Open Standards in the Integrated Ocean Observing System (IOOS)

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1. Introduction

The Integrated Ocean Observing System (IOOS) is a US interagency project led by the National Oceanic and Atmospheric Adminstration. The goal is to provide sustained observational data and model outputs regarding the open ocean, coastal waters, and Great Lakes in the formats, rates, and scales required by scientists, managers, businesses, governments, and the public to support research and to inform decision-making. Starting in 2008, IOOS began implementation of a Data Integration Framework (DIF) that addresses a subset of the complete scope of IOOS. The DIF is a limited-scope project to enable the evaluation of interoperability specifications, to demonstrate the feasibility and value of providing integrated ocean observations, and to provide the beginnings of initial operating capability for a nationwide IOOS data management capability. The initial scope of the DIF included three data assembly centers (DACs), four customers, and seven observed properties, but has since broadened as indicated below.

2. Data Access Services and Encoding Conventions

The Data Integration Framework project identified three general classes of scientific information to target first — *in situ* feature data, gridded coverage data, and images of data — and recommended a web service and encoding convention to be used in each case. These recommendations were intended to standardize a small number of data access methods and thereby to enable a single client application to obtain data from multiple providers, and to harmonize the representation of data from different providers. These services can be established either instead of or in addition to prior arrangements between individual providers and customers. The DIF services and encodings are summarized in Table 1 and described in more detail below. In the context of Figure 3, these data access services are all Pull services.

For *in situ* observations such as those from buoys, fixed sensors and volunteer observing ships, the DIF uses the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS) [1] serving data and metadata encoded in Extensible Markup Language (XML). The XML employs a Geography Markup Language (GML) [2, 3] application schema based on the OGC Observations and Measurements (O&M) specification [4]. We

implemented the SOS "core operations profile," which allows users to request data, observation metadata, or service metadata.

Table 1: Web services and data encodings used in the IOOS Data Integration Framework.

Data Type	Web Service	Encoding
Feature collections (*in-situ* point or profile data, time series, trajectories)	Sensor Observation Service	Geography Markup Language
Regular grids (model outputs, Level 3 satellite data, radar surface currents)	Data Access Protocol or Web Coverage Service	Network Common Data Format
Georeferenced images of data	Web Map Service	Common image formats

For serving gridded observations (including ocean color from satellites, surface currents from high-frequency radar, and model outputs), the DIF adopted both the Data Access Protocol (DAP) [5] and the OGC Web Coverage Service (WCS) [6]. Both protocols are suitable for accessing regular grids; DAP also supports irregular grids. WCS is explicitly called out in the GEOSS architecture and is supported by some commercial off-the-shelf (COTS) Geographic Information System (GIS) tools. DAP is well used in the NOAA scientific community and has been approved as recommended standard by the IOOS DMAC steering team. In practice, many data providers used a software package (THREDDS Data Server) that supports both DAP and WCS. The DIF recommends that gridded data be encoded in Network Common Data Form (NetCDF) [7] with Climate and Forecast (CF) conventions [8].

For images of data, the DIF recommends the Web Map Service (WMS) [9], which generates georeferenced visualizations (i.e., "maps") upon request to the user's specifications. WMS is an OGC specification and an international standard (ISO 19128) [10].

3. Data Provider Implementations

The primary DIF data assembly centers (DACs) are the National Data Buoy Center (NDBC) at NOAA's National Weather Service (NWS), the Center for Operational Oceanographic Products and Services (CO-OPS) in NOAA's National Ocean Service (NOS), and the CoastWatch program in NOAA's National Environmental Satellite Data and Information Service (NESDIS). In the context of Figure 3, NDBC, CO-OPS and CoastWatch are all considered real-time DACs: they provide access to current or recent observations.

The NOAA centers are all Federal (i.e., US government) DACs. We are beginning collaborations with other federal agencies including US Geological Survey, Environmental Protection Agency and US Army Corps of Engineers to standardize or interoperate with their data management practices.

NDBC assembles data from several buoy networks, including NWS meteorological platforms, the Deep-ocean Assessment and Report of Tsunamis (DART) warning buoys, the Tropical Atmosphere/Ocean (TAO) array for global climate studies, and a subset of observing platforms operated by the IOOS RAs. Real-time observations of 6 of the 7 core variables—ocean currents, temperature, salinity, water level, waves, and surface winds—from these buoys have been made accessible using Sensor Observation Service (SOS).

Also at NDBC, gridded surface currents computed from coastal high-frequency radar (HFR) observations of Doppler shifts have been made available using DAP/WCS. Images of the current vectors have been made available using WMS.

CO-OPS operates a variety of fixed stations as part of the National Water Level Observation Network (NWLON) and the Physical Oceanographic Real-Time System (PORTS). Real-time observations of 5 of the 7 core variables—ocean currents, temperature, salinity, water level, and surface winds—from these stations, as well as air temperature, barometric pressure, and water level predictions, have been made accessible via SOS.

At CoastWatch, gridded chlorophyll concentration derived from ocean color observations by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the *Aqua* satellite have been made available using DAP/WCS.

Though not part of the original DIF scope, the IOOS regional associations are now establishing SOS to serve *in situ* observations from buoys or fixed stations and DAP/WCS to provide model outputs.

4. Next Steps

We are now evaluating the results of the DIF projet and lessons learned, and will continue the successful aspects towards a broader IOOS data management capability. Plans include:

- bringing additional datasets and data providers online;
- establishing a Registry of data provider service instances and a Catalog of data holdings;
- establishing a web-based Viewer to provide easy discovery of and access to IOOS data;
- enhancing the metadata available about sensors and datasets in ISO 19115 and OGC SensorML [11];
- augmenting semantic interoperability by adopting controlled vocabularies and identifier conventions for such elements as dataset names, sensor identifiers, geospatial features of interest, and thematic keywords;
- establish additional service types such as format conversion and coordinate transformation;
- defining and reporting Capability Maturity Levels for data and service providers.
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6. References

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