{di}\)
- \(\text{ci} = \text{layer i sound speed, \text{di} = layer i density}\)
- \(\text{diffusivity} = -2*\text{sqr}(\text{brtl})\) for \(\text{lgs} < 1\)
- \(\text{diffusivity} = -2*\text{sqr}(\text{brtl}^*\text{lgs})\) for \(\text{lgs} > 1\)

Maximum backscatter strength \(b_1\) occurs at 90 degrees grazing angle and is determined from density and sound speed measurements from core sample data.

Between 4 and 0 degrees grazing angle, backscatter strength approaches a minimum \(b_2\). Unlike the maximum backscatter strength, this value is frequency dependent. A perfectly flat bottom never actually occurs on the ocean floor. There is always some small amount of roughness associated with a smooth ocean bottom which interacts with the acoustic frequency. Minimum values for backscatter strength are available (Urick, 1983) as a function of sand, silt, clay, and sand-rock mixtures at frequencies ranging from 10 Hz to 300KHz. The frequency dependence was determined to be:

\[
b_2(f) = b_2(12 \text{ KHz}) + 2.0*\log10((f+1)/13)*((2+\log2(\text{grain size}))/2) \quad f<12 \text{ KHz}
\]

\[
b_2(f) = b_2(12 \text{ KHz}) + 1.5*\log10((f+1)/13)*((13-\log2(\text{grain size}))/2) \quad f>12 \text{ KHz}
\]

where:
- \(f = \text{sound frequency in KHz}\)
- \(\text{grain size is in micrometers (um)}\)

The second curve accounts for small scale bottom roughness. In wave-scattering theory (Brekhoversekh, 1982), the vertical scale of roughness is usually specified by the “Rayleigh parameter”

\[
P=2*k*\sigma(\theta)\cos(\theta_0)
\]

where:
- \(P = \text{Rayleigh parameter}\)
- \(k = \text{wave number of sound} = 2*\pi/w/c\)
- \(\theta_0 = \text{angle of incidence of the sound plane wave}\)
- \(\sigma = \text{root-mean-square displacement of the rough surface from its mean level}\)

At \(P \ll 1\), the roughness of the surface is acoustically "smooth", and the surface scatters sound slightly, with the main part of the energy specularly reflected as a coherent wave. At \(P \gg 1\), the surface is acoustically rough and the surface scatters sound
<table>
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<th>Density (g/cm³)</th>
<th>Sound Speed (km/sec)</th>
<th>Impedance (zdo*do)</th>
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Maximum Backscatter = 10*\log_{10}(\frac{zdo-1.5}{zdo+1.5})

Minimum Backscatter = \begin{cases} -46 + 2*\log_{2}(\text{grain size \(\mu m\)}) & \text{shelf/slope/plain} \\ -45 + 1.95*\log_{2}(\text{grain size \(\mu m\)}) & \text{calcareous} \\ -47 + 2.05*\log_{2}(\text{grain size \(\mu m\)}) & \text{diatom} \end{cases}

-21-
in a diffuse manner in a wide angular interval. If sigma is small, then the scattering
sound field can be calculated by the Method of Small Perturbation (MSP) (Brekhovskikh &
Lyasnov, 1982). In this case the problem of wave scattering is reduced to the problem of
radiation by a distribution of "virtual" sound sources. For scattering and backscattering
where \( \theta = \theta_{ao} \),

\[
S1(\theta) = 4 \cdot k \cdot |\cos(\theta)|^{*2} \cdot |k \cdot \cos(\theta_{ao})|^{*2} \cdot G(x)
\]

where:

\[
G(x) = (1/\pi) \cdot (\text{grain size sdev/grain size})^{*2}
\]

To obtain \( S1 \) for the backscatter case, we assume the effect of the large-scale
underlying changes consists in changing the local angles at which the small-scale
roughness is insenstified. Setting \( \theta = \theta_{ao} \) for backscatter and normalizing the
equation for \( S1 \) so that it is equal to the maximum backscatter strength when \( \theta_{ao} = 0 \);

\[
S1(\theta_{ao}) = V_{max} \cdot \cos(\theta_{ao})^{*4} \cdot G(x)
\]

where:

\[
V_{max} = \text{maximum backscatter} = 10^{**}(b1/10.) \text{ in } \text{m}^2
\]

In the above equation the spatial spectrum of small scale isotropic ripple \( G(x) \)
ranges from 0 to 1. Thus the value for \( S1 \) small scale backscatter can never exceed the
theoretical \( V_{max} \).

The third curve accounts for large scale bottom roughness. The MSP method is
only applicable for the case of a small Rayleigh parameter \( P \). However, the roughness
amplitude of the ocean bottom is frequently much greater than the sonar sound wave-
length and the Rayleigh parameter is large. In these cases, the Method of Tangent Plane
(MTP), also known as the Kirchoff approximation, can be used. The tangent plane
method yields good results only for those directions of scattering which are close to
directions of specular reflection. When both scales of roughness are present we use a
method which is the combination of MSP and MTP. It is based on the assumption that
the roughness can be divided into two components a small scale component and a large
scale one. We obtain the two-scale rough bottom model by superimposing the surface
with the small scale displacement upon the surface with a large scale displacement.
The scattering coefficient is represented in the form:

\[
S = S1 + S2 + S3
\]

where:

\[
S1 = \text{small scale roughness scattering calculated from MSP}
\]
\[
S2 = \text{large scale roughness scattering calculated from MTP}
\]
\[
S3 = \text{impedance scattering calculated from MacKenzie}
\]

To obtain \( S2 \), we assume that the slopes of the large waves are isotropic and
normally distributed. In this case:

\[
S2 = \frac{V^{*2} \cdot \exp[-\tan(\theta_{ao})^{*2}/(2 \cdot \text{slope}^{*2})]}{(8 \cdot \pi \cdot \text{slope}^{*2} \cdot \cos(\theta_{ao})^{*4})}
\]

where:

\[
V = \text{reflection coefficient}
\]
\[
\text{slope} = \text{brt2}/2, \quad \text{brt2} = \text{relief height ft} / \text{relief period ft}
\]
Normalizing the equation for \( S2 \) so that large scale backscatter never exceeds the theoretical maximum backscatter strength \( V_{\text{max}} \):

\[
S2 = V_{\text{max}}^{**2}*\exp[-\tan(\theta_{\text{tao}})^{**2}/(2*\text{slope}^{**2})]/\cos(\theta_{\text{tao}})^{**4}
\]

**Using Core Samples to Predict Backscatter Strength**

The scattering strength \( S1 \) is considerably less than \( S2 \) for small incident angles. At angles > 45 degrees, \( S1 \) is greater than \( S2 \). Thus, large scale effects dominate at small angles of incidence (large grazing angles) while small scale effects dominate at large angles of incidence (small grazing angles). Figure 1 was generated using the Mackenzie equation for \( S3 \) only. Figure 2 was generated using the \( S1 \) MSP equation for small scale bottom roughness. Figure 3 was generated using the \( S2 \) MTP equation for large scale bottom roughness. Figure 4 shows an example of hybrid set of curves where both small scale and large scale bottom roughness were present.

Most geoacoustic provinces have a sub-bottom basement of solid rock. The sub-bottom basement acts as a reflector, adding a second backscatter curve to the one produced at the water-sediment interface. Even when there is no sub-bottom basement, there are usually 2-5 sediment layers of distinctly different sediment. The interfaces between sediment layers also act as reflectors, multiplying the number of the backscatter curves. In general the additional layer reflectors induce large fluctuations in measured backscatter strength causing ambiguities in classification. In addition, significant changes in sediment composition cause very small changes (0.1 to 0.2 dB) in received backscatter strength.

To eliminate ambiguities in acoustic classification, a vertical profile of the bottom sediment layers must be obtained from core samples from which sound speed can be derived. Even when acoustic sub-bottom profile measurements are available, core samples are needed to identify the correct depth of sediment layers. Acoustic sub-bottom profilers measure impedance which in itself is ambiguous in density and sound speed.

Horizontal and vertical ambiguities in acoustic backscatter province boundaries can best be resolved by statistical models which combine core sample geology and sonar backscatter acoustic measurements into sediment classes such as those proposed in Table 2. In Table 2, the impedance \( z_o \) is normalized for a water sound speed of 1500 meters/sec. Impedance \( Z \) in Table 2 is obtained using \( \theta_{\text{tao}} = 0 \).

Table 2 shows that impedances and hence backscatter strengths are ambiguous with respect to texture types. Therefore the geological composition must be known to break the ambiguities. The geological composition is referred to in Table 2 as petrology. Petrologies are based on lattice structure as well as differing amounts of CaCO3, CaO3, SiO2, Al2O3, Fe2O3, FeO, MgO and CO2.

The terrigenous/calcareous petrology in Table 2 includes shale, oolites and ostracods. The turbidite/calcareous petrology in Table 2 include petropods and globerina. Monocite quartz has a density of 2.65 and should be grouped under the greywacke petrology which has a density of 2.7. Diocite quartz has a density from 2.8-3.0 gm/cm3. Limestone and chalk are the only petrologies with significant amounts of CO2 (41.5% by weight). Siliceous petrologies contain predominately SiO2 (48.8-89.9% by weight). Calcareous petrologies contain predominately CaCO3 and CaCO3 (42.6-60.0% by weight). Calcite is 99.9% CaCO3 at a density of 2.6-2.7 gm/cm3.
Figure 1. Backscatter strength at 12 KHz due to sediment composition alone

Figure 2. Backscatter strength at 12 KHz due to sediment composition and small scale bottom roughness

Figure 3. Backscatter strength at 12 KHz due to sediment composition and large scale bottom roughness

Figure 4. Backscatter strength due to a combination of sediment composition and small and large scale roughness
Backscatter Depth Dependence

The impedances shown in Table 2 are under atmospheric pressure. Sub-bottom sediment impedances are larger than those in Table 2 because of increased pressure which is dependent on the depth below the water-bottom interface and the type of material directly above. Sub-bottom density corrections are given by Hamilton (1980). While backscatter strength will be increased due to increasing pressure in sub-bottom sediments, it will be reduced by bottom sediment attenuation (Hamilton, 1980).

Synthetic core sample backscatter can be made to match sidescan sonar backscatter and sonar sub-bottom profiler backscatter measurements where core sample and sonar measurements are co-located. For sidescan sonar the first 20 meters of sediment must be defined using core samples. For acoustic sub-bottom profilers, the first 200 meters of sediment must be defined using core samples. If possible, it is prudent to define the sediment vertical structure down to the rock basement. The depth dependence of density $d_i$ in layer $i$ is given by:

$$d_i = d_0 + d_{\text{km}} \times 1.2 \times \pi$$

where:
- $d_0 = \text{dmin}$ Quartz/Sandstone/Chert/Diatom/Radiolarite
- $d_0 = \text{dmax}$ Calcite/Limestone/Chalk/Calcereous
- $d_0 = \text{dmin} + 0.4(\text{dmax}-\text{dmin})$ Basalt/Siliceous
- $d_0 = \text{dmin} + 0.6(\text{dmax}-\text{dmin})$ Shale/Terrigenous/Turbidite
- $\text{dmin} = 1.08 + 0.12\times\text{lgs} - 0.0015\times\text{lgs}^{**2}$ for $\text{lgs} > 0$
- $\text{dmin} = 1.08 + \text{lgs}/40$ for $\text{lgs} < 0$
- $\text{dmax} = 1.40 + 0.078\times\text{lgs}$

The depth dependence of porosity $p_i$ in layer $i$ is given by:

$$p_i = p_0$$

$$= p_0 + d_{\text{km}} \times (0.2-p_0)/1500$$

$$= p_0 + d_{\text{km}} \times (-p_0)/2500$$

where:
- $p_0 = (p_{\text{max}} - \text{pct} \times (p_{\text{max}}-p_{\text{min}}))/100$
- $\text{pct} = (d_0-d_{\text{min}})/(d_{\text{max}}-d_{\text{min}})$
- $p_{\text{min}} = 76.500\times\text{lgs} + 0.95\times\text{lgs}^{**2}$
- $p_{\text{max}} = 98.7.07\times\text{lgs} + 0.144\times\text{lgs}^{**2}$

The depth dependence of sound speed $c_i$ in km/sec is given by:

$$c_i = c_0 + (c_{w-1.5})\times p_0 + d_{\text{km}} \times 1.4$$

$$= c_0 + (c_{w-1.5})\times p_0 + d_{\text{km}} \times 0.9$$

$$= c_0 + (c_{w-1.5})\times p_0 + d_{\text{km}} \times 0.7$$

$$= c_0 + (c_{w-1.5})\times p_0 + d_{\text{km}} \times 0.115$$

where:
- $c_0 = -22624253E2 + 97909041E2\times d_0 - 16196329E3\times d_0^{**2}$
- $+13964808E3\times d_0^{**3} - 66050550E2\times d_0^{**4} + 16211755E2\times d_0^{**5}$
- $-16027792E1\times d_0^{**6}$

for Shale/Terrigenous/Turbidite Sediment

- $c_0 = -15243114E2 + 56831913E3\times d_0 - 85824340E3\times d_0^{**2}$
- $+67832806E3\times d_0^{**3} - 29583282E3\times d_0^{**4} + 67405383E3\times d_0^{**5}$
- $-62594400E1\times d_0^{**6}$

for Calcite/Dolomite/Limestone/Chalk/Calcereous Sediment
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<td></td>
<td>3.7-3.3</td>
<td>8.2-6.9</td>
<td>Khaki</td>
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<td>Sand</td>
<td>Shale</td>
<td>380-96</td>
<td>2.1-2.0</td>
<td>2.0-1.8</td>
<td>4.2-3.6</td>
<td>Gold</td>
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<tr>
<td>Sand</td>
<td>Chalk</td>
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<td>2.1-1.9</td>
<td>4.4-3.8</td>
<td>Pea</td>
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<td>Basalt</td>
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<td>7.4-6.6</td>
<td>Mud</td>
<td></td>
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<td>Sand</td>
<td>Chert</td>
<td></td>
<td>3.3-2.8</td>
<td>7.0-5.6</td>
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<tr>
<td>Silty Sand</td>
<td>Terrig/Calc</td>
<td>72-40</td>
<td>2.0-1.75</td>
<td>1.9-1.65</td>
<td>3.8-2.9</td>
<td>Brown</td>
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<tr>
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<td>Diatomite</td>
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<td>2.8-2.3</td>
<td>5.6-4.0</td>
<td>Bronze</td>
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<td>Diatomite</td>
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<td>2.3-2.1</td>
<td>4.0-3.4</td>
<td>Green</td>
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</tr>
<tr>
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<td>Turbid/Calc</td>
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<td>1.65-1.5</td>
<td>1.57-1.55</td>
<td>2.6-2.3</td>
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<td>Radiolarite</td>
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<td>3.5-2.8</td>
<td>Marine</td>
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<tr>
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<td>19-10</td>
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<td>1.55-1.53</td>
<td>2.4-2.0</td>
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<td>2.9-2.2</td>
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<td>Turbid/Calc</td>
<td>10-2</td>
<td>1.3-1.2</td>
<td>1.53-1.52</td>
<td>2.0-1.8</td>
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<td>1.7-1.6</td>
<td>2.2-1.9</td>
<td>Violet</td>
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<tr>
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<td>Turbid/Calc</td>
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<td>1.2-1.06</td>
<td>1.52-1.505</td>
<td>1.8-1.6</td>
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</tr>
<tr>
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<td></td>
<td>1.6-1.52</td>
<td>1.9-1.7</td>
<td>MotifBlue</td>
<td></td>
</tr>
</tbody>
</table>

\[
\begin{align*}
  c_0 &= 0.12202029E3 - 0.43917458E3 \cdot do + 0.64898887E3 \cdot do^{**2} \\
  &\quad - 0.49815530E3 \cdot do^{**3} + 0.20966730E3 \cdot do^{**4} - 0.45860080E2 \cdot do^{**5} \\
  &\quad + 0.40838129E1 \cdot do^{**6} \\
  \text{for Quartz/Sandstone/Chert/Diatom/Radiolarite Sediment}
\end{align*}
\]

\[
\begin{align*}
  c_0 &= 0.17753047E2 - 0.80645998E2 \cdot do + 0.15048633E3 \cdot do^{**2} \\
  &\quad - 0.13923871E3 \cdot do^{**3} + 0.68300461E2 \cdot do^{**4} - 0.16884488E2 \cdot do^{**5} \\
  &\quad + 0.1656830E1 \cdot do^{**6} \\
  \text{for Basalt/Siliceous Sediment}
\end{align*}
\]

cw = water sound speed in km/sec at the water/sediment interface

Calcereous sediments include calcite, dolomite, limestone, chalk, and calcereous silts, clays, and muds. Terrigenous sediments include shale, terrigenous silts and turbidite silts and clays. Siliceous sediments include the remainder of petrolelogies in Table 2.

**Boundary Classification using Sonar Backscatter**

Accumulation of large numbers of core samples has made it possible to map geological provinces in the ocean. However, the core samples are still too sparsely positioned to provide precise boundary definitions between ocean bottom provinces. Multibeam Sidescan data (Satriano & Fusillo, 1991) can be used as a means of determining the precise location of surface sediment boundaries in latitude and longitude. Sub-bottom boundaries may then be inferred through the use of statistical correlation models.

The correlation of Multibeam Sidescan acoustic measurement data with archival core sample geological data can be performed in real time during survey operations. A Grey Level Coherence Matrix (GLCM) Algorithm developed at the Hawaii Institute of Geophysics (Reed, 1989) has the capability of using synthetic core sample backscatter as "low resolution background" data and merging "high resolution sidescan" data from multibeam sonars. Six geophysical texture measures are extracted from high resolution sonar backscatter data using GLCM: (1) Texture Angular Second Moment, (2) Texture Contrast, (3) Texture Entropy, (4) Texture Angular Inverse Difference Moment, (5) Texture Correlation, and (6) Texture Isotropy. These measures have been shown to be insensitive to variations in look direction or gain settings and thus are correlated with sediment type and bottom roughness. The goal for future investigations is to use these sonar backscatter measures together with core sample ground truth to distinguish the 40 different sedimentary bottom types in Table 2 with greater than 95% confidence.

**CONCLUSIONS**

Peak backscatter strength, backscatter curve shape, and minimum backscatter strength produce ambiguities when attempting to determine sediment granularity, density, and porosity using sidescan sonars. Sidescan can only infer gross differences between high backscatter (rock) and low backscatter (sand-silt-mud sediment).

Accumulation of large numbers of core samples (over 700,000 worldwide) has made it possible to resolve bottom sediment province boundaries in the ocean to within 10-60 nautical miles. Sidescan backscatter measurements could be used to improve province boundary resolution to .1 nautical miles. In addition, sidescan backscatter provides a means to measure fine changes in sediment composition when core samples are
available to break impedance ambiguities. In effect, sidescan backscatter provides a weighting function for sediment texture interpolation between core sample locations.

REFERENCES


AN OVERVIEW OF OCEAN SENSING INFORMATION MODELS

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ABSTRACT

Recently research in applications of remote sensing from space has been developed using Remote Sensing Information Models (RSIM) and presented at the ISPRS Commission IV Symposium, held in Tsukuba, Japan (Ma, 1990a).

What is the new concept of Remote Sensing Information Models? As well known, remote sensing data which include digital tapes and images are only information of earth objects but not earth objects themselves. Therefore, remote sensing data is a part of the field of the information science. There is a long history since three-dimensional terrain models have appeared. There are physical models which have existed in the laboratory such as a river bed model, a soil erosion model, and a debris flow model, and mathematical models which are information models. However, the RSIM differs from physical models and mathematical models.

The RSIM has analytic geometry similar rules and physical simulated rules. Especially, according to physical simulated rules we could build Ocean Remote Sensing Information Models (ORSIM), such as ORSIM of sea surface temperature, ORSIM of sea surface thermal inertia, ORSIM of sea surface thermal diffusion and ORSIM of sea surface concentration of suspended sediment.

This paper discusses existing and future Ocean Remote Sensing Information Models. Particularly, we discuss the future application of NOAA data in ORSIM, ERS data for three-dimensional ORSIM of sea temperature, ORSIM of wave height with microwave, ORSIM of wind speed with microwave, etc., in China.

GENERAL CONCEPTS

Up to now, modern oceanographical methods differ greatly from classical oceanographical methods. A comparison of these methods are shown in Figure 1.

From Figure 1 we find that Ocean Remote Sensing Information Models (ORSIM) are linked to Image Base (IB) and with Graphics Base (GB), while Ocean-Code Models (OCM) are linked to Attribute Base (AB) and Knowledge Base (KB). This method has been implemented into a P.C. 386 system and developed using C language. It was called the Micro-computer Geographical Expert System (CGES). Since MCGES was used as a tool in oceanography, its name has been changed to Micro-computer Oceanographical Expert System (MCOES).

This paper concentrates on the issue of Ocean Remote Sensing Information Models, an important part of the MCOES. Remote sensing data including digital tapes and images (e.g., NOAA or ERS satellite data) are information of sea surface objects. Processing of these digital tapes or images could be accomplished information science. In general, models are simplified form of natural objects. Since the application of three-
Figure 1. Comparison between classical and modern methods (Ma and Zhou, 1992)
dimensional terrain models, there has been a long history of modeling. There are physical models and mathematic objects, such as river bed models, soil erosion models, estuary models, coastal zone models, harbor models, etc. The mathematic models are computer-based information models, such as math models for erosion and sedimentation of coastal zone or estuary. ORSIM can be established by applying physical principles and mathematical methods in a remote sensing image processing system.

There are rules of analytic geometric similarity and rules of physical simulations in ORSIM. The analytic geometric similarities include image scale, and projected transformation dimensions of imagery. The physically simulated rules include characteristics of electromagnetic wave bands, e.g., 0.38-0.70 μm is a visible band, 0.8-1.1 μm is a "Greenness band", 8-14 μm is a temperature band. These can be used to identify different objects from different bands and to classify and extract objects from mixed-bands. Although physically simulated rules are very complex and difficult, they are very important for building ORSIMs.

SOME ORSIMS

ORSIMs of Sea Surface Temperature (SST)

Sea Surface Temperature (SST) is a well-known model in ORSIM. When using ch.4 and ch.5 of NOAA AVHRR satellite images:

\[ \text{SST} = a \cdot \text{ch.4} + b \cdot \text{ch.5} \]  

(1)

where a and b are coefficients estimated by statistic data measured in the different sea areas. This formula is not really an ORSIM of SST. The actual ORSIM of SST must be inferred from physical principles without too many observation data involved. There is much research to be done in this area.

ORSIM of Sea Surface Heat Diffusion (SSHD) (Ma and Ge, 1991)

Assume a current of hot (or warm) water with diffusion heat flows into cooling sea water. Under specific gravity condition, hot water is lighter than cold water. The hot water will be flattening on the cooling sea surface, with a certain thickness. Therefore, we may be able to approach a slow flow in two dimensions. According to laws of energy conservation, diffusion can be represented as

\[ \frac{\partial^2 T}{\partial t^2} = K_0 + K_x(\frac{\partial^2 T}{\partial x^2}) + K_y(\frac{\partial^2 T}{\partial y^2}) + (\frac{\partial K_x}{\partial x})(\frac{\partial T}{\partial x}) + (\frac{\partial K_y}{\partial y})(\frac{\partial T}{\partial y}) \]  

(2)

where T is temperature, \( \frac{\partial T}{\partial t} \) is the temperature change with time, \( K_0 \) is diffusion constant, \( K_x \) and \( K_y \) are diffusion coefficients, \( \frac{\partial T}{\partial x} \) and \( \frac{\partial T}{\partial y} \) are temperature gradients, \( \frac{\partial K_x}{\partial x} \) and \( \frac{\partial K_y}{\partial y} \) are gradients of diffusion coefficients, \( \frac{\partial^2 T}{\partial x^2} \) and \( \frac{\partial^2 T}{\partial y^2} \) are second gradients of temperature. Using NOAA AVHRR, ch.4 + ch.5, we obtain apparent temperatures at digital AT image. The scanning and pathing directions will be constituted a two-dimensional plane in x and y directions. Thus \( \frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}, \frac{\partial^2 T}{\partial x^2}, \frac{\partial^2 T}{\partial y^2} \) will be counted in the images. Using multi AVHRR ch.4 + ch.5 data, we will obtain apparent temperature changes. Certainly, \( \frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}, \frac{\partial^2 T}{\partial x^2}, \frac{\partial^2 T}{\partial y^2} \) are apparent.
By minimizing the sum of squares of deviations of the equation, optional values of \( K_0, K_x, K_y, \partial K_x / \partial x, \) and \( \partial K_y / \partial y \) can be calculated. The equation of diffusion (2) is an ORSIM of sea surface heat diffusion. It is very useful for modeling the ocean current movement between warm and cold water. We have applied the method for an electric power station.

**ORSIM of Sea Surface Apparent Thermal Inertia (SSATI)** (Ma, 1990b)

The thermal inertia

\[
P = \sqrt{K_0 C}
\]

where \( K = \) thermal conductivity, \( \rho = \) density, and \( C = \) heat capacity, is a physical property impeding on the extent of temperature changes in objects.

According to the heat transfer equation and the boundary condition of periodicity from Fourier series, this method could infer the following formula:

\[
\frac{1-A}{\Delta T} = \frac{1}{2S_0 C_2 A_1} \sqrt{w p^2 + \sqrt{2w BP + B^2}}
\]

where \( A \) is albedo, \( \Delta T \) is a daily range of temperature, \( S_0 \) is solar constant; \( C_t \) is transmissivity of atmosphere, \( A_1 \) is a function of solar declination and local latitude, \( \omega \) is the daily angular frequency, and \( B \) is a constant of weather and ground states in the same digital tape. In short, \( S_0, C_t, A_1, \omega, \) and \( B \) are constants in the same digital image. The thermal inertia \( P \) is a function of the albedo \( A \) and the daily range of temperature \( \Delta T \), that is

\[
P = f \left( \frac{1-A}{\Delta T} \right)
\]

(4)

\[
\text{ATI} = \frac{1-A}{\Delta T}
\]

(5)

where ATI stands for Apparent Thermal Inertia. By using AVHRR, ch.1 + ch.2 can obtain the albedo, AVHRR ch.4 day and night data, and the daily range of temperature. Thus, the temperature difference of day and night can be obtained. This results in a typical ORSIM of SSATI.

**ORSIM of Sea Surface Concentration of Suspended Sediment (SSCSS)** (Ma and Li, 1986)

Radiation by sedimentary particles transmits into the sea surface water with a diffusible scattering. Assuming there is a thin layer about 20 cm in the water, and using the transmissive equation, the formula for volume concentration of suspended sediment, the water absorption formula, and the formula of backscattering of Mie:
\[ R = a + b \cdot \exp(CS) \]  

where \( R \) is the reflectivity of digital density values of NOAA AVHRR ch.1; \( S \) is the concentration of suspended sediment; \( a \) and \( b \) are constants on the same digital imagery; \( C = K \cdot h_0 / d \); \( h_0 \) is the transmitted depth of water; \( d \) is the mean diameter of sediment particles; \( K \) is a proportional coefficient; and \( C \) is an approximate constant in the same band. The values of \( a, s \) and \( C \) must be calculated from statistics data of the concentration of suspended sediment of sea surface (20 cm).

**ORSIM IN THE FUTURE**

Characteristics of imagery spectrum, remote sensing information models and simulations of remote sensing images are important for remote sensing information theories. ORSIMs are based on physical principles, mathematical methods and remote sensing image processing systems. Based on ORSIPS (Ocean Remote Sensing Image Processing System), OIS, OES and CAC, the ORSIM could be developed efficiently.

Using NOAA AVHRR data, we might be able to construct ORSIM of the sea surface temperature and three-dimensional sea temperature with data collected by buoys and satellites. The two-dimensional SST is a limited case of three-dimensional sea temperature. Besides ORSIM of two-dimensional sea surface red tide, petroleum pollution, etc., can also be established.

By using ERS microwave band data, ORSIM of sea surface wave height and wind speed can be developed. Wave heights and wind speed models can be derived by simulations in a computer-aided system. Furthermore, we can simulate the SAR images to the computer with ERS microwave images. This provides an efficient method in ocean remote sensing information science.

In the future, research and development of the ORSIM models for oceanic hydrology and dynamic current could be improved.

**REFERENCES**


Ma, A.N., and H. Ge. 1991. The remote sensing information model of thermal diffusion. IGARSS, ESPOO. Finland.
