# Building transparent data access for ocean observatories: Coordination of U.S. IOOS DMAC with NSF's OOI Cyberinfrastructure

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***Abstract*—The NOAA-led U.S. Integrated Ocean Observing System (IOOS) and the National Science Foundation's Ocean Observatories Initiative (OOI) have been collaborating since 2007 on advanced tools and technologies that ensure open access to ocean observations and models. Initial collaboration focused on serving ocean data via cloud computing – a key component of the OOI cyberinfrastructure (CI) architecture. As the OOI transitioned from planning to execution in the Fall of 2009, an OOI/IOOS team developed a customer-based "use case" to align more closely with the emerging objectives of OOI-CI team's first software release scheduled for Summer 2011 and provide a quantitative capacity for stress-testing these tools and protocols. A requirements process was initiated with coastal modelers, focusing on improved workflows to deliver ocean observation data. Accomplishments to date include the documentation and assessment of scientific workflows for two "early adopter" modeling teams from IOOS Regional partners (Rutgers – the State University of New Jersey and University of Hawaii's School of Ocean and Earth Science and Technology) to enable full understanding of data sources and needs; generation of all-inclusive lists of the data sets required and those obtainable through IOOS; a more complete understanding of areas where IOOS can expand data access capabilities to better serve the needs of the modeling community; and development of "data set agents" (software) to facilitate data acquisition from numerous data providers and conversions of the data format to the OOI-CI canonical form.**

***Keywords - data access; ocean observatories, U.S. IOOS, OOI; cyberinfrastructure; coastal modelers, DMAC***

## I. Introduction

### *A. Ocean Observatory Initiative*

The National Science Foundation's Ocean Observatory Initiative (OOI) [1] is working to advance the ocean sciences by developing the infrastructure for sustained ocean observations at key coastal and open ocean locations by providing a new research and education infrastructure to accelerate understanding of the ocean and seafloor and their roles in the earth system. Two coastal arrays, four global arrays in the deep ocean, a cabled observatory over the Juan de Fuca tectonic plate, and a sophisticated cyberinfrastructure comprise the effort.

The OOI is in the second year of a planned five-year design and build process that will end in 2015 with the initial deployment of all elements and 25 years of operations will follow. Innovative ocean observing technologies will be deployed at key locations across the world's oceans. A Regional Scale Nodes deployment will include a cabled seafloor and water column component on the Juan de Fuca Plate off the northwest coast of the United States, providing high power to seafloor and water column instrumentation and high bandwidth for all the associated data. A Coastal and Global Scale Nodes deployment will include two coastal arrays and four open ocean global arrays. The four global arrays will be located in the Gulf of Alaska, the Irminger Sea off southern Chile and in the Argentine Basin. The two coastal deployments will include the Endurance Array off the coast of Oregon and Washington of the United States and the Pioneer Array which will initially be deployed in the mid-Atlantic bight off the east coast of the United States but will be relocated approximately every five years as directed by the ocean science community [1].

Each location will support a broad range of sensors to measure ocean and seafloor processes and properties. Data will be transported via an innovative and sophisticated cyberinfrastructure (CI) to provide two-way connectivity to the observatories and freely serve the data in near-real time. The OOI's open data policy will enable access to data and associated products to scientists, policy makers, educators and the general public.

*B. U.S. Integrated Ocean Observing System*

The United States Integrated Ocean Observing System (U.S. IOOS) [2,3,4] represents a national consortium of governmental and nongovernmental stakeholders with specific interest in marine environmental phenomena occurring in the open ocean, U.S. coastal waters, and the Great Lakes. The core mission of U.S. IOOS is the systematic provision of ready access to this marine environmental data and both observed and model data products in an interoperable, reliable, timely, and user-specified manner to end users/customers in order to serve seven critical and expanding societal needs:

- Improve predictions of climate change and weather, and their effects on coastal communities and the nation;
- Improve the safety and efficiency of maritime operations;
- More effectively mitigate the effects of natural hazards;
- Improve national and homeland security;
- Reduce public health risks;
- More effectively protect and restore healthy coastal ecosystems; and
- Enable the sustained use of ocean and coastal resources.

U.S. IOOS is implemented by a dynamic partnership of federal agencies, strategically located regional associations, and private sector partners working together to effectively deliver and use ocean data and models [5]. It consists of six subsystems: three functional (observing, data management and communications, modeling and analysis) and three cross-cutting (governance and management, research and development, training and education) [5].

In this paper we report findings on the current technical collaboration between the OOI-CI and U.S. IOOS DMAC teams that are exploring common functional requirements to seamlessly enable access to and use of ocean observations data. Section II provides background on the programmatic origins and intersections of the OOI and U.S. IOOS programs. Section III briefly provides a technical introduction to the OOI's CI and IOOS DMAC and describes the initial collaboration. Section IV describes the status of the current collaboration with a detailed description of the features and capabilities of work completed to date. Finally, Section V presents the anticipated next steps.

## II. IOOS AND OOI: DISTINCT BUT SYNERGISTIC

Both the U.S. IOOS and OOI initiatives [6] arose from the recognition that the oceans are fundamentally under-sampled and many processes remain poorly understood, sometimes at the peril of the economy and well being of the nation. As

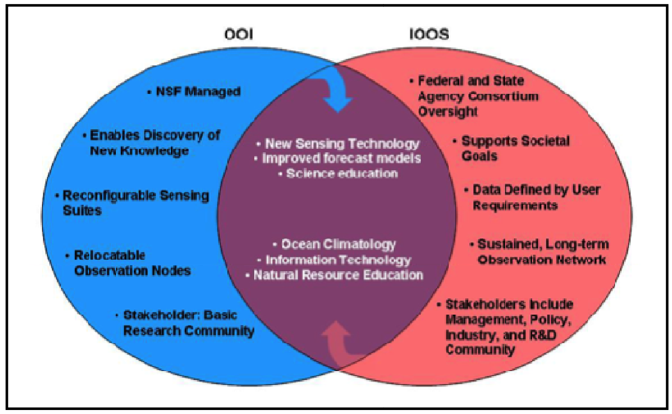


Figure 1. Dinstinctions and synergies between OOI and IOOS.

Figure 1 shows, they are complementary efforts to enhance our access to and understanding of the ocean and oceanographic processes. U.S. IOOS will provide comprehensive, sustained and dependable observations in real time on a broad geographic basis, similar to the observations supporting the forecasts of the National Weather Service, to support information needs and forecasts for resource management, maritime transportation, and a host of other ocean and coastal activities. OOI will provide infrastructure to enable hypothesis-driven basic oceanographic and geophysical research by fostering specialized observations, instruments and activities for the purpose of answering basic research questions, with data available in as close to real-time as practicable.

Figure 2 explores these distinctions in more detail. Whereas U.S. IOOS will depend on established technologies capable of long-term, untended deployments in specific locations, OOI scientists will develop and use the latest technologies and sensors to push the envelope of knowledge and engineering into new oceanographic and computational realms. Just as OOI researchers will benefit from the data and access to the ocean that IOOS' unprecedented spatial and temporal coverage provides, so will IOOS benefit as the techniques,

| | IOOS | OOI |
|---|---|---|
| Data | Driven by societal goals and used to **routinely and continuously deliver data and data products** of known quality **in real time** to decision makers | Governed by the needs of the research community, with **experimental data delivery in near-real-time** ultimately leading to improved predictability of ocean processes in areas of societal need |
| Sensors | Will depend on **highly reliable sensors** and data telemetry to ensure that critical data streams are not interrupted, as well as on operational models for making predictions with known levels of certainty | Will provide the motivation and capability to try out **new, experimental sensors** and to develop new observing strategies that may eventually be adopted by the IOOS system once their reliability for routine operation is established |
| Design | **Primarily stationary operational system**, designed to provide reliable operational data streams | **Highly adaptive**, allowing scientists to respond to ocean event and control and adopt observatory assets and data streams to address new events |

Figure 2. Critical distinctions between IOOS and OOI for data, sensors, and design.

sensors and knowledge gained through OOI-enabled activities migrate from research to societal or civil applications.

## III. First Steps – Focusing on Data Delivery

The functional intersections between the Data Management and Communications (DMAC) subsystem of U.S. IOOS and the emerging cyberinfrastructure component of OOI provided a dynamic opportunity to exercise and establish core aspects of data management and networking interoperability between U.S. IOOS and OOI.

### *A. The U.S. IOOS DMAC Subsystem*

DMAC [3,7,8], when fully realized, will comprise the information technology (IT) infrastructure that enables the interoperable transmission of marine environment data from a data provider to a data/services customer. It will provide end users with access to DMAC-compliant observational and model data products via a suite of components including standards, protocols, facilities, software and supporting hardware systems [5]. As such, DMAC is an evolving framework for integration of large and small independent and heterogeneous data management and communication systems that can operate based on a core set of standards and protocols for data exchange, access and use. The thousands of individual organizations that comprise U.S. IOOS will manage their data in the manner they deem most appropriate to their individual missions, but through DMAC they can magnify the impact of their data, serve a larger community and contribute to long-term reference systems and archives that will benefit generations to come. The U.S. IOOS Program continues to leverage limited resources and existing capabilities developing, deploying, and supporting DMAC capabilities to incrementally deliver a functional enterprise [2,3,5,7,8,9].

### *B. The OOI's Cyberinfrastructure*

The OOI's cyberinfrastructure (CI) [1,7,10,11]] component binds together what will be a globally distributed multi-scale network of observing assets, linking the infrastructure elements, sensors, and models into a coherent system-of-systems. A core CI feature, near-real-time two-way communication between users and deployed ocean systems, is anticipated to transform ocean science from ship-based expeditionary science to a distributed, observatory-based discipline in which investigators can continuously interact with instruments to remotely explore the earth-ocean-atmosphere system. The OOI-CI also will provide a highly distributed set of capabilities that facilitate:

- End-to-end data preservation and access,
- End-to-end, human-to-machine and machine-to machine control of how data are collected and analyzed,
- Direct, closed-loop interaction of models with the data acquisition process,
- Virtual collaborations created on demand to drive data-model coupling and share ocean observatory resources (e.g., instruments, networks, computing, storage and workflows),
- End-to-end preservation of the ocean observatory processes and their products, and
- Automation of the planning and prosecution of observing programs.

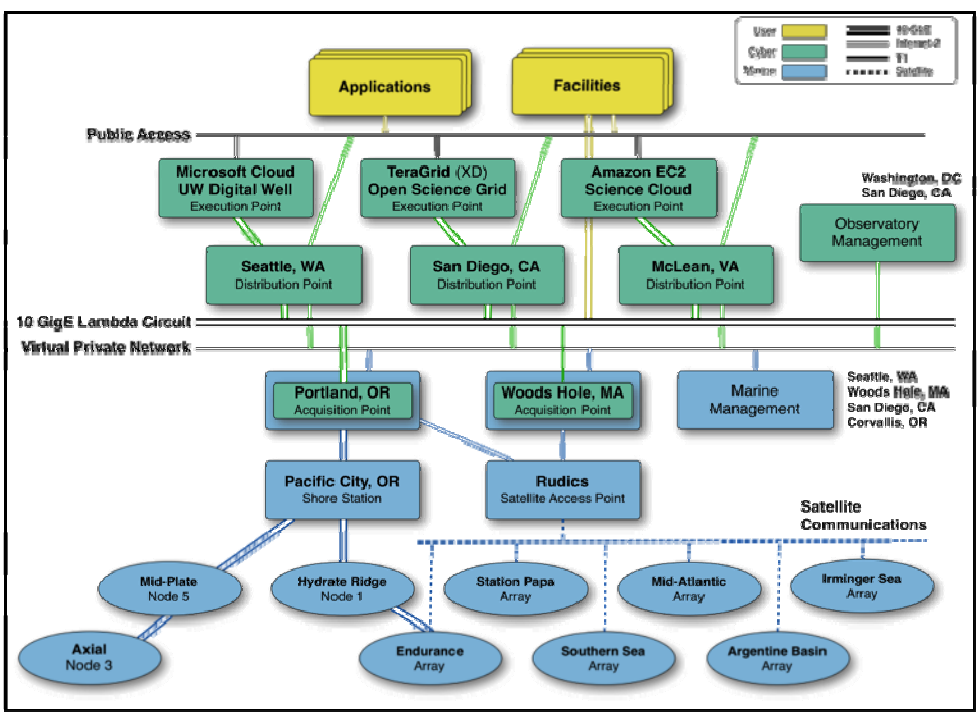


Figure 3. OOI-CI Network Deployment

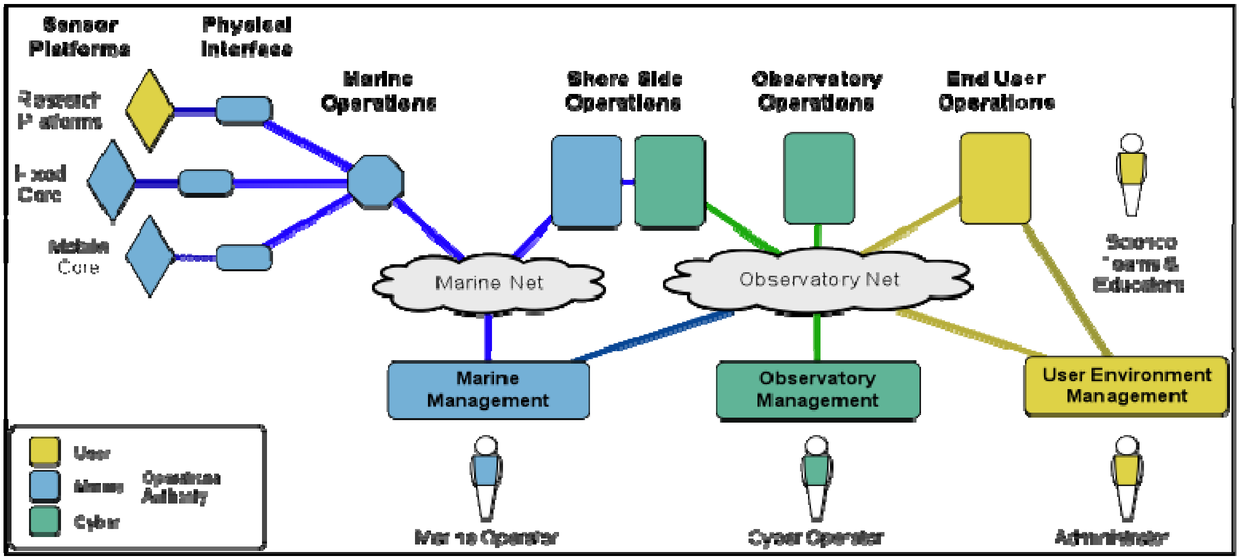


Figure 4. Integrated observatory topology.

The OOI-CI integration strategy is based on two core principles: messaging and service-orientation. All functional capabilities and resources represent themselves as services to the observatory network, with precisely defined service access protocols based on message exchange. The functional capabilities of the CI are provided by assembling and integrating proven technologies and tools using the integration infrastructure. The CI will virtualize computation and storage in order to realize flexible deployment of capability across the OOI network (Figure 3).

Via a repository of deployable features or units, functionality and computational power can be provisioned as needed (elastic computing). This approach reaches its full capacity with cloud computing, where virtualized compute and storage resources are provided over the Internet. Bundling of software components to a target environment (e.g. Amazon's EC2 cloud) can provide for automated provisioning according to policy defined by the OOI-CI operators. Figure 4 depicts the high-level architecture for the anticipated integrated observatory topology.

## IV. Serving IOOS Data using ERDDAP on the Cloud (2007-2009)

Since 2007, the OOI and IOOS programs have partnered on a series of joint activities based on their closely aligned objectives for improving access to and use of ocean observations [12]. Collaboration began in 2007 with a U.S. IOOS grant to the University of California at San Diego's OOI-CI team to explore transparency of data access across different ocean observatories. This project, which anticipated significant intersections between the emerging IOOS DMAC and OOI's planned cyberinfrastructure, preceded Congressional funding for OOI execution. This initial collaboration experimented with serving ocean data via cloud computing—dynamically scalable collection of resources, most often computation and storage, provided as a service over the internet and a key tenet of the OOI-CI.

The first prototype to integrate a targeted set of technologies (OPeNDAP, ERDDAP, THREDDS, GridFields, Amazon Web Services) was developed in 2009. Figure 5 depicts the deployment scenario for this integration, described in more detail in Alexander et al 2009 [12]. Additional activity on this approach was cut short by the arrival of OOI execution funds in the fall of 2009, a risk anticipated in the original project plan.

## V. Improving the Way that IOOS Coastal Forecast Modelers Receive Data (2009 – Present)

### *A. Planning approach and documenting requirements*

In the Fall of 2009 IOOS/DMAC and OOI-CI teams agreed to jointly develop a new collaboration plan as a customer "use case" to inform and stress-test OOI-CI's first software release scheduled for Summer 2011. A requirements and planning process was initiated with U.S. IOOS coastal modelers at Rutgers, the State University of New Jersey, and University of Hawaii's School of Ocean and Earth Science and Technology.

The motivating factor was that most coastal forecast modelers currently use a combination of homegrown scripts and cron jobs to gather the wide variety of data needed to force, provide boundary conditions, assimilate and verify their model runs. Satellite data, HF Radar data, glider data, tagged marine mammal data, drifter data, profile data, time series data, and other weather and ocean model data from numerous providers are used. The OOI infrastructure was proposed as a way to make the process more standardized and robust.

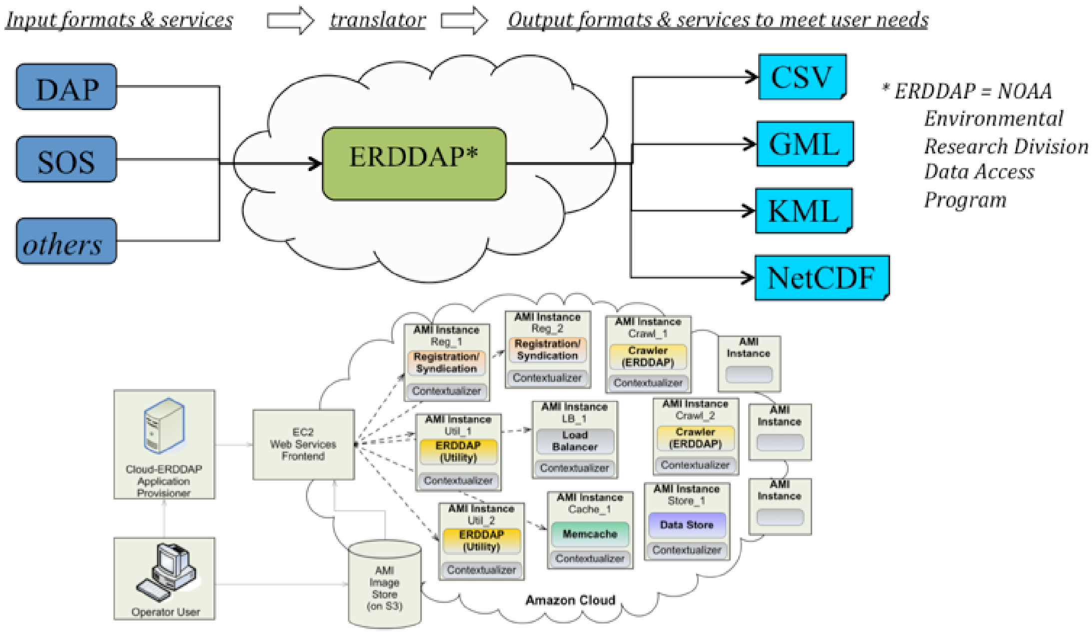


Figure 5. ERDDAP cloud prototype deployment scenario [12].

The project team sought to enable full understanding of users data sources and needs, and define improved workflows to deliver ocean observations data. Other emerging project objectives included:

- establishing a standardized, reliable and efficient system for research and operational modelers to access the data they need freeing them to do actual research;
- enhancing existing methods used to manipulate and disseminate the data to the scientific community;
- providing format conversions so research modelers can more readily use the data; and
- allowing sophisticated consumers of ocean observation data to test OOI-CI's capabilities, providing feedback to developers about the features and robustness of the system.

Planning was completed in February 2010 via a series of intensive bi-weekly meetings from October 2009 to January 2010, facilitated by a senior scientist from NOAA's National Weather Service on detail to U.S. IOOS for this purpose. Execution began in May 2010 [11] with arrival of a dedicated senior IT specialist on the OOI-CI team, and is ongoing. The OOI-CI and IOOS-DMAC teams have conducted bi-weekly conference calls and have had several face-to-face meetings with project customers at Rutgers and UH. Accomplishments include:

- Assessment of scientific workflows for 2 "early adopter" modeling groups (Rutgers, Hawai'i) to enable full understanding of their data sources and needs;
- Generation of all-inclusive lists of the datasets required for early adopter modeling groups;
- Determination of modeler-required datasets that could currently be obtained via IOOS;
- More complete understanding of areas where IOOS can expand capabilities to better serve the needs of the modeling community;
- Development of software "dataset agents" that facilitate acquisition of data from varied data providers, and convert the data to the OOI-CI canonical form; and
- Development of IO Service Provider for NetCDF Java that facilitates the retrieval of data from OOI-CI and can be leveraged behind existing scientific toolsets such as Matlab.

This process of improving access to priority observations includes resolving data access and communication protocols, data and metadata representation and vocabularies, and requisite metadata documentation, and eventually descriptions of data quality as well.

*B. Integrating the use case with OOI-CI's Data Distribution Network*

The coastal modeler use case was conducted in close coordination with the planning and development of the CI's Integrated Observatory Network (ION). The close coordination ensured that anticipated features complemented and informed Release 1 (R1) of the ION, a software release which established the foundation for ION's Data Distribution Network (DDN). Although Release 1 is not intended for public use, it targets test users from the IOOS 'early adopters', and the OOI team's science community.

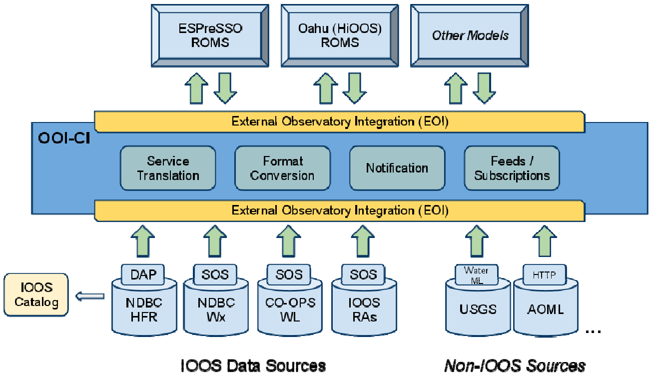


Figure 6. IOOS as external observatory feeding data to a model customer iva OOI.

Capabilities of the DDN that will be visible to those users are publishing data to ION, finding and browsing data resources, initiating data notifications and subscriptions, creating user accounts, and receiving notifications of "events" such as changes in the ambient ocean conditions without delay. Behind the scenes, the system will be capable of data distribution via a publish/subscribe model, scalability to gracefully manage an expanding workload, fault tolerance to ensure continuous operation if one component fails, and security to protect information from misuse, theft or corruption.

From a technical perspective, the ION will include the capacity to "ingest" data products from external data sources, and experimentally from sensors, for storage in canonical and raw forms. Data sources will be characterized with their metadata attributes (describing content, provenance, and format/structure) and distributed via streaming and DAP servers to consumers such as data analysts and numerical modelers. The system will also provide a platform for instrument integration development (control and sensor data acquisition), and provide a distributed service integration and execution platform in more than one programming language.

Numerous and detailed use cases have been developed and prototyped to ensure the complete range of system requirements are successfully accommodated. For example, when a "user" identifies data of interest from an existing or historic data stream, they will "register" through an API or web form with a subscription service and specify delivery modality (format, frequency, address, etc.). The user's registration is verified and data distribution to the user/consumer is routed. Data will be distributed across the DDN without any form of persistence; subscribers are solely responsible for maintaining the information they need. Producers of data have the ability to restrict data access to particular groups of users.

### *C. The External Observatory Interface module – facilitating data integration*

To implement the anticipated functionality to support the agreed-upon use case, the project team first framed an External Observatory Integration module that would become a component of the R1 DDN. The EOI is the means by which measurements external to OOI, for example from IOOS sources such as NDBC SOS, can be distributed to users in community-specific formats via OOI-CI tools and technologies.

A key feature of ION are "agents" that can act to provide particular services. Within the context of EOI, dataset agents are software modules developed to facilitate ingestion of external data sources into ION (conceptually depicted by

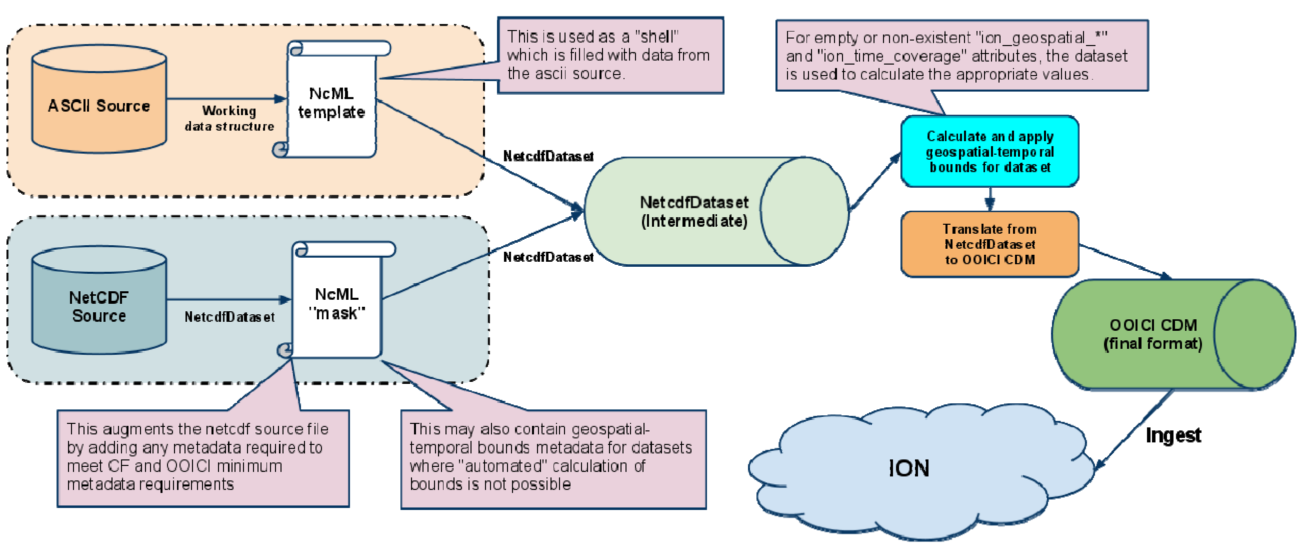


Figure 7. Overview of EOI data acquisition pathway.

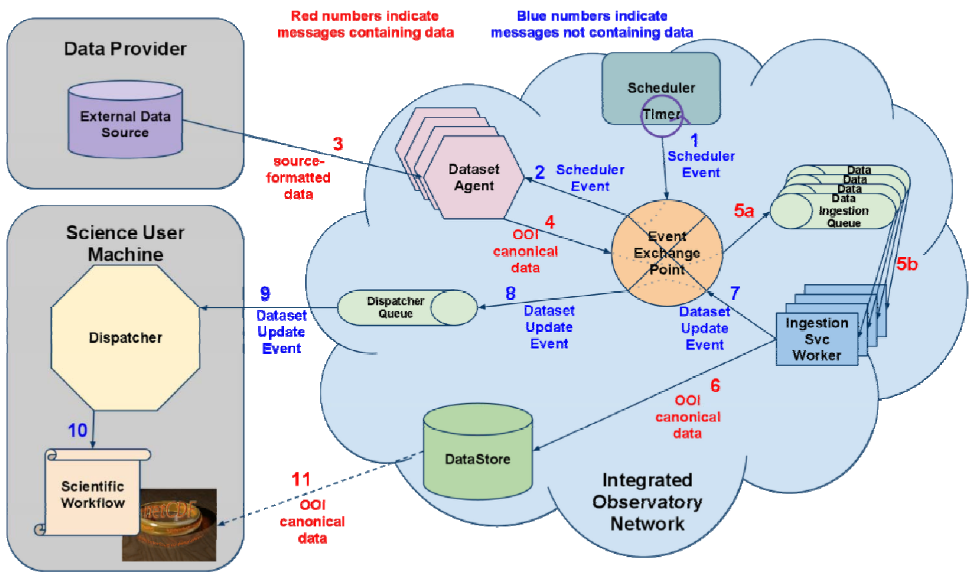


Figure 8. Overview of the flow of data through the OOI-CI Integrated Observatory Network.

Figure 6). Each particular implementation of a dataset agent interfaces with a particular data source, acquiring data from the source, and translating the data, and any related metadata, into the Common Science Data format adopted by OOI (notionally described by Figure 7). This format is at a preliminary stage in Release 1 and will be considerably enhanced for Release 2 and beyond.

New data for a given dataset is acquired as it becomes available from the source and ION provides the capability to stream these data "supplements", as well as any metadata update notifications, to subscribers of the dataset such as the numerical model workflows at Rutgers and the University of Hawai'i. These processes provide end-to-end functionality for the EOI clients - the modelers and other users targeted in Release 1. Figure 8 provides an overview of the flow of data through the OOI-CI ION system, from acquisition via EOI dataset agents to subscription-driven distribution to the client.

Figure 9 depicts how new OOI-CI data access and delivery services and protocols provide substantial efficiencies in bringing data to Rutgers ocean modelers through a much simpler and more efficient pathway. Technology and data achievements to date include: functional NetCDF DAP translation in both JAVA & Python, OOI Common Data Model capable of representing NetCDF data structures, modification of NetCDF-Java (NJ) libraries so that NJ-based clients can consume OOI datastreams as easily as reading local files (this was demonstrated using NCTOOLBOX (http://code.google.com/p/nctoolbox/), an NJ-based toolbox for Matlab - figure 10 shows access of an HFRADAR dataset from OOI-CI via the NCTOOLBOX), integration with scalable infrastructure, establishment of strong (basic) CF metadata compliance, and access provided

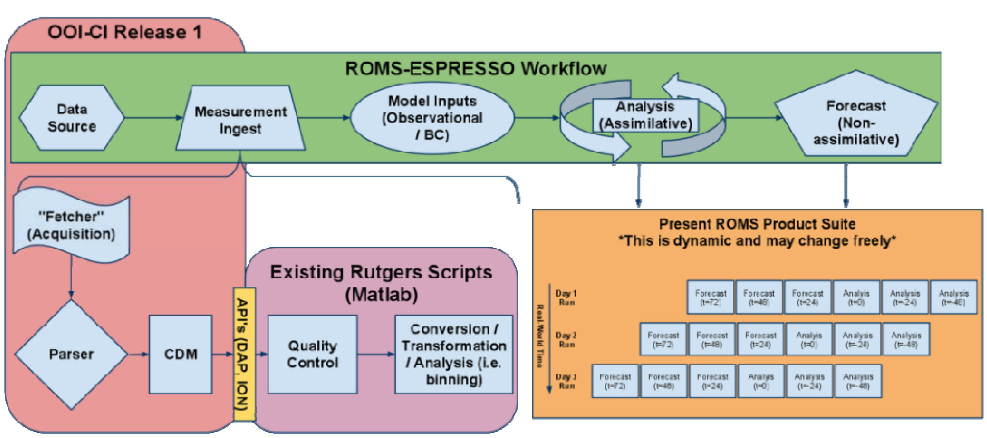


Figure 9. Initial data integration design development for Rutgers modeling team. OOI-CI provides the data acquisition, parsing and translation of data sources required by ROMS ESPRESSO workflow and provides them via a common API.

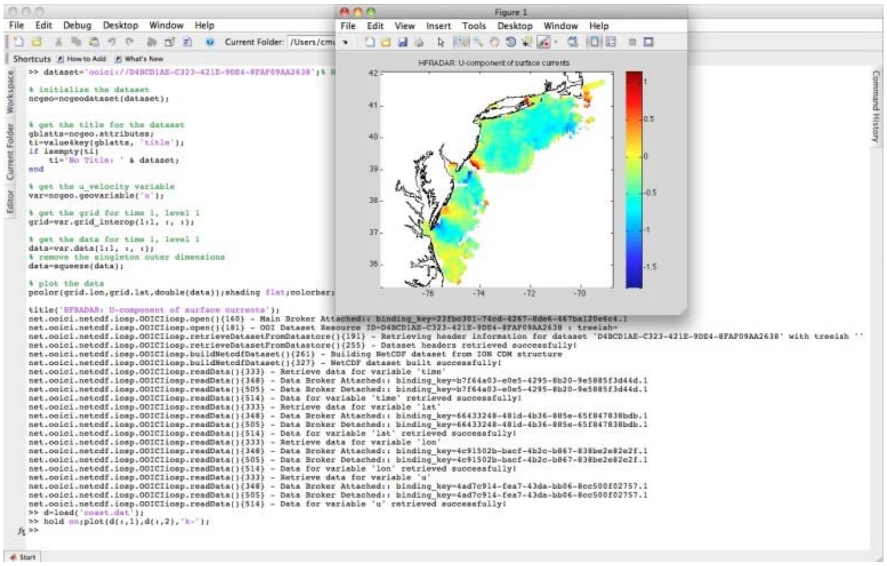


Figure 10. Retrieval of data from OOI ION via the NCTOOLBOX for Matlab.

to a significant set of data products (well over half of the 60-plus desired products). This initial Release 1 deliverable is on schedule to be completed in August 2011. The project plan also provides for development of additional, jointly developed, "use cases" of increasing breadth (i.e. core functions, broader user base, systems design/architecture) in coordination with subsequent OOI-CI software releases over the next four years.

## VI. NEXT STEPS: ANTICIPATED EXPANSION - RELEASE 2

The OOI-CI/IOOS DMAC team is in the process of testing and evaluating the functionality of the EOI module, particularly with respect to performance with the Data Distribution Network of ION's Release 1. This process will include a team of U.S. IOOS beta-testers to assist with the assessment process. The results will strongly inform the developers of the Release 1 OOI-CI components, and will also provide IOOS DMAC team members with early visibility into design and implementation strategies for this extended cyberinfrastructure effort.

As scheduled (Figure 11), the OOI-CI team has also initiated the inception phase for Release 2, the Managed Instrument Network. (Each release runs 16 to 18 months, with releases overlapping by several months by design.) The primary user theme for Release 2 is end-to-end control of data collection and advanced control of managed instruments and sensors to support OOI Marine Observatory instrument providers and operators. A secondary theme is expanded data manipulation, analysis, and visualization tools for observational data consumers. Advanced features to be prototyped in this phase will include ION interfaces for handheld devices such as smart phones and tablets. The infrastructure for Release 2 will include refinement of core services for governance, policy, and federation/organization capabilities.

Roles for two 'external observatory' customer use cases are also anticipated in Release 2, a second phase of collaboration with U.S. IOOS, and the initial collaboration with NEPTUNE Canada (North-East Pacific Time-series Undersea Networked Experiments) (Figure 12). NEPTUNE is the world's first regional-scale underwater ocean observatory that plugs directly into the Internet [13]. It has been operational since December 2009 and already contains many instruments, data stores, and science applications of great value

Anticipated IOOS activity with U.S. IOOS for Release 2 includes maintaining integration and support for ocean modeling groups, assisting ION integration into models via on-demand and data-driven processes, ingestion of model outputs to ION, and establishing a library supporting ION integration into external applications (e.g. Matlab).

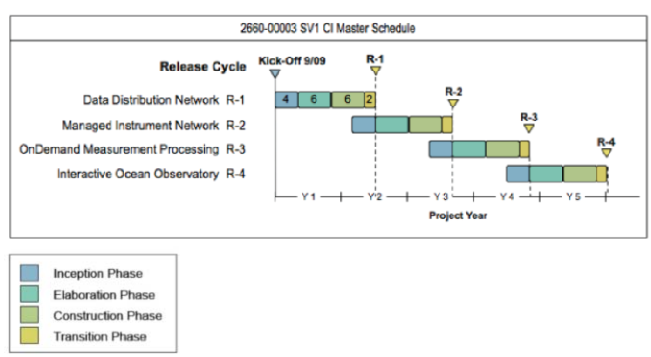


Figure 11. OOI-CI release schedule.

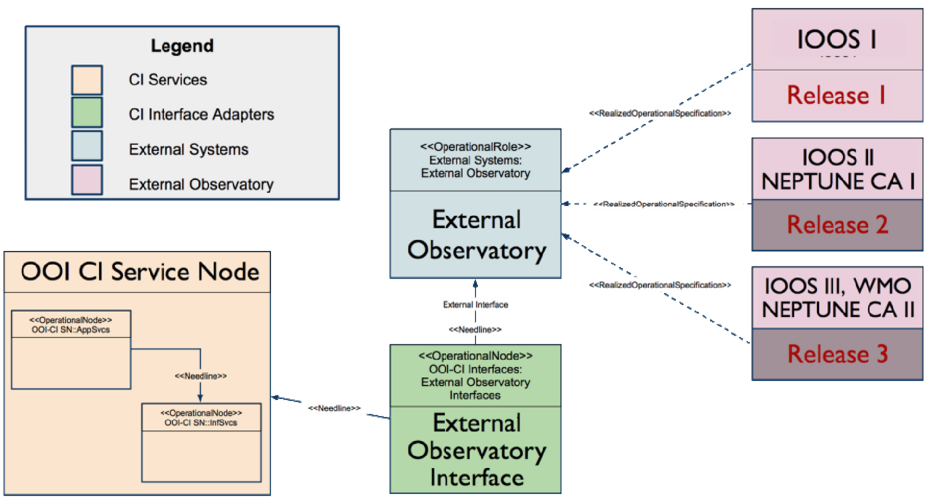


Figure 12. OOI-CI architectural realization through Release 3.

Exploring expanded collaboration strategies through publication of a white paper or possibly a “concept of operations” is also anticipated. The Release 2 collaboration with NEPTUNE is expected to include potential 2-way service exchange opportunities, implementing an initial integration in ION for a subset of NEPTUNE data, and creating a collaborative approach for ontology development and sharing.

Beyond Release 2 there are further collaboration activities planned between OOI and IOOS (and OOI and NEPTUNE Canada), and the teams will explore opportunities for maximizing the exchange of data, software, and resources.

## VII. ACKNOWLEDGEMENT

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