Designation: F2595 – 07

Standard Guide for Unmanned Undersea Vehicle (UUV) Sensor Data Formats[1]

This standard is issued under the fixed designation F2595; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

ASTM has prepared this series of standards to guide the development of autonomous unmanned underwater vehicles (UUVs). The standards address the key capabilities that a UUV system must possess in order to be considered autonomous and reconfigurable:

Autonomous— Capable of operating without operator input for extended periods of time. Implicit in this description is the requirement that the UUV's sortie accomplishes its assigned goal and makes the appropriate rendezvous for a successful recovery.

Reconfigurable— Capable of operating with multiple payloads. The top level requirement is established that the UUV systems will consist of:

Payloads to complete specific system tasking such as environmental data collection, area surveillance, mine hunting, mine countermeasures, intelligence/surveillance/reconnaissance (ISR), or other scientific, military, or commercial objectives.

Vehicles that will transport the payloads to designated locations and be responsible for the launch and recovery of the vehicle/payload combination.

While the payload will be specific to the objective, the vehicle is less likely to be so. Nevertheless, commonality across all classes of UUV with respect to such features as planning, communications, and post sortie analysis (PSA) is desirable. Commonality with regard to such features as launch and recovery and a common control interface with the payload should be preserved within the UUV class.

In accordance with this philosophy, ASTM identifies four standards to address UUV development and to promote compatibility and interoperability among UUVs:

F2541–Standard Guide for UUV Autonomy and Control,

WK11283–Standard Guide for UUV Physical Payload Interface,

F2594–Standard Guide for UUV Communications, and

F2594–Standard Guide for UUV Sensor Data Formats.

The relationships among these standards are illustrated in Fig. 1. The first two standards address the UUV autonomy, command and control, and the physical interface between the UUV and its payload. The last two ASTM standards address the handling of the most valuable artifacts created by UUV systems, the data. Since there are many possibilities for communications links to exchange data, it is expected that the UUV procurement agency will provide specific guidance relative to these links and the appropriate use of the UUV communications standard. In a similar manner, specific guidance is expected for the appropriate use of the UUV data formats.

F2541–Standard Guide for UUV Autonomy and Control—The UUV autonomy and control guide defines the characteristics of an autonomous UUV system. While much of this guide applies to the vehicle and how the vehicle should perform in an autonomous state, the relationship of the payloads within the UUV system is also characterized. A high level depiction of the functional subsystems associated with a generic autonomous UUV system is presented. The important functional relationship established in this guide is the payload's subordinate role relative to the vehicle in terms of system safety. The payload is responsible for its own internal safety, but the vehicle is responsible for the safety of the vehicle-payload system. Terminology is defined to provide a common framework for the discussion of autonomous systems. System behaviors and capabilities are identified that tend to make a system independent of human operator input and provide varying levels of assurance that the UUV will perform its assigned task and successfully complete recovery. A three-axis sliding scale is presented to illustrate the system's level of autonomy (LOA) in terms of situational awareness,

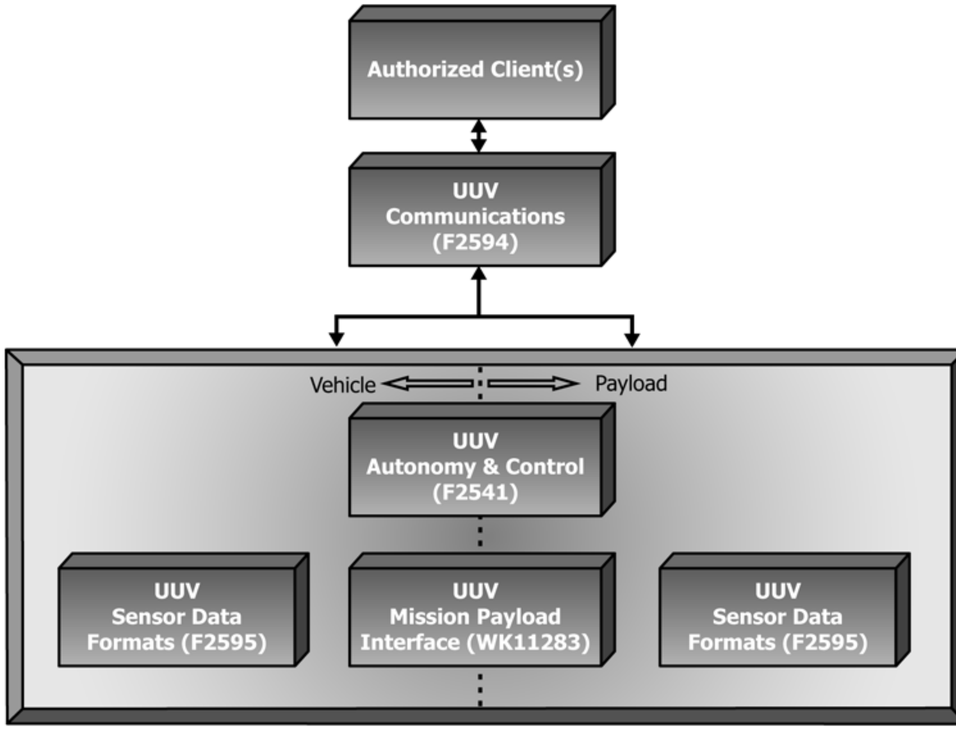

FIG. 1 Notional System Interfaces and Governing Standards

decision-making/planning/execution, and external interaction. The control interface (messages exchanged between the vehicle and the payload) is described and instantiations of this interface for the various classes of UUV are presented in associated appendices.

WK11283–Standard Guide for UUV Physical Payload Interface—The UUV physical payload interface guide is a physical and functional interface standard that guides the mechanical and electrical interface between the vehicle and the payload, and the functional relationship between the vehicle and the payload. In-as-much-as a single physical interface standard cannot address all classes of UUVs, this guide describes the physical interfaces in the body of the guide and provides appendices to guide the instantiation for each of the classes. This guide reinforces the relationship between the vehicle and the payload and confirms the permission-request responsibility of the payload and the permission-granted/denied authority of the vehicle.

F2594–Standard Guide for UUV Communications—The UUV communications standard guides the development of offboard communications between the UUV system and the authorized clients, that is, those agents designated by the UUV operational authorities with responsibility for programming, operating, or maintaining, or a combination thereof, a UUV. An authorized client may also represent an end user of UUV and payload mission data. Such a standard is required to provide for UUV interoperability with multiple authorized agents and to provide the authorized agents with interoperability with multiple UUVs (preferably across the different classes of UUVs). Optical, RF, and acoustic methods of communication are considered. While RF communication is a matured communications mode and existing standards are referenced and adopted for offboard surface communication, underwater acoustic communication (ACOMMS) is an evolving field and interoperability between the different ACOMMS systems is also evolving. Typical ACOMMS systems and protocols are described with typical applications related to bandwidth and range. General comments are provided for optical communication as the use of this mode of communication may evolve in the future.

F2595–Standard Guide for UUV Sensor Data Formats—The UUV sensor data formats guide provides the UUV and payload designer with a series of commonly accepted data formats for

[1] This guide is under the jurisdiction of ASTM Committee F41 on Unmanned Maritime Vehicle Systems (UMVS) and is the direct responsibility of Subcommittee F41.04 on Data Formats.

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underwater sensors. These formats provide the opportunity for two-way interoperability. Their use facilitates the UUV system's ability to process historical environmental data for mission planning purposes. Likewise, use of these formats facilitates the end users' ability to catalog, analyze, and produce recommendations based on current field data. Fig. 1 suggests that both vehicle-specific data as well as payload sensor data should be stored in these data formats.

1. Scope

1.1 This guide establishes the basic sensor data format requirements for Unmanned Undersea Vehicles (UUVs). This guide is intended to influence the development process for the acquisition and integration of various sensor packages, but at the same time, not specify particular solutions or products. An additional intent of this guide is to address the data format standards specifically required for operation of the U.S. Navy's planned 21-in. Mission Reconfigurable UUV System (MRUUVS), which is representative of its heavy weight class of UUVs. Although this initial release of UUV sensor data formats standards primarily focuses on the U.S. Navy's UUV missions comprising intelligence, surveillance and reconnaissance (ISR), mine countermeasures (MCM), and oceanographic data collection, there is broad utility across the spectrum of commercial applications as well.

1.2 Readers of this guide will find utility in referencing Guides F2541, F2594, and WK11283. There is a clear relationship that exists in terms of data formats, external interfaces, and information/data exchange that can be applied in context with the standards invoked in these documents.

1.3 Technical sections of this guide are broken down as follows:

1.3.1 Section 5, the main body of this guide, provides general guidelines for sensor data, including water column and ocean bottom undersea search and survey (USS) measurements, and above-waterline data. It describes required data records, but does not attempt to specify data recording formats, except as already established in existing documentation. Whenever possible, data recording formats are suggested to conform to existing convention, facilitating data processing and use. This guide references standard U.S. Department of Defense (DoD) formats or *de facto* commercial formats where appropriate, such as widely accepted World Meteorological Organization (WMO) or Intergovernmental Oceanographic Commission (IOC) standards.

1.3.2 Section 6 covers related mission data formats such as timing. It also serves as a placeholder for future discussion of vehicle-specific mission data formats. Navigation, vehicle status, and related vehicle information data formats are expected to be addressed in subsequent versions of this guide. Also included in this section are brief discussions on external interface and command and control formats.

1.3.3 Section 7 introduces the topic of metadata formats. Amplification of this subject is warranted and will be incorporated into future versions of the guide.

1.3.4 Section 8 briefly identifies general data storage issues. Onboard data storage decisions will be driven by power requirements, data volume, and media cost.

1.3.5 Section 9 presents an abbreviated summary of the currently recommended data format standards where they could be identified.

1.3.6 Section 10 exists primarily as a placeholder to address relevant technology forecasts that could impact future data formats.

1.4 Though the general guidelines of this guide apply to most oceanographic sensor data, the data types specifically considered here are limited to: water column measurements (including temperature, salinity, currents, optical clarity, and bioluminescence), ocean bottom measurements (including bathymetry, acoustic images, and sub-bottom), ambient noise, and related geophysical parameters. ISR sensor data and other data collected on or above the surface are addressed by reference to governing U.S. military data standards. Discussion of electromagnetic and electro-optical (EM/EO) data formats (including atmospheric refractivity) is also included.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F2541 Guide for Unmanned Undersea Vehicles (UUV) Autonomy and Control (Withdrawn 2015)[3]

F2594 Guide for Unmanned Undersea Vehicle (UUV) Communications

WK11283

2.2 *DoD Documents:*[4]

DoD Bathymetric Library (DoDBL)

DoD Directive 8320.2 Data Sharing in a Net-Centric Department of Defense

2.3 *IEEE Standards:*[5]

ISO/IEC 12207 Standard for Information Technology Software Life Cycle Support

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from the U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., N.W., Mail Stop: SDE, Washington, DC 20401.

[5] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331.

IEEE/EIA 12207 Industry Implementation of International Standard

2.4 *ISO Standard:*[6]

ISO/TC 211 Geographic Information/Geomatics

2.5 *Military Standards:*[7]

MIL-STD-2500B(2) National Imagery Transmission Format (Version 2.1) for the National Imagery Transmission Format

MIL-D-89029 Military Specification for Bathymetric Databases[8]

MIL-PRF-89049 Vector Product Format (VPF)[9]

MIL-PRF-89049/10 Tactical Ocean Data—Level 0

MIL-PRF-89049/11 Tactical Ocean Data—Level 1

MIL-PRF-89049/12 Tactical Ocean Data—Level 2

MIL-PRF-89049/14 Tactical Ocean Data—Level 4

2.6 *Other Documents:*

Ambient Noise Data Base (ANDB) Preliminary Database Definition Document NRL SSC 21 January 2005[10]

AOCO COMINT Joint Interface Control Document Standards[11]

AOCO ELINT Joint Interface Control Document Standards[11]

Charter File Format Naval Oceanographic Office[12]

Digital Bathymetric Database, Variable Resolution (DBDB-V) Version 5, Naval Oceanographic Office[12]

Generic Sensor Format (GSF) Specification, Version 2.02, Naval Oceanographic Office, 20 June 2003[10]

Geoacoustic Database Variable Resolution (GDBV) Database Definition Document, NRL Stennis Space Center, 19 December 2003[10]

L-PUMA Forward Looking Sonar (FLS) ICD, Interface Control Document (ICD) for the Littoral Precision Underwater Mapping (L-PUMA) System Forward Looking Sonar (FLS), NAVSEA 8293252

Marine Geophysical Data Exchange Formats (MGD-2000), National Geophysical Data Center[12]

Mine Countermeasures Report Format (MCMREP)[13]

Software Requirements Specification for the Mine Warfare and Environmental Decision Aids Library (MEDAL), Build 7 Maintenance Release, MEDAL-DI-00001-5.1.0, Office of Naval Research, May 2002[10]

Tactical Decision Aids (TDAs), Applicable TDAs include the aforementioned MEDAL, plus Interactive Multisensor Analysis Training (IMAT), Personal Computer (PC) IMAT, Geophysical Fleet Mission Program Library (GF-MPL) and the Advanced Refractive Effects Prediction System (AREPS)[10]

UNIfied Sonar Imaging Processing System (UNISIPS) Version 5, Naval Oceanographic Office[14]

3. Terminology

3.1 *Acronyms:*

3.1.1 *ANDB*—Ambient Noise Database

3.1.2 *AOCO*—Airborne and Overhead Cooperative Operations

3.1.3 *AREPS*—Advanced Refractive Effects Prediction System

3.1.4 *ASCII*—American Standard Code for Information Interchange

3.1.5 *ASW*—Anti-Submarine Warfare

3.1.6 *ATA*—Advanced Technology Attachment

3.1.7 *BIIF*—Basic Imagery Interchange Format

3.1.8 *CCS*—Combat Control Systems

3.1.9 *CMOS*—Complementary Metal Oxide Semiconductor

3.1.10 *COI*—Communities of Interest

3.1.11 *COMINT*—Communications Intelligence

3.1.12 *CONOPS*—Concept of Operations

3.1.13 *COTS*—Commercial Off The Shelf

3.1.14 *DBDB-V*—Digital Bathymetric Database - Five

3.1.15 *DCGS-N*—Distributed Common Ground Station-Navy

3.1.16 *DoD*—Department of Defense

3.1.17 *DoDBL*—Department of Defense Bathymetric Library

3.1.18 *DVL*—Doppler Velocity Log

3.1.19 *ELINT*—Electronic Intelligence

3.1.20 *EM/EO*—Electromagnetic/Electro - Optical

3.1.21 *EARS*—Environmental Acoustic Recording System

3.1.22 *FGDC*—Federal Geographic Data Committee

3.1.23 *FLS*—Forward Looking Sonar

3.1.24 *GDBV*—Geoacoustic Database Variable Resolution

3.1.25 *GDD*—Global Data Dictionary

3.1.26 *GEODAS*—Geophysical Data System

3.1.27 *GFMPL*—Geophysical Fleet Mission Program Library

3.1.28 *GIF*—Graphics Interchange Format

[6] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

[7] Available from National Geospatial-Intelligence Agency (NGA), NGA Office of Corporate Relations Public Affairs Division, MS D-54, 4600 Sangamore Rd., Bethesda, MD 20816-5003, Jan. 1995.

[8] MIL-D-89029 is the current data standard for Digital Bathymetric Databases including DBDB-0.1 (0.1 minute horizontal resolution) and DBDB-0.5 (0.5 minute resolution). Both of these databases are classified.

[9] VPF is a format for vector databases and is used primarily for geospatial data including terrain, bathymetry and additional layers of information.

[10] Available from the Office of Naval Research, 1002 Balch Blvd., Code N14, Stennis Space Center, MS 39522-5001.

[11] Airborne & Overhead Cooperative Operations Unclassified ELINT Joint Interface Control Documents (V 3.2, & V 3.3), 25 March 2005 with Errata Sheets 1 and 2 and COMINT Joint Interface Control Documents (V 4.0), 25 March 2005 with Errata Sheets 1 and 2, available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., N.W., Mail Stop: SDE, Washington, DC 20401.

[12] Available from National Geophysical Data Center, E/GC 325 Broadway, Boulder CO, 80305-3328.

[13] Available from Commander, Mine Warfare Command, 325 Fifth Street SE, Corpus Christi, TX 78419-5032.

[14] Available from The Naval Oceanographic Office's Oceanographic and Atmospheric Master Library (OAML), 1002 Balch Blvd., Code N14, Stennis Space Center, MS 39522-5001.

3.1.29 *GIG*—Global Information Grid

3.1.30 *GOOS*—Global Ocean Observing System

3.1.31 *GRL*—Global Revocation Library

3.1.32 *GSF*—Generic Sensor Format

3.1.33 *HFBL*—High-Frequency Bottom Loss

3.1.34 *HIE*—Historical Ice Edge

3.1.35 *ICD*—Interface Control Document

3.1.36 *IDL*—Interactive Data Language

3.1.37 *IEEE*—Institute of Electrical and Electronics Engineers

3.1.38 *IMAT*—Interactive Multisensor Analysis Training

3.1.39 *MINT*—Imagery Intelligence

3.1.40 *IOC*—Intergovernmental Oceanographic Commission

3.1.41 *IOOS*—Integrated Ocean Observing System

3.1.42 *IRIG*—Inter Range Instrumentation Group

3.1.43 *ISO/TC 211*—International Organization for Standardization Technical Committee 211

3.1.44 *ISR*—Intelligence, Surveillance, and Reconnaissance

3.1.45 *ISR&T*—Intelligence, Surveillance, and Reconnaissance & Targeting

3.1.46 *JAUS*—Joint Architecture for Unmanned Systems

3.1.47 *JPEG*—Joint Photographic Experts Group

3.1.48 *JICD*—Joint Interface Control Document

3.1.49 *LFBL*—Low-Frequency Bottom Loss

3.1.50 *L-PUMA*—Littoral-Precision Underwater Mapping

3.1.51 *MIZ*—Marginal Ice Zone

3.1.52 *MCM*—Mine Countermeasures

3.1.53 *MCMREP*—Mine Countermeasures Report

3.1.54 *MEDAL*—Mine-warfare Environmental Decision Aids Library

3.1.55 *MGD*—Marine Geophysical Data

3.1.56 *MLO*—Mine-Like Object

3.1.57 *MIW*—Mine Warfare

3.1.58 *MRUUVS*—Mission Reconfigurable Unmanned Undersea Vehicle System

3.1.59 *NGA*—National Geospatial-Intelligence Agency

3.1.60 *NGDC*—National Geophysical Data Center

3.1.61 *NAVOCEANO*—Naval Oceanographic Office

3.1.62 *NITF*—National Imagery Transmission Format

3.1.63 *NOAA*—National Oceanic and Atmospheric Administration

3.1.64 *NSIF*—NATO Secondary Imagery Format

3.1.65 *NSP*—National System Processor(s)

3.1.66 *NTP*—Network Timing Protocol

3.1.67 *PC-IMAT*—Personal Computer - Interactive Multisensor Analysis Training

3.1.68 *PUMA*—Precision Underwater Mapping

3.1.69 *SAE*—Society of Automotive Engineers

3.1.70 *SAS*—Synthetic Aperture Sonar

3.1.71 *SATA*—Serial Advanced Technology Attachment

3.1.72 *SI*—International System of Units

3.1.73 *SIGINT*—Signals Intelligence

3.1.74 *SLS*—Side Looking Sonar

3.1.75 *SML*—Sensor Modeling Language

3.1.76 *SN*—Shipping Noise

3.1.77 *SPL*—Sound Pressure Level

3.1.78 *SSN*—Submersible Ship Nuclear

3.1.79 *SUBLAN*—Submarine Local Area Network

3.1.80 *SWFTS*—Submarine Warfare Federated Tactical Systems

3.1.81 *TACLAN*—Tactical Local Area Network

3.1.82 *TDA*—Tactical Decision Aids

3.1.83 *TIFF*—Tagged Image File Format

3.1.84 *TSP*—Tactical System Processor(s)

3.1.85 *UNISIPS*—Unified Sonar Image Processing System

3.1.86 *USS*—Undersea Search and Survey

3.1.87 *UUV*—Unmanned Undersea Vehicle

3.1.88 *VD*—Vertical Deflection

3.1.89 *WMO*—World Meteorological Organization

3.1.90 *XML*—Extensible Markup Language

4. Significance and Use

4.1 While the emphasis of this initial UUV data formats guide is focused on the collection and processing of environmental parameters gleaned from UUV sensors executing military operations, it is relatively easy to translate these guidelines to the commercial sector. The type of data collected may differ, but the standardization of the data formats, whether for scientific, economic, or military applications does not. Standardized data formats are equally leveraged for myriad pursuits such as determining the extent of global warming, maintaining security of offshore petroleum facilities, or measuring the sustainability of the oceans' biomass. Military applications of UUVs often mandate unusual and even non-standard data collections and formats. As a result, conforming to national and international standards may not always be possible. However, to the maximum extent practicable, data collection formats and standards should follow World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC), and similar national and international standards.

4.2 The U.S. Navy has recently updated the vision for UUV operations in its UUV Master Plan.[15] This Master Plan articulates nine high-priority prospective UUV missions. The top priority for UUV missions is the collection of maritime ISR data. Data formats for communications intelligence (COMINT) and electronic intelligence (ELINT) information have

[15] The Navy Unmanned Undersea Vehicle (UUV) Master Plan, November 9, 2004.

been addressed in unclassified documents described by Airborne & Overhead Cooperative Operations (AOCO). These Joint Interface Control Documents (JICD) stipulate essential formats and standards for tactical sensors and their associated communications systems in order to be interoperable with national overhead and airborne intelligence, surveillance, and reconnaissance and targeting (ISR&T) architectures and systems.

4.3 Other UUV military missions specifically called out in the Master Plan include conducting mine countermeasures (MCM), anti-submarine warfare (ASW), and oceanography. In the case of these three capabilities, ocean data collection is integral to the mission. Payloads capable of executing this data collection have already been established for surface and air-deployed sensors and are readily extended to UUVs. However, there may be some payloads, such as bioluminescence sensors, that may not be currently configured to fit UUV form factors.

4.4 Tactical Decision Aids (TDAs), generally computer programs and models, are used to support sensor and weapons systems throughout the military. As a result, quality environmental data are required as inputs to these programs. TDAs such as Mine Warfare and Environmental Decision Aids Library (MEDAL), Interactive Multisensor Analysis Training (IMAT), PC IMAT, Geophysical Fleet Mission Program Library (GFMPL) and the Advanced Refractive Effects Prediction System (AREPS) are examples. The goal of all environmental data collected by military UUVs is that it readily supports these and other TDAs and operational requirements without heavy manipulation from one data format to another.

4.5 UUVs collect data on ocean properties, underwater terrain, obstructions and mines, the presence of chemical or biological agents in air and water samples, and above-the-surface photographic and radio frequency samples. The collection of this data leverages a primary advantage of the UUV, which is to gather data covertly in a denied maritime setting that can be used by intelligence and mission planners in developing and executing tactical actions. The underwater data, along with accurate navigational fixes, must also be available to the UUV for its use in maintaining safe operational depth and executing precise navigation and maneuvering. Finally, the data are also integral to performing any post-mission analysis and mission reconstruction.

4.6 The Department of Defense has begun an effort to build the Global Information Grid (GIG). As an integral part of the GIG, a data strategy is being developed. DoD Directive 8320.2 starts the chain of requirements specifying how data will be shared. The UUV data formats standards espoused in this guide and any future revisions should be developed in accordance with this strategy. The requirement to associate metadata so that data can be discoverable is invoked in DoD 8320.2. The requirement that data semantic and structural agreements shall be promoted through communities of interest (COIs) is another important concept introduced by DoD 8320.2. Data content needs to be determined and agreed upon by producers of the data and the customers of the data. Clearly, for this guide to be most beneficial across both the military and civilian UUV communities, it needs to be developed closely with the customers of UUV data and supported by continual feedback from the UUV community.

5. Sensor Data Formats

5.1 *General Water Column and Ocean Bottom Guidelines*—Water column and ocean bottom data measurements and metadata formats are most useful for analysis during and after a mission if the following are included:

5.1.1 Measurement value or values,

5.1.2 Geo-referencing (latitude/longitude), including depth,

5.1.3 Resolution of the measurement,

5.1.4 Averaging (ensemble) choices,

5.1.5 Time at which the measurement was taken, and

5.1.6 Accuracy and precision of the primary and supporting measurements.

5.2 *Low Volume Data Versus High Volume Data:*

5.2.1 Low volume data can be described as observations that do not occur at a rapid rate. The desired low volume format is XML. Specifically, adherence to the Sensor Modeling Language (SML) as an XML vocabulary for self-describing dynamic sensor data is recommended.

5.2.2 High volume data includes multi-beam data and imagery. General data formats for this type of data are described in 5.5.

5.3 *Governing U.S. Military Specifications*—Two specifications that should be invoked for presenting water column and ocean bottom data are MIL-PRF-89049 and, MIL-D-89029. The 89049 standards cover certain layer types within the digital nautical chart production environment such as bottom contours, OP AREAS, etc. The 89029 is the current data standard for Digital Bathymetric Databases including DBDB-0.1 (0.1 min horizontal resolution) and DBDB-0.5 (0.5 min resolution). Both of these 89029 databases are classified.

5.4 *Specific Water Column Guidelines:*

5.4.1 *Temperature and Salinity*—Temperature and salinity measurements are often point measurements at UUV depth. If possible, averaging of data should be avoided. Plain text metadata for the measurement normally consists of the value of the measurement; the resolution or precision of the measurement; and the latitude, longitude, depth, and time of the measurement. If averaging or sub-sampling of the data was performed, the method should be fully described in the metadata.

5.4.2 *Ocean Currents*—Current information can be measured in a variety of ways aboard UUVs. Most widely used methods include:

5.4.2.1 *Doppler Current Profilers or Doppler Velocity Logs (DVL)*—DVLs are sonar systems designed to measure Doppler information from debris and bubbles in the water column for the purpose of determining speed and direction of the vehicle. DVLs are often used as part of an integrated undersea navigation solution that includes inertial sensors. DVLs can also be used in "bottom lock" or "ice lock" mode to track the bottom or pack ice above the vehicle for accurate navigation input. For environmental characterization, raw DVL current data should be provided at the rate collected and averaged in post-processing to ensure the integrity of the ensemble averaged data. The processing method should be defined by the metadata. Depth bins at the highest resolution possible are preferred, but different bins can be used to optimize the UUV's mission.

5.4.2.2 Set and drift calculations. Glider UUVs, for example, may measure current by determining set and drift from their predicted navigation solution. As a result, the calculated current may not be depth related or point specific but integrated over the track from point to point. This data must be annotated to reflect that it is not point data, but averaged data.

5.4.2.3 Deployment of fixed current measurement instruments.

5.4.2.4 If averaging, sub-sampling of the data, or other data processing method is used, the method should be fully described by the metadata. All current data should be collected in delimited ASCII format (or easily convertible binary) containing location, time, depth, speed, and direction values when possible.

5.4.3 *Optical Clarity and Bioluminescence*—Optical clarity and bioluminescence are used in planning and executing mine warfare (MIW) operations. Optical clarity and bioluminescence data are collected from a variety of platforms to include UUVs. Optical clarity has traditionally been measured as "secchi depths" relating to the familiar secchi disk method. In UUV applications, an optical transmission sensor measuring absorption, backscatter, or other parameters, or a combination thereof, can be used to determine optical clarity. Absorption is typically measured in 1/m units and can be related to secchi depths. Other parameters can produce similar relationships to secchi depth. Additionally, ocean color can be collected in any method that yields a Forel-Ule or equivalent color rating. Bioluminescence data is usually quoted as photons/sec/ml at a point, depth, time, and location. A variety of instrumentation types including photomultiplier tubes are used to measure the light emitted from organisms generating bioluminescence.

5.5 *Specific Ocean Bottom Guidelines:*

5.5.1 *Bathymetry:*

5.5.1.1 *Ping Data*—Ping data is simply the sonar return information (soundings) collected by bathymetric sonars together with supporting measurements such as platform attitude, sound velocity profiles, error corrections, and so forth. Generic sensor format (GSF) is one data format that supports both single-beam and multi-beam bathymetry data. GSF was developed for use as an exchange format in the DoD Bathymetric Library (DoDBL). It should be noted that the National Geospatial-Intelligence Agency (NGA) maintains the DoDBL and is expected to move toward open, international standards in the future. Formats similar to GSF are under development for the interchange of vector data, such as hydrographic soundings and features and raster data, such as grid bathymetry and processed acoustic imagery. GSF is designed to efficiently store and exchange information collected by geophysical measurement systems prior to post-processing. The records currently defined include:

(1) Header record,

(2) Swath bathymetry ping record to contain multi-beam bathymetry data,

(3) Single-beam sounding record to contain single-beam data,

(4) Summary record to record the temporal and spatial extremes of the data,

(5) Sound velocity profile record,

(6) Navigation error record to allow the positional error estimate associated with a given data point to be described,

(7) Processing parameter record to define the state of the data recorded in the file sensor, and parameter record to record the state of the sensor when the data were produced,

(8) Comment record for annotating the data, and

(9) History records that provide an audit trail of processing that has been applied to the data.

5.5.1.2 Not all record types must be present to describe the data, for instance, a file may consist only of ping records if only those data are available or desirable. All records contain a time field consisting of precise time and are normally, but not necessarily, in chronological order. The imaging sensor type and model should be defined in the metadata. The format of each GSF data record is defined in the GSF specification.

5.5.1.3 *Littoral-Precision Underwater Mapping (L-PUMA) Bathymetry Data and Precision Underwater Mapping (PUMA) Data:*

(1) An Interface Control Document (ICD) for the L-PUMA System Forward Looking Sonar (FLS) has been released as NAVSEA ICD 8293252 and is available from the NAVSEA PMS 403 UUV Program Office. UUV bathymetry data formats can be derived from this ICD which addresses sonar imagery formats employed for U.S. Navy military operations. Single ping sonar imagery formats and multi-ping sonar imagery mosaic map formats (that will supersede the single ping format) are described. The multi-ping imagery is exportable via screenshot utility in standard graphics formats (JPEG, GIF, TIFF, and so forth). The use of the Geo-TIFF image format is also being evaluated with initial promising results.

(2) L-PUMA Forward-Look Sonar Sensor Interface Messages—Parameters for specific message headers are described in the aforementioned ICD. In general, the below described messages are provided to the UUV by the L-PUMA system whenever the sonar is in the Mapping or Obstacle Avoidance Modes. These sonar data products are provided as inputs to the UUV for use in autonomous decisions and vehicle control. These messages include information for detected and localized mine-like objects, obstacles to navigation, moving contacts, and for bottom bathymetry data ahead of the vehicle. The L-PUMA Stationary Obstacle Report message is sent from the L-PUMA sonar controller to the UUV to indicate detected and localized positions for large stationary objects that are within the LPUMA sonar field of view. The L-PUMA Moving Contact Report message is sent from the L-PUMA sonar controller to the UUV to indicate detected and localized positions for small or large moving objects that are within the L-PUMA sonar field of view. The Mine-Like Object (MLO) Contact Report message is sent from the L-PUMA controller to the UUV to indicate detected and localized stationary MLO targets within the L-PUMA sonar field of view. The L-PUMA

Terrain Data message is sent from the L-PUMA controller to the UUV to indicate the estimated depth of the seafloor within the L-PUMA sonar sector ahead of the vehicle.

(3) UUV bathymetry data should also be compatible with the PUMA format. The latest version (APB-04) of the PUMA processing system produces the Charter File Format of bathymetry for MEDAL interfacing. Work is in progress to incorporate the Digital Bathymetric Database-Five (DBDB-V) as a bathymetry format export option as well. GSF is not anticipated to be supported in future APB releases, although it can be if deemed necessary.

(4) Raster Images—As described, PUMA and L-PUMA imagery is exportable in standard graphics formats (JPEG, GIF, TIFF, and so forth). The Geo-TIFF image format is currently being evaluated.

(5) Contact Data—Contacts of interest are bottom and tethered mines and mine-like contacts as well as clutter (for example, wrecks, pilings, etc.) The APB-04 version of the PUMA processing system produces Mine Countermeasure Report (MCMREP) contact data formatted for MEDAL interfacing.

5.5.2 *Sub-bottom Data*—An increasingly important area of mine countermeasures and undersea warfare is characterization of the ocean bottom. Data collected often include latitude and longitude, bottom type, layer thickness, reflectivity, and other parameters. Tools utilized to gather this information include sub-bottom profilers, core samplers, and inversion techniques. The Naval Oceanographic Office (NAVOCEANO) collects and processes sub-bottom data (attenuation, density profiles, sound speed, sediment type, and so forth) on a regular basis. These databases are stored in several formats: the legacy Low-Frequency Bottom Loss (LFBL) and High-Frequency Bottom Loss (HFBL) databases, and the newer Geoacoustic Database Variable Resolution (GDBV) format. There are nearly a hundred SEG-Y formats for geoacoustics collection varying by end user and end application. These formats were developed largely by the oil and gas industry. Since the end product is often graphical in nature (in many cases simply traces of acoustic return or images), data format is often not relevant.

5.6 *Imagery Data*—A variety of sensors are used aboard UUVs to collect imagery. In the optical area, both still and video cameras using artificial light sources are often used for visible-spectrum collection. Either digitally-collected or images scanned from film are readily ingestible into a variety of tactical support and GIS systems. Typical image formats include TIFF, JPEG, BMP, and GIF in both compressed and uncompressed form. Movie formats are numerous including MPEG, AVI, and others.

5.6.1 Laser Line Scan systems can produce very detailed imagery and consist of laser illuminators and optical sensors such as CCDs or avalanche photodiodes. These images yield (after processing) files similar to video and still cameras and are easily handled in most information processing systems.

5.6.2 Acoustic "imagery" is commonplace today and sensor types include Side Looking Sonar (SLS) (backscatter information), multi-beam sonar (high-resolution ping-by-ping digital terrain models), and imaging sonars that function similarly to SLS systems. Native data formats are largely determined by the manufacturer, but most are easily converted to Navy-standard formats such as Unified Sonar Image Processing System (UNISIPS) for side-scan sonar and GSF for single- and multi-beam sonars.

5.7 *Unified Sonar Image Processing System (UNISIPS)*—The Naval Oceanographic Office (NAVOCEANO) collects and processes acoustic ocean bottom imagery from multiple sensors at varying resolutions ranging from 12-kHz hull-mounted swath systems to high-frequency 100 to 500-kHz towed systems. The UNISIPS is a NAVOCEANO collection of programs that support post-acquisition processing of this data. Specifically developed as a generic format for storing acoustic imagery scan line data, it supports common COTS formats (such as the Triton Elics "xtf"). The UNISIPS format is a multi-channel (up to five channels of data) multi-bit (can be 8, 16, 24, or 32 bit) image format. This format allows collected imagery data to be stored in its original precision instead of being reduced down to 8 bits. UNISIPS includes numerous sonar imaging utilities, including raw hydrophone data-to-imagery converters, digital mosaic tools, and interactive image processing and visualization functions. UNISIPS has collected and processed data from a variety of UUVs during fleet exercises. The Mine Warfare (MIW) Environmental Decision Aids Library (MEDAL) directly ingests UNISIPS output.

5.8 *Side Looking Sonar (SLS)*—The NAVOCEANO standard for side looking sonar is UNISIPS. One effective SLS system leverages Synthetic Aperture Sonar (SAS) technology. Since SAS is essentially a large array/small aperture SLS variant, its output data can also be made compatible with UNISIPS.

5.9 *Ambient Noise*—Ambient noise is a critical input to the sonar equation, and therefore is used extensively in ASW Tactical Decision Aids (TDA). The Ambient Noise Data Base (ANDB) Preliminary Database Definition Document highlights several potential database types, including omni-directional single frequency, omni-directional multi-frequency, and directional multi-beam data. Parameters typically include, but are not limited to, sensor type, frequency, direction, sound pressure level (SPL) in dB, integration time, median, correlation time, standard deviation.

5.9.1 The majority of ocean ambient noise collection for military applications is performed by NAVOCEANO. As described by the Chief, Naval Meteorology and Oceanography Command: "Ambient noise may be defined as the sound produced in the sea by marine life, shipping activity, terrestrial movements, precipitation and other underwater or surface activity outside the acoustic detection equipment. The Shipping Noise (SN) database considers only shipping noise and that of surface wind and polar ice. Shipping noise consists of low resolution SN, high-resolution SN, directional SN, and historical ice edge (HIE) shipping noise.

5.9.2 The Low-Resolution SN Data Set describes estimated omni-directional and horizontally directional shipping noise and spectra. These estimates, accompanied by noise statistics, are provided for a receiver at a depth of 100 m and for a nominal frequency of 50 Hz. The Low-Resolution SN Data Set has a spatial resolution of 5° with a seasonal temporal resolution.

5.9.3 The High-Resolution SN Data Set describes estimated omni-directional shipping noise and spectra only. These estimates are provided for a receiver at a depth of 100 m and a nominal frequency of 50 Hz. The spectral range is 10–1000 Hz for predominantly under-ice areas, and 25–15 000 Hz for predominantly open-water areas. The High-Resolution SN Data Set has a spatial resolution of 1⁄12 ° (5 min) and a seasonal temporal resolution.

5.9.4 The Directional SN Data Set describes estimated horizontally directional shipping noise for a receiver depth of 1000 ft and a nominal frequency of 50 Hz. The spatial resolution of the Directional SN Data Set is *Vi* degree for the Mediterranean and 1° elsewhere. The Directional SN Data Set has an azimuthal resolution of 5° with a seasonal temporal resolution.

5.9.5 The HIE SN Data Set describes the mean ice edge and the surrounding marginal ice zone (MIZ) for each month. HIE is an important factor in determining the omni-directional-noise levels in areas of transition between open water and under ice. The spatial resolution of the HIE Data Set is 1⁄12 ° (5 min) with a monthly temporal resolution. Using moored Environmental Acoustic Recording System (EARS) buoys, omni-directional ambient noise is collected up to full ocean depth. With recent efforts to begin collecting towed-array ambient noise data, fixed depths and frequencies may become less commonplace.

5.10 *Other Geophysical Data*—The National Geophysical Data Center (NGDC) has developed a series of data formats for various purposes. Among these are several formats for the exchange, storage, and dissemination of marine geophysical data. These "MGD-2000" formats are used extensively by the GEODAS software as well as other software applications.

5.10.1 *MGD77*—The data in the Marine Trackline Geophysics Database is in the MGD77 Format. This is an ASCII exchange format for marine geophysical data. Each formatted survey unit contains all observations that conveniently constitute a data subset (for example, a port-to-port survey) and consists of both a Header file to document survey information and a data record file in time series containing fields for date, time, bathymetry, magnetics, gravity and seismic navigation.

5.10.2 *HYD93*—The data in the Hydrographic Surveys Database is in the HYD93 Format. This is an ASCII exchange format for hydrographic data. Each HYD93 formatted survey represents all observations that conveniently constitute a data subset (generally a specific area targeted for mapping, with one or more port-to-port operations). Each survey consists of both a Header file to document survey information and a data record file in time series containing fields for Survey-Id, latitude, longitude, depth, depth-type and cartographic code.

5.10.3 *ARO88*—The ARO88 Header Format is an ASCII exchange format for meta-data (documentation) for Aeromagnetic survey data. This format contains fields such as dates, instrumentation, reference fields used, flight data, and the format for the data records, which come in a multitude of formats.

5.10.4 *GRD98*—The GRD98 Format is a digital format for the storage of gridded data. Though developed for bathymetric/topographic data, the format can handle virtually any type of gridded data. It is very utilitarian format and contains no documentation about the grids (such as information about references, methods and datums used, etc.). Rather, GRD98 formatted files only contain grid-structure information followed by the grid cell data values.

5.10.5 *VCT00*—The VCT00 Format is a digital format for the storage of 2-D vector data. Though developed for high resolution boundary (coastline) data, the format can handle other types of vector data such as contours. It is very utilitarian format and contains no documentation about the data (such as information about references, methods and datums used, etc.). Rather VCT00 formatted files only contain vector data records and headers with minimal geographic and file-indexing information.

5.10.6 *XYZ03*—The XYZ03 Format is a digital format for the storage of xyz (longitude, latitude, value) geospacial potential field data. It is very efficient format in that it is binary integers and the record size (12 bytes) is small and yet contains latitude, longitude, and value precision sufficient for most users. The format contains no headers and thus no documentation about the data (such as information about references, methods and datums used, etc.).

5.11 *Above-Waterline Sensor Data:*

5.11.1 *ISR Data*—The Distributed Common Ground Station-Navy (DCGS-N) is an interoperable and net-centric system of systems that will provide multi-intelligence processing, exploitation, and targeting support for the military Commanders. DCGS-N information will be accessible via multi-function, all-source intelligence workstations embedded within a joint common operating environment utilizing DoD and intelligence community-compliant standards, protocols, languages, and file formats. Representative ISR sensor data collected from the UUV environment includes the IMINT, ELINT and COMINT as described below. Such data contribute to campaign planning, targeting (deliberate and time-sensitive), combat assessment and execution, maritime strike and interdiction, and the Intelligence Preparation of the Environment (IPE).

5.11.1.1 *Imagery Intelligence (IMINT) or Optical Data*—Formats for ISR optical sensor data should adhere to MIL-STD- 2500B(2), which establishes the requirements for the National Imagery Transmission Format Version 2.1 (NITF 2.1).[4] This version has been developed to keep the imagery format consistent with the emerging ISO Basic Imagery Interchange Format (BIIF) and the NATO Secondary Imagery Format (NSIF).

5.11.1.2 *Electronic Intelligence (ELINT)*—Formats for ISR ELINT data should adhere to the interface standards and requirements established for AOCO ELINT National System Processor(s) (NSP) and Tactical System Processor(s) (TSP) to accomplish cooperative tactical overhead collection of data. The AOCO ELINT JICDs (Versions 3.2 and 3.3) define the formats of all AOCO ELINT data and messages transferred between the NSP and the TSP. This JICD also addresses the message sets used in the following AOCO ELINT Concept of Operations (CONOPS): Tip and Tune, Tip and Report, Synchronized Tune, Quick Tune, and Tip and Fuse.

5.11.1.3 *Communications Intelligence (COMINT)*—Formats for ISR COMINT data should adhere to the AOCO COMINT JICD (Version 4.0) which establishes the external interface requirements for various SIGINT NSP and various SIGINT TSP to accomplish cooperative collection of data. The AOCO COMINT JICD defines the data exchange formats of messages for bidirectional transfer between the processors at National and Tactical sites to accomplish cooperative collection of data for geolocation. The AOCO JICD defined message set is also used in the COMINT geolocation CONOPS and includes data push and data pull descriptions and where appropriate, a reference emitter registration and tasking capability.

5.11.2 *Electromagnetic (EM) and Electro-optical (EO)*—Electronic surveillance, radar, and communications systems often make use of atmospheric refractivity data collected in a variety of ways. Most military and commercial propagation prediction systems utilize "M Unit" data which is widely regarded as industry standard. All refractivity data collected by UUV sensors for the support of electro-optical systems should be in delimited American Standard Code for Information Interchange (ASCII) format, consisting of height and M Unit pairs. One standard U.S. Navy electro-optical tactical decision aid is the Advanced Refractive Effects Prediction System (AREPS) which will directly ingest this profile data. Binary versions of this data are acceptable if they are of a format that is readily convertible to ASCII format.

6. Mission Data Formats

6.1 *Timing*—A crucial piece of information required for accurate data collection is timing. Latencies in electronic subsystems can greatly affect high sample rate systems such as attitude sensors and multibeam sonars and their correlation to other sensors. On many platforms, precision clocks updated using precision timing services or GPS, or both, are common. Distributed timing networks aboard some platforms can be used to insure accurate time is available to all sensors (facilitating exact correlation between data types collected). All data collected aboard UUVs should similarly have timing accuracy and precision standards that meet end user requirements for temporal resolution and accuracy. As a result, formats such as the American Inter Range Instrumentation Group (IRIG) Time Code Formats and Network Timing Protocol (NTP) should be followed where applicable to ensure timing accuracy and precision for collected sensor data is known to end users. IRIG accommodates accuracies down to 10 (isec and NTP, using 64-bit stamps, has even greater potential. The National Institute of Standards and Technology, Time and Frequency Division, has readily available information on NTP and relevant standards.

6.2 *Vehicle Mission Data Formats*—Specific navigation, vehicle status, and related vehicle mission information data formats are expected to be addressed in future versions of this guide.

6.3 *External Interface Data Formats*—Often the UUV support and launch platforms (host platforms) may be consumers or distributors, or both, of data obtained by the UUV during missions. While host platforms can vary widely, in the case of a U.S. Navy submarine (SSN) acting as a host, interface compatibility is necessary with the Submarine Warfare Federated Tactical Systems (SWFTS) and onboard Combat Control Systems (CCS) (for example, AN/BYG-1, ARCI, or CSRR) to facilitate the processing, use, and distribution of data. The external interface signals between SWFTS subsystems and the UUV will normally be by fiber connections through the Tactical Local Area Network (TACLAN) and the Submarine Local Area Network (SUBLAN). In this case, the SWFTS interface products (for example, GRL, GDD, and IDL) will define the data formats and frequency of transmission along with other pertinent data attributes.

6.4 *Joint Architecture for Unmanned Systems (JAUS)*—The Society of Automotive Engineers (SAE) has formed Technical Committee AS-4, an Unmanned Systems Standards Committee to develop JAUS into an aerospace standard. This ASTM effort will leverage, where appropriate, the work of SAE AS-4 in the pursuit of UUV command and control standards which are currently being developed using the JAUS version 3.2 format. More detailed discussion of SAE/JAUS message formats can be found in Guide F2594.

6.5 *Security*—Security of data must be considered for military UUV operations. The two primary 21-in. MRUUVS missions, MCM and ISR, will generate classified data. Issues of concern include memory security, encryption, and protection in support of possible vehicle compromise or loss. Specific guidelines for data security are beyond the scope of this version of the document, but may be added in the future.

7. Metadata Formats

7.1 *Initial Considerations*—Expansion of this section is anticipated in future versions of this guide. Generally, metadata must align with the Federal Geographic Data Committee (FGDC) Metadata Content Standard, as well as the extensions for remotely sensed data.[16] ISO/TC 211 also has a standard that addresses metadata. It is recommended that a minimum set of metadata that transcends all UUV sensor types be developed.

8. Data Storage Media

8.1 *General Data Storage Media Guidelines:*

8.1.1 Power consumption, read/write rates, record size and volume, physical unit size, and environmental factors (shock, vibration, and so forth) are the primary drivers for choices of data storage devices for UUVs. Device performance must be adequate to support data collection requirements. The data storage device should be capable of withstanding sudden loss of power without damage or corruption and loss or data. Specific program applications may provide additional criteria that may take precedence over the guidance contained in this section.

8.1.2 It is expected that vehicle media should remain indigenous to the vehicle and payload media be removable to support vehicle turn around and data off load.

[16] Federal Geographic Data Committee, "Content Standard for Digital Geospatial Metadata," Version 2.0, 1998. (FGDC-STD-001 June 1998).

8.1.3 UUV and payload software including data storage should be developed, tested, and maintained under the guidelines in IEEE/EIA 12207, Industry Implementation of International Standard ISO/IEC 12207.

8.2 *Classified Data Storage*—Guidelines for storing classified data is beyond the scope of this guide, but may be added in the future.

9. Recommendations

9.1 *Low Volume Data Collection*—Adherence to SML as an XML vocabulary for self-describing dynamic sensor data is recommended for the below parameters.

9.1.1 *Temperature and Salinity Data*—No specific formats are recommended other than the general requirements listed in 5.4.1.

9.1.2 *Ocean Currents Data*—Collect data using DVLs, depth-differentiated vector profiles. The vehicle's speed and heading is normally provided as part of the DVL data set.

9.1.3 *Ocean Optics/Bioluminescence Data*—Optical clarity has traditionally been measured as "secchi depths" relating to the familiar secchi disk method. In UUV applications, an optical transmission sensor measuring absorption, backscatter, or other parameters, or combination thereof, can be used to determine optical clarity.

9.2 *High Volume Data Collection*—As described for the data below.

9.2.1 *Bathymetry Ping Data*—GSF is presently recommended for single ping beam sonar data, but will likely be replaced in the near future.

9.2.2 *Bathymetry Imagery Data*—Several acceptable data format standards exist for multi-beam imagery. Most existing COTS system formats (such as the Triton Elics "xtf," Klein Sonar "sdf," and Oceanic Imaging Consultants GeoDAS "ois") are compatible with UNISIPS, and hence, with MEDAL. PUMA and L-PUMA support Raster images in JPEG, GIF, TIFF and Geo-TIFF formats. Additionally, MEDAL interfacing can be accomplished through the Charter bathymetry format and in the near future, the DBDB-V format. Specific to SLS systems, the use of the UNISIPS data format is recommended.

9.2.3 *Ocean Sub-Bottom Data*—Formats as prescribed by NAVOCEANO including the legacy Low-Frequency Bottom Loss (LFBL) and High-Frequency Bottom Loss (HFBL) databases, and the newer Geoacoustic Database Variable Resolution (GDBV) format.

9.3 *Other Data:*

9.3.1 *Ambient Noise*—There are several potential database types, including omni-directional single frequency, omni-directional multi-frequency, and directional multi-beam data. Parameters typically include, but are not limited to, sensor type, frequency, direction, sound pressure level (SPL) in dB, integration time, median, correlation time, standard deviation. Governing NAVOCEANO standards should be used for such parameters.

9.3.2 *Geophysical Data*—The MGD-2000 series is the recommended exchange format for marine geophysical data (bathymetry, magnetics, gravity and seismic navigation).

9.3.3 *Above-Waterline Sensor Data*—All atmospheric refractivity data collected by UUV sensors for the support of electro-optical systems should be in delimited ASCII format, consisting of height and M Unit pairs. IMINT data formats should leverage MIL-STD-2500B(2), which establishes the requirements for the NITF 2.1. ELINT and COMINT collection should prescribe to ISR data formats specified in existing AOCO and other applicable U.S. military directives.

9.4 *Metadata*—Metadata should align with the Federal Geographic Data Committee (FGDC) Metadata Content Standard.

10. Technology Forecast

10.1 *Integrated Ocean Observing System (IOOS)*—Increasing emphasis on the ocean observing related to health of the environment and commercial and military applications has resulted in the formation of new observing programs and consortiums. The U.S. Integrated Ocean Observing System (IOOS), Intergovernmental Oceanographic Commission's (IOC- UNESCO) Global Ocean Observing System (GOOS), and a variety of local, regional and national contributors are involved in the largest distributed, sustained ocean observing network in history. Inputs into observing networks will come from fixed distributed and mobile platforms around the globe including military, civilian, and commercial platforms carrying a variety of sensors.

10.2 *Network Common Data Form (NetCDF)*—While there continues to be a variety of native sensor data formats, there are some emerging model and processed data outputs that the Naval Oceanographic Office and National Oceanic and Atmospheric Administration (NOAA) are adopting for a significant volume of its data. One of these is NetCDF or Network Common Data Form. While complex, the format is flexible and allows the inclusion of multiple parameters and can simplify databases in comparison to some other commonly used formats.

10.3 *Future Technology*—UUVs can play a significant role in both contributing to and benefiting from this flow of quality environmental data. Future standards will emerge from these ventures that will necessitate changes to UUV data formats and collection methods. Both users and developers should be prepared to evolve with observing programs to address new requirements and standards.

11. Keywords

11.1 data format; data storage media; sensor data format; unmanned undersea vehicle; UUV