MBARI

Ocean

Observing

Systems

(MOOS)

Data **M**anagement

Workshop **R**eport

Preface

There were three areas of developing technology that I thought would make research in the deep waters of the oceans much more effective in the future. … The third is the progress that is being made in computer science and data communication. Deep water research involves immense amounts of data. I have the impression that much more time is being spent in collecting data than in looking at it and analyzing it. We believe that situation can be greatly improved.[1]

- David Packard, August 28, 1988

In February of 1999 a 3-day workshop was held to begin developing an institutional plan for the MBARI Ocean Observing System. Issues involving shore-side data management and representation were deferred during this workshop. At the time we recognized that these issues were complex enough to warrant their own discussion. The final recommendation from the 1999 was "establishment of a parallel effort to support MOOS data management issues"[2].

This is the report from the 2-day MOOS Data Management workshop held at the Monterey Bay Aquarium on March 27-28, 2000. About 32 people, including Marcia McNutt and four people external to MBARI, attended the first day where technological issues were presented and science use scenarios were discussed. Twelve people attended the second day where the essential needs of the MOOS data system were identified.

1. Executive Summary

MOOS Data Management workshop participants were first introduced to the science experiments that were being planned as part of the MOOS program. An effort was made to distill the common data needs from each of the use scenarios. Common themes emerged from our discussions and include:

- MOOS data will be heterogeneous
- Event detection will be done on the instrument or as a process operating on the archive. For the latter event detection process, real-time is defined as 6 hours.
- Processing will be done outside of the data archive
- Quick and easy access to raw instrument data in its native format is required. This need not be elaborate.
- A need to know what data exist and their methods of access – a catalog service is needed

Other attributes of the data system include:

- All raw data will be archived in its native format.
- Instrument calibrations and information regarding deployment and recovery, should be digitized and made available electronically; people need to be removed from this process wherever possible. (The success of the catalog and the data system depends on this being done well.)
- All data items should be time stamped and have a mechanism to be geo-referenced.
- It will employ an architecture that supports distributed processing and archiving of higher order data products.

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[1] *Oceanography*, November 1988, p 47.
[2] The Future of MOOS. http://www.mbari.org/MUSE/MOOS/MOOSfinal.doc

The results of this workshop provide information to the next step of the MOOS data management project, which is to produce a functional requirements document. And following that will be the design work that will lead to a final design by the end of 2000.

2. Day 1 - Technology issues and use scenarios

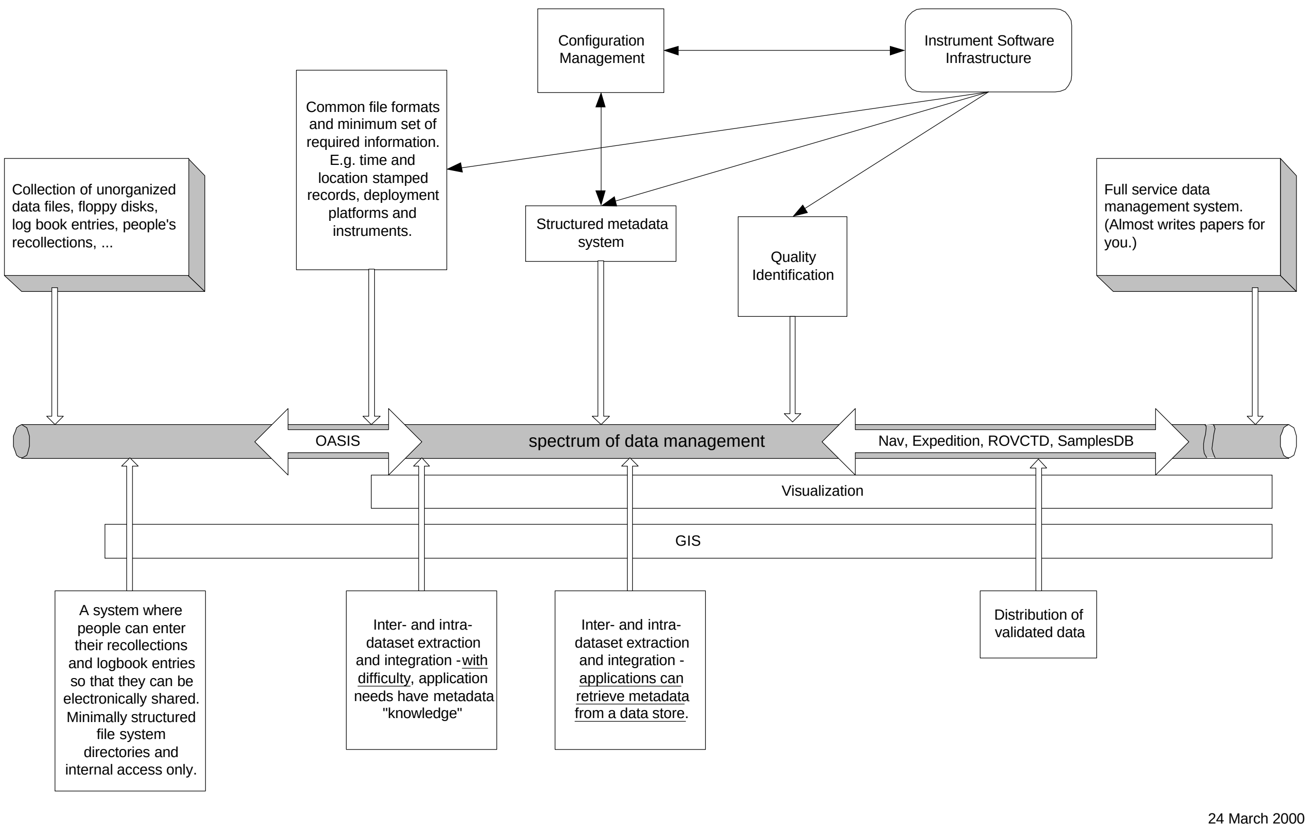
The first day of the workshop consisted of invited speakers giving presentations and the discussions that followed. Morning talks and discussions concerned technology challenges and opportunities while the afternoon consisted of MOOS System science use scenario presentations and discussions. Following is a summary of these presentations and discussions.

Marcia McNutt, MBARI president, welcomed the attendees and presented this list of considerations for the MOOS data management system:

1. it should be expandable
2. it needs to be broader in types of data managed - not all types can be reduced to numbers
3. the data must be easily calibrated and validated
4. there should be plenty of capacity for metadata
5. data need to be easily interfaced to analysis programs, such as Matlab^{tm}
6. it must be long-lived in its use – we don't want to hold a workshop again in 2 years
7. above all, it must be affordable

Mike McCann, Information Applications Group (IAG) leader at MBARI, presented a diagram (Figure 1) of data management concepts. This diagram is presented to help frame the discussion around such issues as configuration management, metadata, and quality identification. The view here is a spectrum of data systems from disorganized files, recollections, and logbook entries to highly structured homogeneous data models. Depending on the needs identified by this workshop there is a place along this spectrum where the MOOS Data Management system should set its target.

Data Management Concepts



- Figure 1. Spectrum of data management concepts. Heterogeneous systems lie on the left, homogeneous on the right. Metadata availability is essential for effective use of most datasets. If a structured matadata system is available, e.g. a catalog of datasets that includes information about the data elements within them, then writing applications to make use of the data is easier because those applications can programmatically refer to the catalog for knowledge about the data.

Todd Anderson (MBARI, IAG) presented the data system for the existing OASIS (Ocean Acquisition System for Interdisciplinary Science)[3]. The OASIS system is depicted in Figure 1 as being on the left side of the spectrum. The data are available as flat text files within a directory hierarchy and the configuration management is carried out in an *ad hoc* fashion.

Dr. Ted Tsui from the Naval Research Lab in Monterey presented two data systems. The first is a highly structured relational database paired with a flat-file archive that is used to provide near real time observations to forecast models. A customized Application Programming Interface was developed (TEDS[4]) to feed the data to the METCAST server which then uses the HTTP protocol to serve data to its clients. The second is the Master Environmental Library[5], which employs a three-level architecture for serving data from its data warehouse. It makes use of FGDC[6] for metadata management and provides end-user access to flat files.

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[3] http://mww.mbari.org/oasis/InternalDoc/download.html
[4] http://www.nrlmry.navy.mil/~lande/TEDS/
[5] http://mel.dmso.mil/
[6] http://fgdc.er.usgs.gov/

Richard Chinman, the Distributed Ocean Data System program manager from the University Corporation for Atmospheric Research gave a presentation on "Interoperability at the Data Level"[7]. He gave definitions of three types of metadata, and they bear repeating here:

1. Directory level - consists of broad descriptions of the contents of data sets; used to locate data sets of potential interest.
2. Inventory level - consists of a detailed list of granules (e.g., individual satellite passes, AUV dive, CTD cast) within a data set; used to find the data of interest.
3. Data level - consists of the actual data objects.

Marcia's considerations 4 & 5 above imply that MOOS data must *interoperate*. The ability to interoperate is determined by the metadata provided. At all levels there are two groups of metadata:

- Syntactic metadata – Information about the data types and structures at the computer level; often referred to as the data model. (*Use* metadata)
  - ✓ Data types: byte, float, integer, …
  - ✓ Data structures: list, sequence, array, …
- Semantic metadata – Information about the content of the data; what the variables mean, their ranges, (*Search* metadata)

A continuum of approaches was also presented. This continuum corresponds roughly to the spectrum presented in Figure 1. The costs associated with implementing homogeneous and heterogeneous systems are indicated below:

- Homogeneous system - all data in same format, using the same application (right side of Figure 1)
  - ➢ Most demanding on data providers and data users
  - ➢ After initial design and development, least demand on system designers
- Heterogeneous system - multiple data formats, multiple applications (left side of Figure 1)
  - ➢ Most demands on the system designers throughout its life-cycle
  - ➢ Least demanding of data providers and users

The Distributed Oceanographic Data System (DODS[8]) is interoperable at the syntactic level and partially interoperable at the semantic level. DODS can fulfill many of the needs of the MOOS data system. Diverse data sets can be installed on a DODS server and be accessed from data analysis tools such as Matlab[tm] and Ferret/Live Access Server. Partners are needed in the DODS cluster to improve semantic data interoperability. (MBARI's effort to provide the catalog service for MOOS data may contribute toward improving semantic data interoperability for DODS.)

Butler Hine from NASA Ames gave a lessons-learned presentation based on several years of experience with NASA's space missions. In the past NASA managed its data according to missions. All data logging was vehicle specific and was mission time-line stamped; there were different databases for engineering and science data. All raw data was kept. Now, with the Earth Observing System NASA is inverting the way data is managed. Instead of the vehicle being the focus, the object being observed (e.g. a planet) is the focus for organizing the data management.

The importance of visualization was also presented. Data visualization is important because it gives scientists ability to make decisions quickly and typically less than 10% of data collected is even looked at. Now

[7] http://dcz.dods.org/~chinman/dods/moospresentation1.html
[8] http://unidata.ucar.edu/packages/dods/

autonomous agents can mine the data for features of interest and display them with symbolic annotations. Such a system has been successfully used for data from the Infrared Astronomical Satellite (IRAS) [9].

Duane Edgington presented the goals for MBARI's Instrument Software Infrastructure project that aims to provide a plug and play adapter for instruments that will be used in MOOS. This infrastructure will provide data to the MOOS data management system. One technical challenge for MOOS is to define what we want MOOS instruments and platforms to report, and also how it is we are going get them to report.

Jim Bellingham introduced the MOOS program. MOOS Data Management is one of several projects whose goal is to build institutional observational assets. The use scenario discussions that follow will be used to extract the functional requirements for the data management system. Development of the MOOS system is both incremental and cumulative (demonstrated annually with field experiments); the data system should be implemented this way as well. Because MBARI scientists will be integrating data from other sources we must concede on the homogeneous approach and accept that the system will be heterogeneous.

Upper water column processes

Michael Matthews presented the use scenario for upper water column processes[10]. The MUSE expedition to be executed in August of 2000 will create a wide variety of data from approximately 20 different platforms. Discussion followed and here are some of the key points raised:

- The system we come up with should be interoperable with other institutions. It will be unrealistic to assume that all instruments will have an identical interface. What is important is to track the kind of instrument that is used, by MBARI or another institution, and be able to know, for example, if a suspected observed anomaly is the result of using a different sensor, or not.
- Given that MOOS data is heterogeneous and that we want a system that will scale to dozens of sensors, our approach in these discussions should be to identify the common essential needs for each science use.
- The web has changed the way we can get data and put things together – there is no requirement to have a "centralized" view of data archiving.
- Data sources will not be just from MOOS instruments. There will be remotely sensed information and output from numerical models. The MOOS data system need not make copies of these data, but it should be designed to interoperate with these kinds of data.

There was discussion on event detection and what that means. An instrument, such as a seismometer, can be programmed to do event detection, and the data system need not handle this. For event detection that requires integration of multiple data sources the requirement is to have data immediately (within the nominal MOOS event response time of 6 hours)[9] available in an easily accessible archive. Figure 2 shows how this archive might work. The "archive" is a distributed set of data stores that has some common interface allowing for multiple operations or processes to work on the data. These include event detection, quality control, and other processing or transformation of data products. The results of these processes go back into the distributed archive and are available for export.

[9] http://ic-www.arc.nasa.gov/ic/projects/bayes-group/autoclass/
[10] MOOS System Functional Requirements document

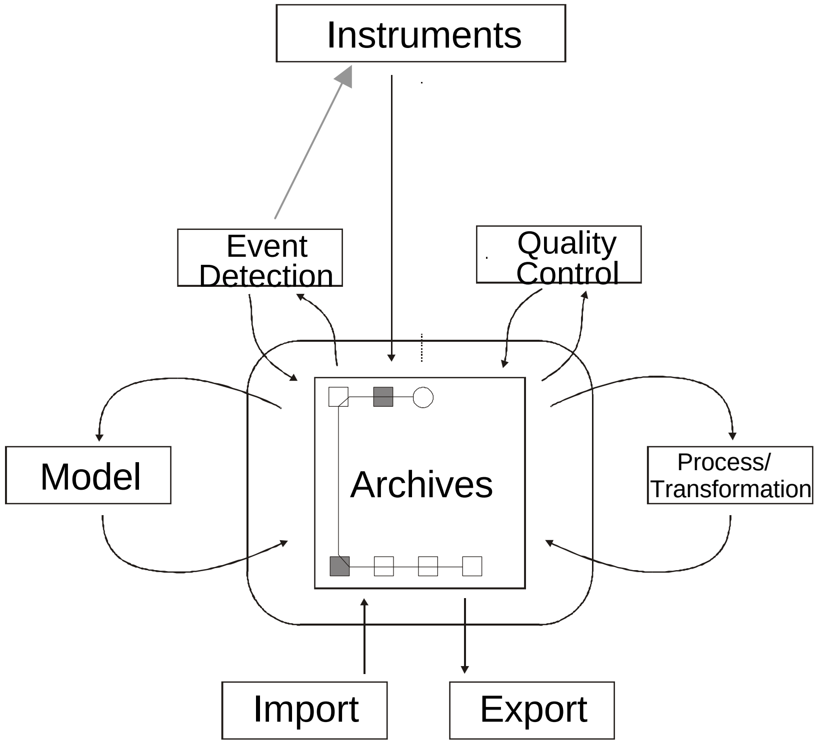


Figure 2. General diagram of distributed archives with interface for processes to operate on the data outside of the archive. The arrow back to the Instruments indicates commands that can be sent to alter sampling strategy, for instance. The nodes within the Archives box represent distributed data stores and the rounded box surrounding the Archives signifies a common interface for accessing and storing data.

Seismicity and ridge processes

Debra Stakes presented the seismicity and ridge processes science use scenario[9] and we discussed the data needs. Here are some of the issues:

- Seismometers from this scenario can generate up to 90 MB of data per day of deployment.
- Time synchronization among the instruments is important to locate events, millisecond accuracy equates with about 100m precision in location.
- Need daily messages (about 1 KB in size) indicating instrument health and whether major events took place.
- A data catalog is needed to indicate what data exist and methods of access.
- We can submit our data to the IRIS system[11], but this data bank holds only the largest earthquakes.
- Would need to correlate volcanic plume events (as measured by AUV transects) with seismic data.

Canyon processes

Charlie Paull presented the canyon processes use scenario[9] which aims to measure mass wasting and turbidity events with Monterey submarine canyon system. The needs for data are to have the ability to couple traditional geologic data (e.g. sediment core profiles), measured events (e.g. flow and turbidity anomalies), and terrain data. This implies a certain level of interoperability between these various data sources. This scenario has similar requirements for event detection as the seismicity and ridge processes scenario. Figure 3

[11] http://www.iris.washington.edu/IRISquery/

is a different view of Figure 2. It shows that we envision a single API (Application Programming Interface) for access to the archive and that event detection logic can be implemented within the instrument package and as a process operating from the archive.

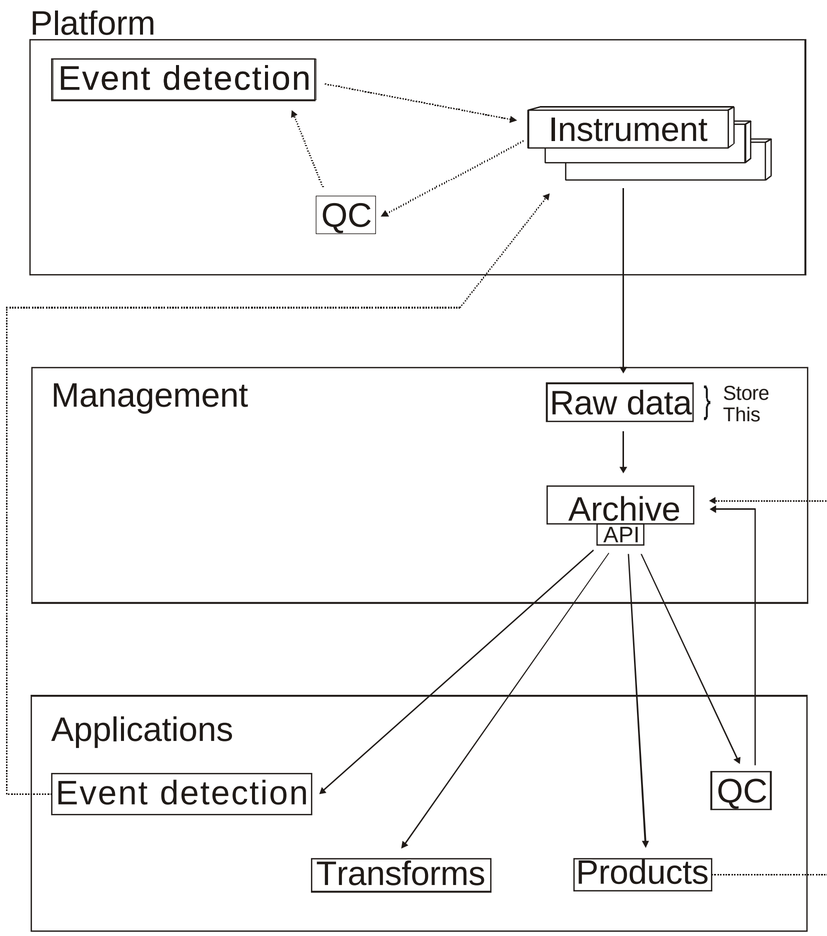


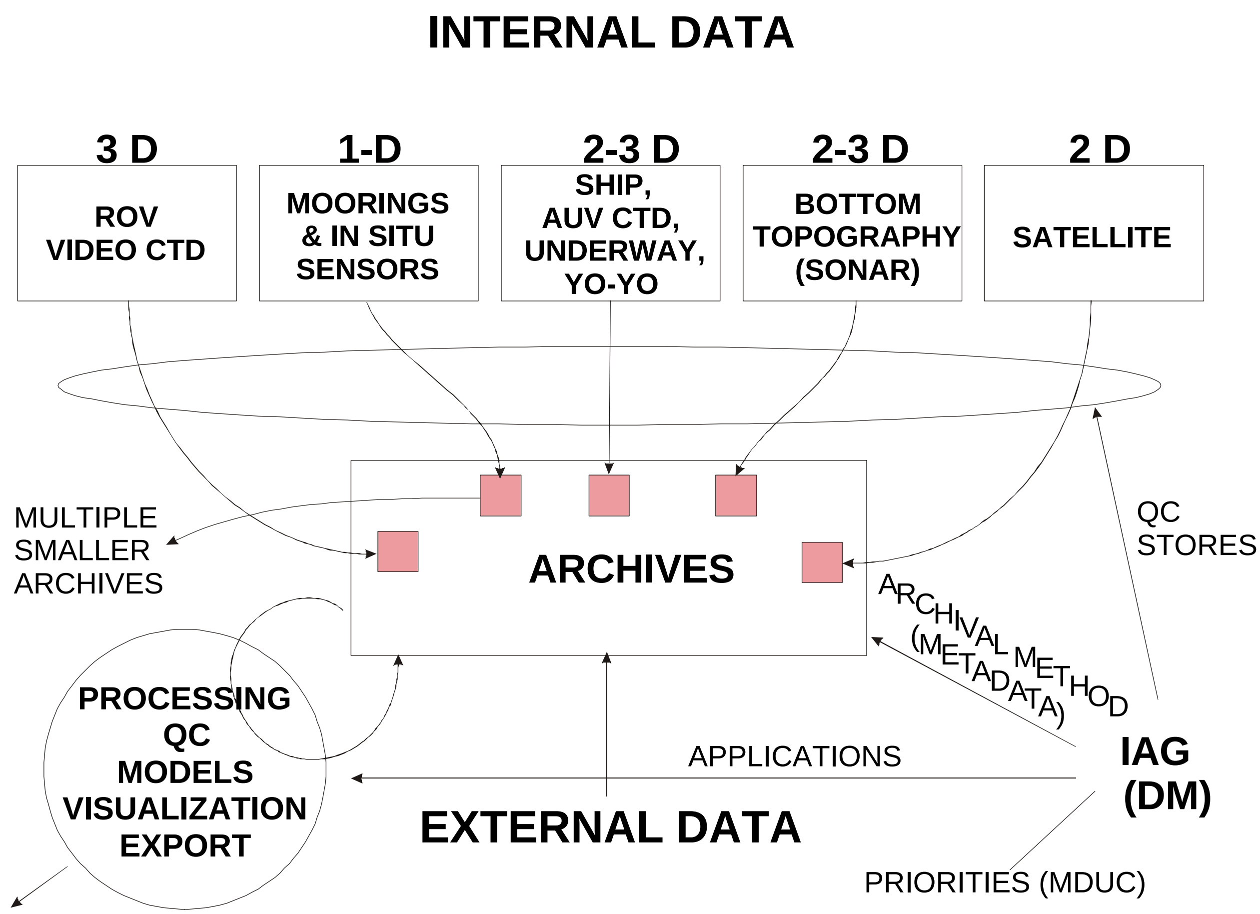
Figure 3. Expanded view of Figure 2 showing two kinds of event detection and a common Application Programming Interface for accessing the distributed archive.

Discussion

Butler Hine had some simple suggestions for data management:

- Digitize everything, log book entries, …everything.
- Timestamp everything

Francisco Chavez presented a diagram which encompasses several issues, including how does MBARI set up the process for data management, and policy (Figure 4). In response to Francisco's question Marcia commented on the existing roles and responsibilities within MBARI. The Data Users Committee is in place to decide data policy issues and whether the processing, quality control, and archiving of particular data streams are handled as institutional or specific science group tasks. The Information Application Group's (IAG) role is to facilitate access to data by implementing common interfaces. In addition, IAG will play an active role in implementation of database architecture, management and access.



- Figure 4. Diagram indicating the process of data management at MBARI. The Information Application Group (IAG) defines and implements archival and catalog procedures. Priorities for institutional data are set via the MBARI Data Users Committee (MDUC). External data, processing, visualization, export, and creation of smaller archives can proceed in groups outside of IAG.

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3. Day 2 - Essential needs

The participants for day 2 of the workshop assembled to fill in any holes from the first day's discussions, identify the *essential* needs of the MOOS data system, and summarize the recommendations.

We discussed levels of data for various data streams. For nearly any kind of data stream we can define levels of data. For example, for **swath bathymetry** there are raw files of individual pings and raw navigation data. These data can be defined as level 0 raw data. These are then edited to produce edited, level 1 files; these edited files are then processed to make level 2 processed files. From these files we can create higher level files such as gridded bathymetry that can be directly imported into visualization tools such as ArcView. This process is well defined and currently operates effectively to meet its specific goals. We should not attempt to duplicate existing effective systems, but add value by provide a consistent catalog to their data products. For these kind of data the MOOS data system would need to tell you which particular mapping data exist. In this case the MOOS data management system serves as a catalog to various levels of processed data products within an existing system. One strategy for designing the catalog service is to have the goal of making the researcher's life easier. Example information that would be needed in the catalog includes:

- What kind of data went into making the gridded data
- What kind of sonar was used
- What algorithms were used

- When and where the data were collected

There needs to be multiple ways to search the catalog. Data should be retrieved in common and easily used formats, e.g. geoTiff, ArcView ASCII grid files.

Seismic data processing is similar to swath bathymetry processing in that there is an established process and a separately funded project devoted to making the data usable. There is a similar need for a catalog service for seismic data and it should provide the following summary data:

- First arrival times for events
- Locations of the events
- Mechanisms of the events

These data will improve over time as more data is processed from various instruments and the models are improved. The reprocessing will be done by the seismic group which will maintain control of the data. The catalog service needs to "point" to these data so that when they are updated the catalog refers to the most up-to-date results. There needs to be multiple ways to search the catalog, such that it makes sense to the end user. A search from the catalog should offer data such that the locations of events can be visualized in ArcView and the seismograms loaded into Matlab, for example.

Needs for **Upper water column** data processing and management tend to be more heterogeneous. For specific data (e.g. a CTD cast, an ADCP deployment) the processing can be well established; however, upper water column science entails combining many of these different kinds of data in order to create a consistent picture of the oceanographic processes. Many specific data processing, analysis, and visualization tools exist for working with these kinds of data. Please see the appendix for a list of such tools currently in wide use by the oceanographic community (Appendix B).

At a base level, the MOOS Data Management system should provide data for import to these tools such that the end-user can organize and visualize data in a way that makes the most sense. A challenge for the Data Management system is to provide interoperability such that various data sets can be combined within a particular tool.

At a higher level there would be processes operating on the data to create more easily used products, for example a gridded dataset of sea surface temperature as recorded by a shipboard underway system. This higher level product would be made known to the MOOS Data catalog.

One way to categorize data is by its dimension:

- 1-Dimensional data (e.g. Temperature time series at a mooring)
- 2-Dimensional data (e.g. satellite imagery)
- 3-Dimensional data (e.g. AUV track, model output or observational data conditioned for model input)

<u>Data availability</u>

We briefly discussed availability of data. Should all data be made available to users outside of MBARI? One suggestion is that if data are placed in the catalog then they should be made available to all that need to use them. There are cases, however, when it makes sense to place an embargo on data for quality assurance or first publishing privileges, even if it is in the catalog. We need to investigate and identify such instances and be able to implement a system that will allow these levels of access control.

4. Recommendations

To summarize, here are the main recommendations from the workshop:

1) Save all raw data in its native format
2) Attempt to make all data available, even if it's at a crude level
3) Need to archive higher-order products (including processed data files) and register their existence in a catalog
4) Need to catalog these data sets. At minimum these catalogues must contain:

- What format the file is in
- Which sensor captured the data
- What software produced this data set
- Who to contact regarding this data set
- Original capture date/time "box"
- Latitude/Longitude(/Pressure) "box"
- General comments about the data/file

5) Need to query this catalog (both with human interface and programmatically)
6) Digitize all records including log books (this makes the catalog more useful)
7) Data archives and processing will be distributed amongst people and machines
8) Use World Wide Web to provide access

The above recommendations relate to a "core" MOOS data system architecture. Additional features are required in order to make the data usable, and they typically relate to creating higher-order data products:

1) Convert data from native formats to formats recognized by visualization packages
2) Identify individual sensors, units, etc. for visualization labeling and axes range limit settings
3) Read and identify individual sensors, units, etc. inside a variety of file formats
4) Combine/merge disparate data to common formats and time intervals

Issues regarding calibration, validation, and metadata capacity are implied but not specifically addressed by these recommendations. Details on these issues should be fleshed out in the analysis and design work that follows. Another concern is the scalability and affordability of the MOOS data system. Scalability in the number and variety of sensors is of greater concern than scalability in the quantity of a particular data type. To achieve scalability with automatic metadata capture and configuration control we depend on successful outcomes from the MOOS Instrument Software Infrastructure project. With ISI-compliant instruments and platforms we have hope of being able to affordably provide quality data products from dozens of sensors.

5. Appendix A: Workshop attendees

Those who attended the second day are indicated in the right-most column.

Name	*Affiliation*	*Email address*	*Second day*
Todd Anderson	IAG	todd@mbari.org	✓
Holly Baum	IAG	holly@mbari.org	✓
Jim Bellingham	Dev	jgb@mbari.org	
Kurt Buck	Sci - Benthic Bio	buck@mbari.org	
Dave Caress	Sci - Seismicity	caress@mbari.org	✓
Mark Chaffey	Dev	chma@mbari.org	
Francisco Chavez	Sci - Upper water	chfr@mbari.org	✓
Richard Chinman	UCAR	chinman@ucar.edu	✓
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Dan Davis	Dev	dada@mbari.org	✓
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6. Appendix B: Oceanographic data processing and visualization tools

Within the oceanographic community there are several tools, most of them freely available, for analyzing and visualizing oceanographic data. Recreating functionality provided by these tools is not in the best interest of the MOOS data management system. We have surveyed tools that have the best application for the needs of the MOOS system. The table below summarizes the attributes of each of them. This is no means an exhaustive list, yet a subset of these tools put in place at MBARI can satisfy many of the common needs that we've identified. In particular, DODS and Live Access Server can be installed and modified to provide application program, and end-user access to distributed heterogeneous data. These tools are also well suited for handling gridded model data as well as observational records. As we look ahead to collaborative efforts in data assimilation and ocean prediction we need to make sure the data system we adopt is capable of facilitating these sort of interactions.

On the innovative edge are tools such as VisAD which is a pure-Java library of advanced functions for data processing and visualization. As we identify needs for custom MOOS data management applications we need to first survey the "marketplace". This table is one such survey.

Name	**DODS (Distributed Oceanographic Data System)**	**NOAAServer (project in progress)**	**WebWinds**	**VisAD**	**Live Access Server**	**GIS/Geodatabase**	**Ocean Data View**	**Java OceanAtlas**
Description	Clients access data over internet from DODS servers	Clients access data over internet from NOAA servers	Desktop client, data visualization system	Java component library for interactive and collaborative visualization and analysis of numerical data.	Visualize gridded data from web	GIS	Software package for the exploration and visualization of oceanographic bottle, CTD, and XBT data	Java application for graphic exploration of oceanographic section data
Web Access	No browser display, must have local client	Browser display	Can run as a helper application	Applet	Yes	Through Internet Map Server (IMS)	No	No
Interface	Matlab GUI (can make your own)	Applet in Browser	Java Swing windows	Standalone Swing or Applet	Web browser	Desktop or browser	Desktop	Java desktop application
Interface Design	intuitive, easy to use		awkward, but flexible			Customizable	intuitive, easy to use	
Input File Formats	NetCDF JGOFS HDF FreeForm DSP (contains Matlab client and dataserver)	MetaData in FGDC	HDF, NetCDF, PDS, FITS, VICAR, raw binary, ascii text	netCDF, FITS, HDF-EOS, McIDAS, Vis5D, GIF and JPEG		Files - shapefiles, DXF, DLG, IGDS, TIGER, CGM, EPS, SDTS; Images - ERDAS, BIL, TIFF, TIN		"spreadsheet" (tab-delimited ascii text), JOA binaries, NODC-SD2, future: NODC-SD3, WOCE, NetCDF

Name	DODS (Distributed Oceanographic Data System)	NOAAServer (project in progress)	WebWinds	VisAD	Live Access Server	GIS/Geodatabase	Ocean Data View	Java OceanAtlas
Export Formats	Depends on client; Matlab - mat files, ascii		FITS, VICAR, NetCDF, raw	NetCDF, VisAD objects	GIF, Spreadsht, NetCDF, Ascii, ArcView gridded, VRML globe	EPS, Adobe Ilustrator; Images- TIFF, JPEG, BIL, BIP, ERDAS, Grid, VRML, TIN	graphics can be exported to GIF or postscript	"spreadsheet" (tab-delimited ascii text), JOA binaries
Platforms	binaries for Unix, src for self-bldg on others	Unix	Unix, Mac, Windows 95/98/NT	Unix, Mac, Windows 95/98/NT	Unix, NT w/ Xwindows	Unix, Windows	Windows 95/98/NT	Windows 95/98/NT, Unix, Linux
Object Oriented		Yes	Yes	Yes	No	new object data model in Arcinfo 8		Yes
Implementa-tion	C++ libraries	Java/CORBA	Java	Java	Perl, Ferret, XML	customization in VB, VBA, C++, Avenue	?, download binaries from website to install	Java
Data Model	Various defined by "Data Descriptors"			General math model, flexible				
Visualization Types	Matlab GUI: scatter, line, contour, image, pcolor, quiver	scatter, line, contour, maps	scatter, line, contour, maps	scatter, line, contour, maps, 3D	scatter, line, contour, maps	AML	scatter, line, section, maps	profiles, contours, station maps
Visualization Implementa-tion	Matlab, IDL, Ferret, ncview are "DODS-ready"	SGT	Java graphics	Java graphics	Ferret			
Printing support						Many plotters, laser printers supported. Publication quality prints.	"graphics can be printed on any printer"	
Architecture	Client/Server (one server per datafile type, eg NetCDF)	Web client and Server	Client/Server	Client/Server				
Availability and Support	downloadable, support via email	available, supported	only binaries avail. Downloaded over web	downloadable, support via email	downloadable, support via email		only binaries avail. Downloaded over web	only binaries avail. Downloaded over web
URL	http://www.unidata.ucar.edu/packages/dods/	http://www.joss.ucar.edu/NOAAServer/index.html	http://webwinds.jpl.nasa.gov/	http://www.ssec.wisc.edu/~billh/visad.html#intro	http://ferret.wrc.noaa.gov/Ferret/LAS/ferret_LAS.html	http://www.esri.com	http://www.awi-bremerhaven.de/GEO/ODV/index.html	http://www.oceanatlas.com/java_oceanatlas_home_page.htm

Name	DODS (Distributed Oceanographic Data System)	NOAAServer (project in progress)	WebWinds	VisAD	Live Access Server	GIS/Geodatabase	Ocean Data View	Java OceanAtlas
Additional Notes		must interact w/ NOAA personnel to particpate		has VisAD spreadsheet	example site generates profile, XZ & XY contours, creates GIF (can't manipulate), DODS connection	Highly customizable, same level as Matlab in this respect. High quality output Can use data to create new data through data fusion.	"draws orig. data pts or gridded fields based on the orig. data. Gridded fields can be color-shaded and/or contoured. Supports five different map projections data format allows dense storage and direct data access. Even extensive data collections containing thousands of stations can easily be maintained and explored on inexpensive desktop and notebook computers."	