Arc Marine

GIS for a Blue Planet

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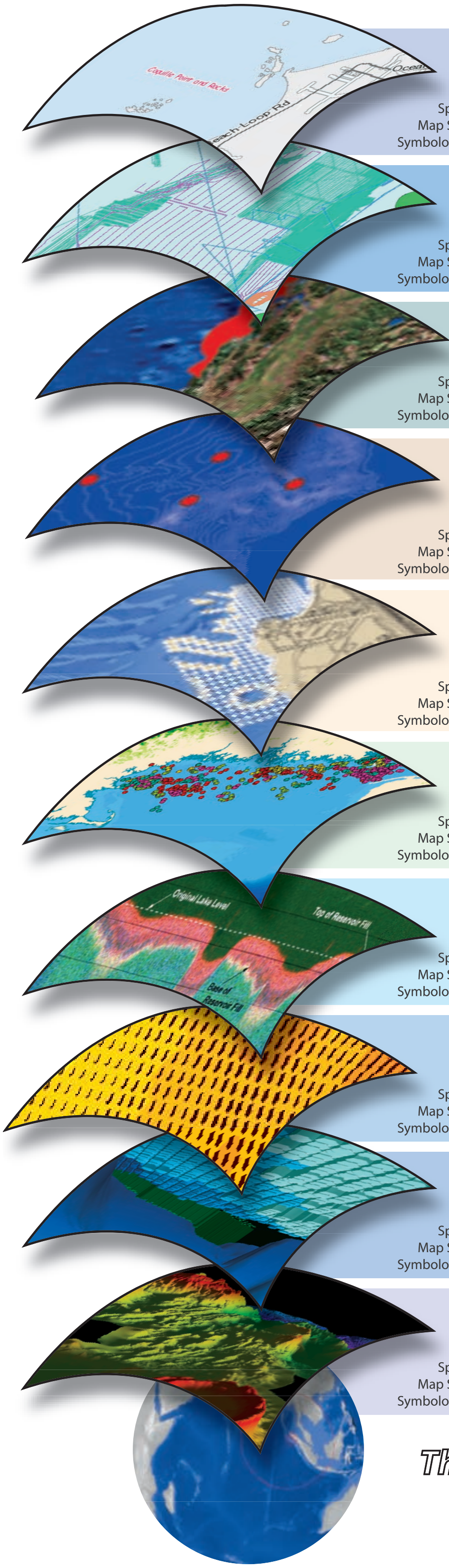
chapter two

Common Marine Data Types

The Common Marine Data Types concept is a general framework for envisioning the core feature classes required to represent coastal and marine data. Because coastal and marine applications must often represent spatially and temporally dynamic processes in a three-dimensional volume, the data types attempt to extend standard geospatial features to include more explicit relationships between spatial, temporal, and depth (volume) referencing. This framework is intentionally designed to be generic and inclusive. With a few exceptions, the Common Marine Data Types define the broadest possible categories of marine features, not specific features for specific marine applications. Adding broad extensions to standard point, line, area, and surface feature classes allows for more precise representation of time and place. The two main purposes of the Common Marine Data Types concept and diagram are to help define and better understand the core features of the Arc Marine data model and to communicate these core design issues to the marine GIS user community.

Arc Marine Data Model



Layer	**Shorelines**
Map Use	Interface between land and water, shoreline change analyses for erosion/accretion, hazards, planning
Data Source	Derived from coastal survey maps, nautical charts, aerial photos, LIDAR
Representation	Linear features
Spatial Relationships	Can be animated/modeled based on map units to represent tidal variance
Map Scale and Accuracy	Typical map scales range from 1:5,000 to 1:20,000; locational accuracy typically 10 m
Symbology and Annotation	Line symbology drawn with varying weights annotated with VDatum; national cartographic standards often used

Layer	**Tracks and Cruises**
Map Use	Shiptracks during a cruise, tracks of vehicles towed from a ship or deployed from a ship untethered, autonomous
Data Source	Shipboard or vehicle GPS logs storing time, date, and position
Representation	Linear features
Spatial Relationships	Tracks have a direction with time stamps along route, particularly keep sampling stations
Map Scale and Accuracy	Typical map scales range from 1:24,000 to 1:50,000; locational accuracy ~10 m
Symbology and Annotation	Line symbology drawn with varying weights and patterns, annotated with date/time and ship/vehicle

Layer	**Time Duration Features**
Map Use	Fisheries or algal bloom trawls, marine protected area boundaries, habitats, drifter tracks, oil spills
Data Source	Derived from survey maps/charts, legal definitions, clipping/masking; various measuring devices
Representation	Linear and polygonal features
Spatial Relationships	Size, shape, area and direction change over time; may be animated
Map Scale and Accuracy	Typical map scale is 1:24,000; locational accuracy ~10 m
Symbology and Annotation	Line and polygon symbology with varying weights, patterns and fills

Layer	**TimeSeries Locations**
Map Use	Variations in time of variables measured at fixed observations stations at sea and onshore
Data Source	Fixed or moored measuring devices such as hydrophones, acoustic doppler current profilers (ADCP), ocean bottom seismometers (OBS), tide gauges
Representation	Point features
Spatial Relationships	Points can be related to center of a grid cell or associated to a time series or numerical model
Map Scale and Accuracy	Typical map scales range from 1:10,000 to 1:24,000; locational accuracy ~10 m
Symbology and Annotation	Point marker symbology with associated instrument attributes

Layer	**Instantaneous Measured Points**
Map Use	Variations in space of variables measured at a given moment in time through the water column
Data Source	Instrument casts such as conductivity-temp-depth (CTD), expandable bathythermograph (XBT), sound velocity profile (SVP), fish density, etc.
Representation	Point features, vertical profiles
Spatial Relationships	Points can have varying depths associated to a single location, as well as multiple measurements
Map Scale and Accuracy	Typical map scales range from 1:10,000 to 1:24,000; locational accuracy ~10-50 m
Symbology and Annotation	Point marker and linear symbology annotated with associated instrument attributes

Layer	**Location Series Observations**
Map Use	Tracking a series of recorded instances of a given species with varying time intervals
Data Source	Telemetry recorders and transmitters, animal/bird sightings, ship-mounted ADCP
Representation	Multipoint features, often with line symbols to establish animal track
Spatial Relationships	Multipoints can have varying depths associated to multiple locations, grouped into a series based upon ID
Map Scale and Accuracy	Typical map scales range from 1:10,000 to 1:24,000; locational accuracy ~10-50 m
Symbology and Annotation	Point and line symbology annotated with species type

Layer	**Survey Transects**
Map Use	Geomorphic, sediment transport, or hydrodynamic analyses along profiles or cross sections, subsurface profiling
Data Source	Derived from bathymetry, scientific mesh, one-dimensional hydrological models; measured by sub bottom profilers
Representation	Interpolated, linear profile view of a surface or subsurface
Spatial Relationships	Cross sections perpendicular to shoreline or flowline; profiles at varying azimuths to align with surface control point or baseline
Map Scale and Accuracy	Typical map scale is 1:24,000; locational accuracy ~10 m
Symbology and Annotation	Line symbology for surface; often for subsurface tone, contrast and balance of grayscale according to data values

Layer	**Scientific Mesh**
Map Use	Mapping output of finite element models, hydrodynamic and hydrologic models, sea surface temperatures
Data Source	Numerical models and satellite datasets
Representation	Regularly or irregularly spaced point features, scalars or vectors; raster, TIN model
Spatial Relationships	Attribute values can be used to create interpolated surfaces of magnitude with point values representing direction
Map Scale and Accuracy	Map scale varies and locational accuracy can range from 1 m to 1 km depending on data
Symbology and Annotation	Rendered with graduated point symbols to reflect magnitude, rotated to represent direction; may be animate

Layer	**Mesh Volumes**
Map Use	Pelagic or open water environment
Data Source	Derived features from scientific meshes, point data from stationary, fixed, suspended, or floating devices
Representation	Extended cube or hexagonal pillars stacked to represent volumetric areas
Spatial Relationships	Volumes can be related to mesh points between varying depths, or from bathymetry to sea surface
Map Scale and Accuracy	Map scale varies and locational accuracy depends on data type and resulting volume calculation
Symbology and Annotation	May be polygonal with varying 3D base heights; applied transparency

Layer	**Bathymetry and Backscatter**
Map Use	Terrain analysis, benthic habitat classification, morpho-tectonic interpretation, cartographic background
Data Source	Interpolation of irregularly or regularly spaced single or multibeam soundings, lidar
Representation	Raster with depth or backscatter intensity, TIN surface model
Spatial Relationships	Coincident with point from which it was derived, or interpolated; if raster, each cell has a depth; if TIN, each face joins to form surface
Map Scale and Accuracy	Typical map scales and locational accuracies for shallow regions are 1:2,400/1 m, or 1:20,000-1:50,000/100 m for deep ocean
Symbology and Annotation	Usually shown with graduated colors; may be overlain with contours

The Thematic Layers

Introduction

The representation of the geography, behavior, and relationships of coastal and marine features is an especially challenging task for traditional geographic information systems. The dynamic nature of ocean and coastal systems and the three-dimensional nature of water volumes require a fundamental rethinking of the often static and planar representation of spatial features used in terrestrial applications. Coastal and marine features require a broad extension of our general view of geographic data types to accommodate more complex marine applications. We must extend the standard point, line, and polygon (area) representation of geographic features to meet the volumetric and temporally dynamic nature of marine environments.

The need to extend the fundamental structure of common geographic data types influenced the core design of the Arc Marine data model from the onset. A generic data model was needed to meet the core challenges of designing a more temporally dynamic and volumetric representation of marine features. The core idea was to develop "common data types" as core building blocks for the development of specific features classes for coastal and marine applications. These common data types needed to be broad and comprehensive to represent the wide range of features that marine analysts and managers would encounter when developing projects.

Developing these core data types was part of the initial phase in what is usually a three-stage process in data model design, increasing in abstraction as one goes from human-orientation to implementation in a computer (Laurini and Thompson 1992; Zeiler 1999; and Arctur and Zeiler 2004). The conceptual phase involves the challenges of defining the overall scope and content of the model and identifying the common, essential features modeled in most GIS projects within an application domain. Next is the creation of an analysis diagram with the identification of major thematic groups and an initial set of object classes within these groups. The Common Marine Data Types diagram was developed as an extension of the analysis diagram in that the groups included a number of classes to indicate specific data layers. The diagram focuses on the initial acquisition of ocean and coastal data. Thus, it is concerned with the accurate sensing and collection of measurements from the marine environment and the transformation of these measurements from raw to processed for GIS implementation. Therefore, the Common Marine Data Types diagram provides a high-level overview of the themes and products available for a specific marine GIS project.

Next, an initial model is built in Unified Modeling Language (UML) and a schema is generated in the ArcCatalog application. The UML diagrams and schema are at the "logical" stage in the data modeling process. The UML is exported to an Extensible Markup Language Interchange (XMI) template or *.mdb repository. Fortunately, the marine community will not have to deal directly with UML (unless it wants to!). Instead, with UML in hand, users may take advantage of an existing collection of CASE (computer aided software engineering) tools in ArcGIS in order to generate their own schema (the final, "physical" stage). For example, in ArcCatalog, the Schema Wizard can be used to translate the XMI template or *.mdb repository into an empty geodatabase. This in turn allows users to populate that geodatabase with their own data for use in a specific GIS project, with the necessary feature classes, attributes, and relationships from the data model intact.

The Arc Marine development team took another approach after quickly finding that no one marine data model could define the seemingly unlimited number of possible features that researchers and managers use in coastal and marine applications. The team shifted its focus to developing an inclusive and explicitly generic definition of the core data types that generally described the spatial and temporal features of coastal and marine data. This exercise allowed us to step back and envision the broadest categories of marine data. Where marine datasets were not sufficiently represented by standard geographic features (points, lines, or areas) we developed new terms to describe new classes such as "location series points" or "time duration areas." We intended this approach to articulate new representations of common marine features that could be shown through combinations of spatial features and time series tables in the data model architecture.

While the Common Marine Data Types concept allows for the development of core functional features, this representation is too generic to convey the detailed definitions and nomenclature for specific marine applications. We could not hope to develop a unified model that would use the specific terms and definitions of the ocean exploration, fisheries management, marine conservation, shipping, navigation, and other marine user communities simultaneously. Instead, we wanted users to generically apply common data types presented in Arc Marine as the core model shared across these more specific user communities. These marine user communities can then modify the generic features into specific classes to fit the naming conventions and specific applications of a variety of marine applications, analyses, and industries. For example, a fisheries management user community may develop a modified fisheries submodel that contains specific feature names that fit its needs more specifically (figure 2.1). The fundamental issue is that if a wide range of marine geospatial practitioners adopt the common Arc Marine core model, then they can develop analytical tools and applications to function across these core features classes that also benefit the larger marine user community.

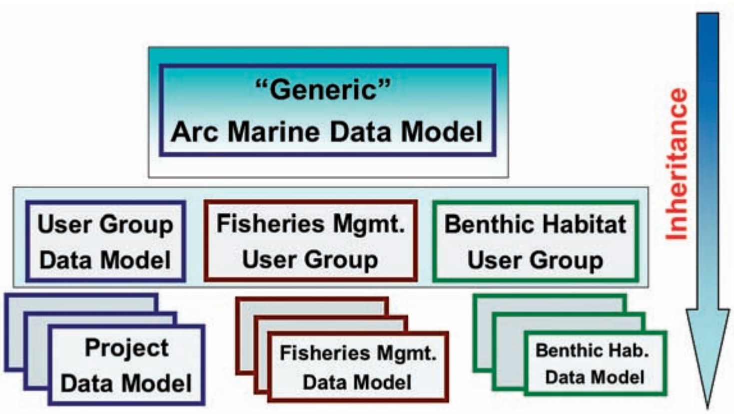


Figure 2.1 Arc Marine data model implementation hierarchy from generic features to various user groups to specific projects within a user group.

The Common Marine Data Types

The team built Common Marine Data Types through a fairly straightforward process (Breman et al. 2002). We considered examples of a wide variety of marine observations and geographic features for their fit using standard geographic features classes: points, lines, areas, rasters, and so on. A new, generic data type was defined to meet the need if these categories did not accurately represent the marine features. Generic feature classes were generated intentionally to promote the idea that these are broad categories, not specific types of marine data. In the Common Marine Data Types diagram (figure 2.2), note the Feature Point, Feature Line, and Feature Area. These features are continuations of standard GIS feature classes. The new names, such as Instantaneous Points or Location Series Points, are feature types defined specifically to meet marine user needs.

The development of new marine data types is analogous to the development of early extensions of core geographic data types to serve specialized applications in GIS. For example, we combined line features into series to form routes in a network model. We also combined multiple polygon features using a table into regions representing spatially disaggregated areas. This concept of using time series or location series tables to create new representations of geographic data is central to the development of new features in the Arc Marine data model. The development of the Common Marine Data Types can be illustrated by considering two different types of points features commonly used in coastal and marine applications: Feature Points and Measurement Points.

Marine Points

A Feature Point could be a fixed object, such as a permanent monument, a structure, or fixed buoy that does not require any specific measurement or time attribute. The standard point feature common to standard GIS applications would sufficiently represent this feature as a fixed x,y location in space and would allow for attributes to be attached or related to this feature. The feature would be considered as not having any required temporal attributes, but in a marine environment a required z-elevation value would be necessary to relate the feature to a vertical datum.

Instantaneous Points and Time Series Points

Instantaneous Points and Time Series Points extend the concept of Marine Points by allowing users to select appropriate representations of their data based on the definition of the time and location attributes. Each of these subtypes is distinguished by differences in the way they represent the time and location of the marine measurement.

Subtype: Instantaneous Points

Often the time of an observation is critical to the representation of the data and further analysis for marine GIS applications. A conductivity-temperature-depth (CTD) cast from a vessel measures salinity, temperature, and depth for a particular moment in time at a particular location and depth. Similarly, an observer spotting a right whale notes the location as well as the time of observation. Our ability to analyze and relate marine observation data to other marine features is inherently tied to our ability to locate the observation in time and

Arc Marine Common

Marine Points

Feature Points

ID
X,Y
Z

Examples:
marker buoy, transponder, other fixed, geography

Instantaneous Points

Instant
Subtype

ID
X,Y
Z or ΔZ
$m_1 \ldots m_2$
t

Examples:
CTD, XBT, SVP casts at ΔZ, fish density, tide gauge, etc., at surface or a single Z

Location Series
Subtype

ID
ΔX,Y
ΔZ
$m_1 \ldots m_2$
$t_1 \ldots t_2$

Examples:
telemetry, bird/mammal sighting, ship mounted ADCP

Time Series Point

Time Series

ID
X,Y
Z or ΔZ
$m_1 \ldots m_2$
$t_1 \ldots t_{infinity}$

Examples:
current meter, moored ADCP at ΔZ, obs. buoy, hydrophone, OBS at single Z

Survey
Subtype

Examples:
aerial coastal survey, lidar, SCUBA/free swim obs.

Sounding
Subtype

Examples:
single beam bathy

Marine Areas

Feature Area

ID
$X_1,Y_1,X_2,Y_2 \ldots X_1,Y_1$
Z
m

Examples:
Marine boundaries (e.g., sanctuary, MPA), habitats, patches, lava flows, clipping, masking

Time Duration Area

ID
$X_1,Y_1,X_2,Y_2 \ldots X_1,Y_1$
Z
m
$t_1 \ldots t_n$

Examples:
No-take zones, oil spills, harmful algal bloom

ACRONYMS—definitions

ADCP—acoustic doppler current profiler
ARGO—array for real-time geostrophic oceanography
BIL—band interleaved by line (for remotely sensed images or grids)
CTD—conductivity, temperature, depth
EEZ—exclusive economic zone
GeoTIFF—georeferenced tagged image file format
LIDAR—light detection and ranging
MPA—marine protected area
OBS—ocean bottom seismometer
ROV—remotely-operated vehicle
SCUBA—self-contained underwater breathing apparatus
SST—sea surface temperature
SVP—sound velocity profile
TIN—triangulated irregular network
U/W—underwater (also often refers to "underway")
VDatum—vertical datum
XBT—expendable bathythermograph

Marine Data Types

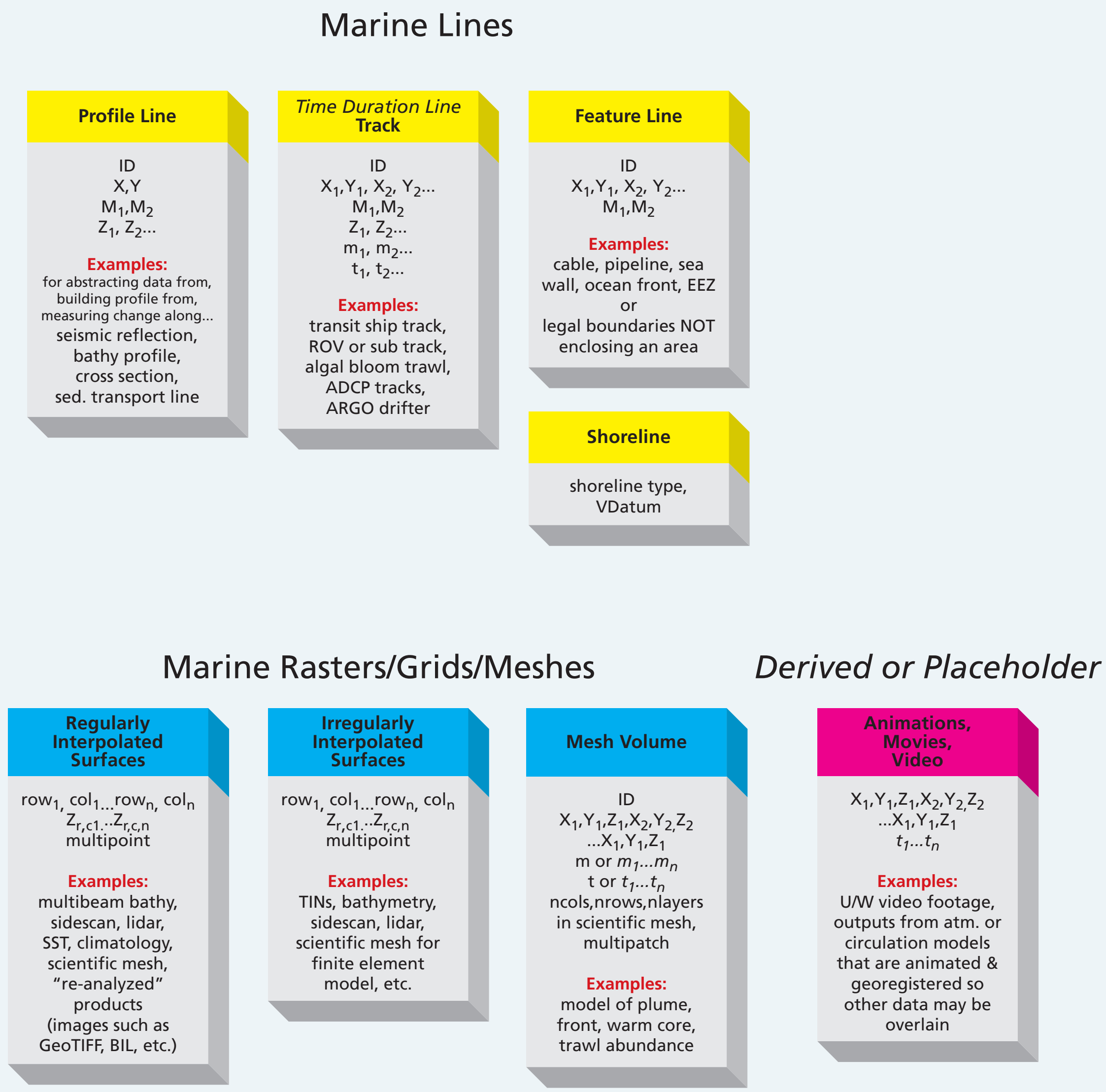


Figure 2.2 The Arc Marine Common Marine Data Types diagram on these two pages was developed as part of the conceptual framework for the data model. Note the "examples" (red headings), which list specific instruments, vehicles, real-world features, or products. Headings in italic eventually became abstract feature classes in the Arc Marine UML, while other headings became feature classes or subtypes. Lowercase "m" denotes a measurement in the field, uppercase "M" is a GIS geometry measure, and "t" is time.

space. So the development of a feature class subtype specifically designed to represent data tied to an instant in time is essential for a wide number of marine applications.

The Instantaneous Point subtype provides a common feature class that requires a location (x,y,z) as well as a time (t) description in addition to any measurement (m_1...m_n) attributes collected at that location in space and time. Each observation in this generic data type is independent.

Subtype: Location Series

Another data type common to marine applications pertains to objects moving in the ocean environment. A vessel moving along a track, an autonomous vehicle conducting a dive, and the telemetry track of a satellite-tagged animal all represent multiple locations in space and time for a single entity. The Location Series subtype represents a series of point locations for an identified feature. The unique series identification number identifies the locations as belonging to an individual, and the related time tables establish the temporal sequence of the series. Numerous location series applications can be envisioned for marine applications. Any moving object where the time and location is recorded as a point fits into this general category. As with all of the common data types, the generic Location Series subtype could be modified and augmented to fit the specialized needs of particular marine GIS applications.

Subtype: Time Series

While Location Series provides the generic representation for moving points, the Time Series subtype provides a representation for features that stay in a fixed location but record attribute data over time. Again, numerous marine features readily fit this description. A weather buoy recording wave heights and wind speeds at a fixed location, a sea turtle nesting beach where observers record the number of hatchlings each season, and a gauging station in an estuary that records changes in salinity are all fixed geographic locations with attributes measured at different time intervals. So Time Series points can provide a common data type for a wide variety of common monitoring applications in coastal and marine environments.

Specialized point subtypes: Soundings and Survey Points

Two common types of marine point features were given specialized subtypes in the organization of the Common Marine Data Types schema. Soundings, the measurement or estimate of a depth value (z) at a location with no other attributes, is a very common point feature in marine applications and was assigned a separate subtype to represent this simple feature. A related data type, Survey Points, also measures a single defined measurement (e.g., lidar elevations) at a discrete geographic location with no other required attributes.

Line features

Lines features (indicated as data category "Feature Line" in figure 2.2) are another common feature for representing geographic data and have been extended into specialized subtypes in the Arc Marine data model. The three common line features are Profile Line, Time Duration Line, and Feature Line.

Profile Line

The Profile Line subtype provides a common data type for the representation of attributes along a linear feature. Some common examples in marine GIS applications would be a bathymetric profile constructed from a bathymetric grid (with change measures along that profile), cross sections, seismic reflections, or transport lines. Chapter 6 describes many more examples.

Time Duration Line

Just as point observations in marine applications often need to be explicitly related to the time, lines also often need to be represented with starting and stopping time as well as starting and stopping location. We developed the Time Duration Lines data type to provide marine GIS users with a common feature that requires a starting time, an ending time, and duration as core attributes. Types of common marine applications could be recording the sampling effort of a research vessel along legs of a survey, the duration of a trawl, and a segment of an autonomous vehicle track. With the required time attributes, each of these types of Time Duration Line features could be associated with other marine features based on the time of the observation along the line. This allows for a more direct method of associating dynamic environmental features (e.g., sea surface temperature—SST—or Beaufort Sea State) with the location and the appropriate period of time for the line.

Feature Line

Many marine features are most appropriately represented by standard line features. An undersea cable, a jurisdictional boundary, or a shipping lane could all be readily represented with a standard Feature Line. Feature Lines require a unique identifier, a vector of x,y coordinate pairs, as well as free-form measurement attributes unique to the particular application.

Specialized line feature: Shoreline

One category of Feature Line is so common and essential for coastal and marine applications that we provided a specialized subtype. Shoreline is a subtype of Feature Lines in that it demarcates essential boundaries of oceans and estuaries, but Shoreline definitions must also be explicitly stated (e.g., Mean Low Water versus Mean High Water) and must relate to a vertical datum to be properly represented. The specialized Shoreline subtype requires a shoreline type and a VDatum attribute to assure consistency in the representation and interpretation of shoreline features.

Marine Areas

Area features in the marine environment are divided into two common types: Feature Areas represented as static, time-independent areas, and Time Duration Areas that require changing time attributes for their representation.

Feature Area

Any marine area that can be represented by a static polygon can be appropriately represented as a Feature Area. Three straightforward examples of Feature Areas are the permanent jurisdictional area of a marine sanctuary, benthic habitat features, or the area contained within the exclusive economic zone (EEZ) of a nation. Feature Areas require a unique identifier, a vector of x,y coordinates forming the boundary, a depth (z) attribute, as well as user-defined measurement (m) attributes.

Time Duration Area

Many features of the marine environment or management responses may be ephemeral. Shellfish habitat may be demarcated as exceeding pollution thresholds for a portion of the year; seasonal area management (SAMs) and dynamic area management (DAMs) fisheries closures may be invoked for particular seasons or after specific events; and oil and gas leases may persist for specific periods of time. These three examples represent a geographic area feature tied to a specific starting and stopping time. The team developed the Time Duration Area data type to allow for this appropriate representation of marine features that persist for specified periods of time. This type of time-dependent area feature allows for users to make queries concerning overlaps in space and time. The Time Duration Area feature requires a beginning and ending time attribute in addition to the standard variables required for general area features.

Marine Rasters, Grids, Meshes

A large proportion of geospatial information used in marine applications originates as regularly interpolated surfaces. Bathymetry surfaces, oceanographic remote sensing (SST; sea surface height, SSH; or chlorophyll *a*, Chla), hydrodynamic measurements, and circulation models represent a significant proportion and volume of the data used in coastal and marine GIS and analysis. Arc Marine provides three generalized data types to represent these surface features: Regularly Interpolated Surfaces, Irregularly Interpolated Surfaces, and Mesh Volumes.

Regularly Interpolated Surfaces

Regularly Interpolated Surfaces, such as raster or image data, are a commonly used data format for many marine applications. ArcGIS GRID data, GeoTiff, Band Sequential (BSQ), and Band Interleaved (BIL) data formats represent many standard formats of currently supported raster data. In addition, a number of oceanographic and climatologic data products are distributed in hierarchically organized data formats such as network Common Data Form (netCDF) or hierarchical data format (HDF). ArcGIS (version 9.2 and beyond) will support direct read of the netCDF data format. This is further discussed in chapter 8.

Irregularly Interpolated Surfaces

Triangular irregular network (TIN) models and many finite element models form representative surfaces by identifying a minimum set of triangle facets using critical nodes and edges. The Delaney triangulation algorithm is used to validate the optimal selection of triangular surfaces. TIN models are used extensively as an efficient format for representing terrain surfaces (e.g., lidar beach surveys) or variable density nodes near shore hydrodynamic models. Again, further discussion may be found in chapter 8.

Model Meshes

A new feature type was defined to fill a special need for many marine modeling and analysis applications (particularly finite element modeling). Model Meshes allows for the representation of data as a multilayer stack of column and row mesh data. The structure of this feature allows for a flexible definition of regularly spaced mesh features, with discrete mesh node locations defined in x,y, and z dimensions. This is further discussed in chapter 7.

Animations, Movies and Video

The final category of common data types addresses the growing need to georegister and link animations, movies, video, and other nontraditional information to spatial features for marine applications. Video footage of benthic habitats collected by an autonomous underwater vehicle (AUV), aerial surveys of seabird colonies, or fixed video cameras collecting data on port traffic will require the ability to link dynamic video data to geographic locations and specific time periods. This linkage will be derived through required x,y,z spatial locations coupled with a required time attribute (t).

Conclusion

The Common Marine Data Types concept defines broad categories of coastal and marine data representations using intentionally generic feature classes and subtypes. The goal of this design was to create a general framework that was then implemented using combinations of required attributes and relationships in Arc Marine feature classes. The Common Marine Data Types and subsequent features defined in the Arc Marine data model are intended to be general building blocks that users can modify and rename to more specific features for specific coastal and marine applications. The most important role of the Common Marine Data Types is to communicate the general framework required to represent spatially and temporally dynamic features to users in the marine GIS community. This has been and will continue to be an evolving and adaptive framework for envisioning necessary features for the marine user community and for modifying and refining each revision of Arc Marine.

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