Project No. 249024

NETMAR

Open service network for marine environmental data

Instrument: *Please tick*	CA	✓ **STREP**	IP	NOE

ICT - Information and Communication Technologies Theme

D2.1 Review of projects, initiatives & technologies addressing system architectures for distributed Environmental Information Systems (EIS)

Reference: D2.1_Review_of_projects_initiatives_and_technologies_r1_20100618

Due date of deliverable (as in Annex 1): M0 + 3
Actual submission date: 18 June 2010

Start date of project: 1 February 2010 Duration: 3 years

Coastal and Marine Resources Centre (CMRC), University College Cork, National University of Ireland

Revision 1

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

European Commission
Information Society and Media

NETMAR

Open service network for marine environmental data
Project Reference: 249024
Contract Type: Collaborative Project
Start/End Date: 01/03/2010 - 31/01/2013
Duration: 36 months

Coordinator: Prof. Stein Sandven
Nansen Environmental and Remote Sensing Center
Thormøhlensgate 47, Bergen, Norway
Tel.: +47-55205800
Fax. +47 55 20 58 01
E-mail: stein.sandven@nersc.no

Acknowledgements

The work described in this report has been partially funded by the European Commission under the Seventh Framework Programme, Theme ICT 2009.6.4 ICT for environmental services and climate change adaptation.

Consortium

The NETMAR Consortium is comprised of:

- Nansen Environmental and Remote Sensing Center (NERSC), Norway (coordinator).
  Project Coordinator: Prof. Stein Sandven (stein.sandven@nersc.no)
  Deputy Coordinator: Dr. Torill Hamre (torill.hamre@nersc.no)
  Quality Control Manager: Mr. Lasse H. Pettersson (lasse.pettersson@nersc.no)
- British Oceanographic Data Centre (BODC), National Environment Research Council, United Kingdom
  Contact: Dr. Roy Lowry (rkl@bodc.ac.uk)
- Centre de documentation de recherche et d'expérimentations sur les pollutions accidentelles des eaux (Cedre), France.
  Contact: Mr. François Parthiot (Francois.Parthiot@cedre.fr)
- Coastal and Marine Resources Centre (CMRC), University College Cork, National University of Ireland, Cork, Ireland.
  Contact: Mr. Declan Dunne (d.dunne@ucc.ie)
- Plymouth Marine Laboratory (PML), United Kingdom.
  Contact: Mr. Steve Groom (sbg@pml.ac.uk)
- Institut français de recherche pour l'exploitation de la mer (Ifremer), France.
  Contact: Mr. Mickael Treguer (mickael.treguer@ifremer.fr)
- Norwegian Meteorological Institute (METNO), Norway.
  Contact: Mr. Jan Ivar Pladsen (janip@met.no)

Author(s)

- Declan Dunne, CMRC, d.dunne@ucc.ie
- Ali Al-Othman, CMRC, a.alothman@ucc.ie
- Trung Pham, CMRC, t.pham@ucc.ie
- Yassine Lassoued, CMRC, y.lassoued@ucc.ie
- Anthony Patterson, CMRC, a.patterson@ucc.ie
- Torill Hamre, NERSC, torill.hamre@nersc.no
- Peter Walker, PML, petwa@pml.ac.uk
- Mickael Treguer, Ifremer, mickael.treguer@ifremer.fr
- Jan Ivar Pladsen, METNO, janip@met.no

Document approval

- Document status: Release 1
- WP leader approval: 2010-06-18
- Quality Manager approval: 2010-06-18
- Coordinator approval: 2010-06-18

Revision History

Issue	Date	Change records	Author(s)
Draft 1.0	2010-03-09	Issue draft layout of report	D. Dunne
Draft 1.1	2010-03-17	Input on HUMBOLDT, MyOcean, and Sensor Web Enablement	M. Treguer
Draft 1.2	2010-03-30	Input on GIGAS	T. Hamre
Draft 1.3	2010-04-06	Input on GENESIS	T. Hamre
Draft 1.4	2010-04-06	Input on GEOSS, GMES, WFS, and Service chaining standards and tools	P. Walker
Draft 2.0	2010-04-08	Issue of draft 2	D. Dunne
Draft 2.1	2010-04-12	Input on SWING and ENVISION	D. Dunne, A. Al-Othman
Draft 2.2	2010-04-13	Input on Service-Oriented Architecture Principles and Standards	D. Dunne, A. Al-Othman, T. Pham, Y. Lassoued
Draft 2.3	2010-04-13	Input on OPeNDAP, and Portal standards and tools	T. Hamre
Draft 2.4	2010-04-14	Input on INSPIRE	J.I. Pladsen, D. Dunne
Draft 2.5	2010-04-14	Input on WIS	J.I. Pladsen
Draft 2.6	2010-04-16	Updated WFS	P. Walker
Draft 2.7	2010-04-16	Input on ORCHESTRA and SANY Sensors Anywhere	D. Dunne, A. Al-Othman
Draft 2.8	2010-04-19	Input on SEIS, SISE, and ECOOP	D. Dunne, A. Al-Othman
Draft 2.9	2010-04-20	Input on Data discovery standards and tools	D. Dunne, T. Pham
Draft 2.10	2010-04-21	Input on Data portrayal standards and tools	D. Dunne
Draft 2.11	2010-04-22	Input on SeaDataNet, and WCS	D. Dunne
Draft 2.12	2010-04-23	Input on Introduction	D. Dunne
Draft 3.0	2010-04-23	Issue of third draft	D. Dunne
Draft 3.1	2010-04-27	Input on Data processing service standards and tools	P. Walker, D. Dunne
Draft 3.2	2010-04-28	Input on Executive Summary and Conclusions	D. Dunne
Draft 4.0	2010-04-28	Issue of fourth draft	D. Dunne
Draft 4.1	2010-06-02	Input on non-Java based portals	T. Hamre
Draft 4.2	2010-06-02	Input on GENESI-DR	P. Walker, T. Hamre
Draft 4.3	2010-06-17	Input on Ocean Data Portal, Observing System Monitoring Center, and Ocean Biogeographic Information System	A. Patterson, D. Dunne
Draft 4.4	2010-06-18	Minor modifications addressing reviewers comments	D. Dunne, T. Hamre, P. Walker
1	2010-06-18	Final version of the report	D. Dunne

Executive Summary

NETMAR aims to develop a pilot European Marine Information System (EUMIS) for searching, downloading and integrating satellite, in situ and model data from ocean and coastal areas. EUMIS will use a semantic framework coupled with ontologies for identifying and accessing distributed data, such as near real-time, model forecast and historical data. EUMIS will also enable further processing of such data to generate composite products and statistics suitable for decision-making in diverse marine application domains.

This report reviews initiatives, projects, and technologies addressing the area of system architectures for distributed Environmental Information Systems (EISs), and gives initial direction towards the NETMAR architecture specification. The review has focused on identifying standard notations and methodologies for architectural design, as well as widely accepted technologies and tools for web service development in the field of EIS.

The majority of the reviewed initiatives and projects have developed a service-oriented architecture (SOA) and several follow the ISO/IEC 10746 RM-ODP (Reference Model for Open Distributed Processing) standard to define their architecture. It is therefore recommended to use RM-ODP to describe the NETMAR architecture using an incremental and iterative approach for analysis and design.

It is further recommended that NETMAR's architecture design be driven by service-oriented architecture (SOA) design principles, and based on open standards from the Internet Engineering Task Force (IETF), World Wide Web Consortium (W3C), Organization for the Advancement of Structured Information Standards (OASIS), International Organization for Standardization/Technical Committee 211 (ISO/TC 211), and Open Geospatial Consortium, Inc. (OGC).

OGC standards are particularly important for implementing the NETMAR service network. NETMAR will deploy Catalogue Service for the Web (CSW), Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), Sensor Web Enablement (SWE), Open-source Project for a Network Data Access Protocol (OPeNDAP), and Web Processing Service (WPS) services. A number of tools supporting these protocols have been reviewed. Table I-i lists the recommended tools for NETMAR.

To enable easy plug-in of multidomain and multilingual use cases, it is recommended that the NETMAR system architecture should be pragmatic, e.g. no or minimal modification of standards, and incorporation of semantics into metadata via controlled vocabularies using a simple Uniform Resource Identifier (URI). The exact relationship between the semantic framework, uncertainty propagation, and other NETMAR subsystems needs to be further defined in context of the NETMAR network of services. In conjunction with use cases requirements, this will be defined in the NETMAR architecture specification using an incremental and iterative approach.

The NETMAR service chaining subsystem will make it easier to construct complex services on demand. A graphical chaining editor will be created which will allow users to define their own workflows. Although some tools were identified that could be useful for the development of the service chaining editor, these are not yet as mature as the OGC data delivery protocols listed above. It is therefore recommended to further investigate such tools before choosing the most promising chaining editor system.

NETMAR will use a portal framework to integrate all client-side subsystems of NETMAR (i.e. service discovery and access, service composition, and GIS viewer with decision-support) into a coherent portal. Several portal frameworks and two Java-based standards for

developing portal components have been reviewed. The most promising portal frameworks found were Liferay and Apache Jetspeed 2. These frameworks both support the latest standards for Java-based portal components, but as other programming languages such as Python may be used to develop portal components, it is recommended to further investigate portal frameworks before making a final decision.

NETMAR is expected to contribute to the Single Information Space in Europe for the Environment (SISE), and in turn support the development of the Shared Environmental Information System (SEIS). Other FP7 projects such as GIGAS, ENVISION and UncertWeb are also contributing to the Single Information Space in Europe for the Environment. It is recommended to further scope recommendations and innovations in these projects.

NETMAR is expected to support the implementation of the INSPIRE Directive. It is therefore recommended that the NETMAR architecture specification follows the INSPIRE technical guidelines and implementation rules, which include, among others, using OGC CSW for discovery services, OGC WMS for view services and OGC WFS for download services. As INSPIRE guidelines and implementation rules are updated during the course of the NETMAR project, it is also necessary to incorporate these changes into the NETMAR system architecture if and as appropriate.

The FP7 MyOcean and the FP6 SeaDataNet projects are key European projects concerning marine data. Because NETMAR also covers the thematic area of marine data, it is recommended that NETMAR, where possible, seek to converge with and compliment appropriate elements of these projects (e.g. common vocabularies).

Protocol/Subsystem	**Recommended tool**
CSW	GeoNetwork
WMS	GeoServer or MapServer (if required by service provider)
WFS	GeoServer
WCS	GeoServer, MapServer of THREDDS Data Server
SWE	Constellation
OPeNDAP	THREDDS Data Server/Dapper (server); DChart/ncWMS (client)
WPS	PyWPS
Workflow engine	None (further investigation and trials are needed)
Portal framework	Liferay or Apache Jetspeed 2

Table I-i Recommended tools for NETMAR protocols and subsystems

Contents

1 Introduction

1.1 Background

NETMAR aims to develop a pilot European Marine Information System (EUMIS) for searching, downloading and integrating satellite, in situ and model data from ocean and coastal areas. It will be a user-configurable system offering service discovery, access and chaining facilities using OGC, OPeNDAP and W3C standards. It will use a semantic framework coupled with ontologies for identifying and accessing distributed data, such as near real-time, model forecast and historical data. EUMIS will also enable further processing of such data to generate composite products and statistics suitable for decision-making in diverse marine application domains.

NETMAR will develop interoperability and connectivity between heterogeneous data systems to meet the demand for information from different user groups. Standardising data and metadata formats, as well as exchange protocols, is the first step to bridging existing marine data systems. The next step is to define the semantics of the services, including an uncertainty model, to allow transparent computer-based discovery. Developing a semantic framework for marine data services, backed by a multilingual and multidomain ontology enabling searches across (human) languages and application domains, is therefore a key task. EUMIS will enable search for and use single services, as well as to compose new and more powerful services by service chaining, defining the workflow of the composite service using existing services as “building blocks”. EUMIS will then merge established standards and tools with these new “building blocks” for application in practical monitoring of the marine environment. This will be done through a set of use cases in different European seas, where identified users will test and evaluate the EUMIS. The use cases include monitoring and forecasting of oil spills, plankton blooms and Arctic sea ice. Furthermore, the use cases will validate an ecosystem model, study the relation between physical and biological variables and data exchange with coastal web atlases.

One important objective of the NETMAR project is to design an architecture for the networking of environmental services and systems that will be used as the foundation for the EUMIS pilot and serve as blueprint for similar systems within the framework of GMES and SISE. The system architecture is guided by use case definitions for the application domains listed above, and has strong interactions with the development of ontologies, semantic framework, service networks, and EUMIS subsystems. The development and integration of subsystems will be done in an iterative manner, allowing early detection of discrepancies (if any) between the agreed architecture and interfaces, and the actual implementations of subsystems. The developed subsystems will be based on open source software, and will be offered as contributions to SISE (Single Information Space in Europe for the Environment) and SEIS (Shared Environmental Information System). The EUMIS subsystems will therefore support the implementation of the INSPIRE Directive and be of benefit to the implementation of GMES and GEOSS.

1.2 Objective of this report

The objective of this report is to review initiatives, projects, standards and technologies addressing system architectures for distributed Environmental Information Systems (EISs), and to give initial direction towards the NETMAR architecture specification. The scope of this report concerns overarching architecture solutions and standards, data access and processing services, subsystem and portal development. Other key technologies and tools for ontologies and semantic frameworks, are described in two other reports, NETMAR deliverables D3.2 [BODC10] and D4.1 [CMRC10] respectively.

1.3 Terminology

System architecture – A system architecture is the conceptual design that defines the structure of a software system and the interrelationships between its components.

Service-oriented architecture – A service-oriented architecture (SOA) is a form of distributed system architecture. A SOA consists of service providers and service consumers who are connected through well-defined interfaces.

Environmental information system – An environmental information system is an information system which specialises in the discipline of environmental data and its procedures.

Framework (software framework) – A software framework is a reusable software template or skeleton from which selected functionally and components can be configured, extended and integrated to build the overall software system.

1.4 Organisation of this report

Chapter 2: Initiatives and Projects
This chapter summaries significant initiatives and projects that have been identified as relevant to the development of NETMAR's distributed environmental information system. It gives an overview of their contribution concerning relevant policy objectives and/or architecture solutions.

Chapter 3: Service-oriented architecture principles and standards
This chapter outlines service-oriented architecture principles, and standards from the Internet Engineering Task Force (IETF), the World Wide Web Consortium (W3C), the Organization for the Advancement of Structured Information Standards (OASIS), ISO/TC 211 Geographic information/Geomatics, and the Open Geospatial Consortium (OGC).

Chapter 4: Data discovery standards and tools
This chapter outlines service standards and tools which enables discovery of geospatial datasets.

Chapter 5: Data portrayal standards and tools
This chapter outlines service standards and tools which enables portrayal of geospatial datasets.

Chapter 6: Data access standards and tools
This chapter outlines service standards and tools which enable direct access to geospatial datasets.

Chapter 7: Data processing standards and tools
This chapter outlines service standards and tools which enables geo-processing of geospatial datasets.

Chapter 8: Service chaining standards and tools
This chapter outlines standards, workflow engines and tools which enable the chaining of these services.

Chapter 9: Portal standards and tools
This chapter outlines web portal standards and portal frameworks.

Chapter 10: Conclusions

This chapter gives recommendations and initial direction towards the specification of the NETMAR architecture.

2 Initiatives and Projects

This chapter presents significant initiatives and projects that have been identified as relevant to the development of NETMAR's distributed environmental information system. It gives an overview of their contribution concerning relevant policy objectives and/or architecture solutions.

2.1 Initiatives

This section reviews policy initiatives, and longer term projects and programmes

2.1.1 *GEOSS*

The Global Earth Observation System of Systems (GEOSS) is being developed by the Group on Earth Observation (GEO) to link together existing and planned observation systems around the world and to support the development of new systems where required. It addresses nine areas of importance to people and society [GEO09]:

1. **Disaster**: Reducing loss of life and property from natural and human-induced disasters.
2. **Health**: Understanding environmental factors affecting human health and well-being.
3. **Energy**: Improving management of energy resources.
4. **Climate**: Understanding, assessing, predicting, mitigating, and adapting to climate variability and change.
5. **Water**: Improving water cycle.
6. **Weather**: Improving weather information, forecasting, and warning.
7. **Ecosystems**: Improving the management and protection of terrestrial, coastal, and marine ecosystems.
8. **Agriculture**: Supporting sustainable agriculture and combating desertification.
9. **Biodiversity**: Understanding, monitoring, and conserving biodiversity.

The GEOSS Common Infrastructure (GCI) consists of web-based portals, clearinghouses for searching data, information and services, and registries containing information about GEOSS components, standards, best practices and requirements. Figure 2-1 identifies the main GEOSS component types [GEO10]. The "GEO Portal" provides a single access point for users searching and accessing data. There are currently three portal prototypes:

- Compusult GEO Portal: http://www.geowebportal.org
- ESA/FAO GEO Portal: http://www.geoportal.org
- ESRI GEO Portal: http://geoss.esri.com/geoportal

The GEO Portals connect to existing databases and services using information held in the GEOSS Clearinghouse. This Clearinghouse provides access to a distributed network of catalogue services that support the interoperability arrangements of GEO. Information is also made available to those with limited or no Internet access via "GEONETCast", a network of communication satellites which transmits data products to users. The GEOSS GCI is based around a service-oriented architecture and provides:

- Catalogue/registry services using OGC CSW, ISO 19115/19119, ISO 23950
- Portrayal and display services using OGC WMS and KML
- Data access services using OGC WFS, WCS and OPeNDAP
- Service Chaining and Workflow using ISO 19119, BPEL and OGC WPS

NETMAR will contribute to the implementation of the marine component of GEOSS by providing an integrated framework of remotely sensed, in situ and model data.

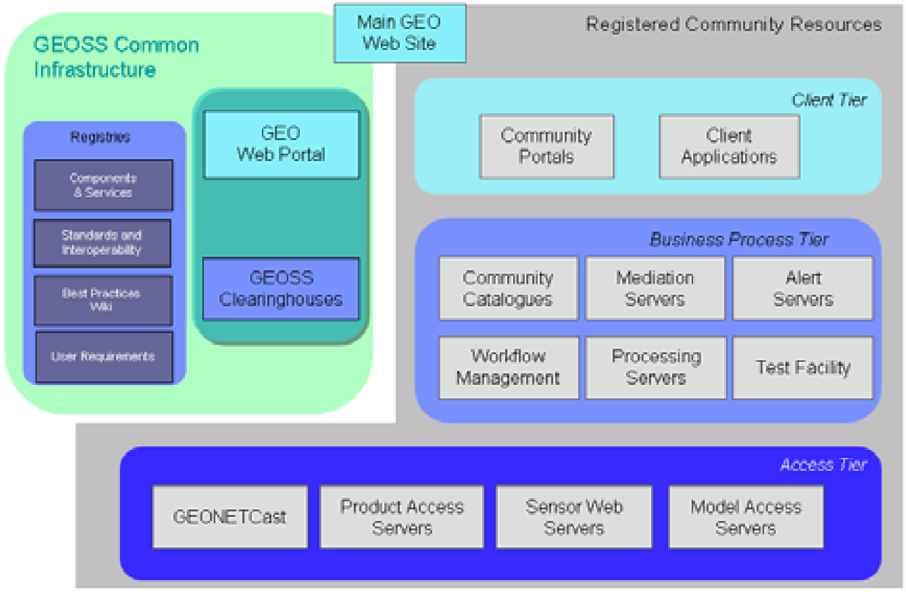

Figure 2-1 GEOSS architecture components
(source: http://www.earthobservations.org/documents/cfp/20100129_cfp_aip3_architecture.pdf)

2.1.2 *GMES*

Global Monitoring for Environment and Security (GMES) is an overarching programme for the implementation of a European capacity for Earth observation. It is Europe's main contribution to the implementation plan for a coordinated and integrated Global Earth Observation System of Systems (GEOSS). The objective is to provide timely access to high quality information, services and knowledge; and to provide decision-makers, who rely on strategic information about environmental and security issues, with independent and permanent access to reliable data. The GMES capacity is based on four interrelated components as represented by the "GMES diamond" (cf. Figure 2-2):

- services;
- observations from space;
- in-situ (including airborne) observations;
- data integration and information management capacity.

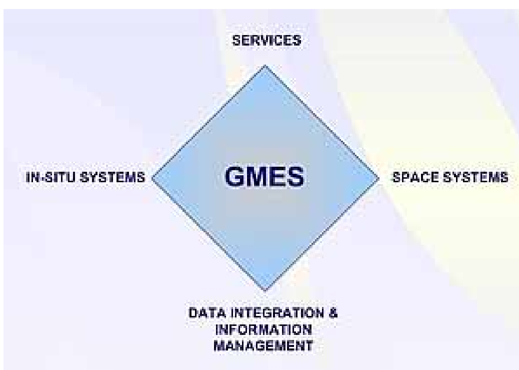

Figure 2-2 GMES diamond
(source: http://www.dappolonia-research.com/invesatwiki/index.php/GMES)

GMES has three themes:

1. **Land, marine and atmosphere information**
   ensuring systematic monitoring and forecasting the state of the Earth's subsystems at regional and global levels.

2. **Climate change information**
   helping to monitor the effects of climate change, assessing mitigation measures and contributing to the knowledge base for adaptation policies and investments.

3. **Emergency and security information**
   providing support in the event of emergencies and humanitarian aid needs, in particular to civil protection authorities, also to produce accurate information on security related aspects (e.g. maritime surveillance, border control, global stability,...)

Services within GMES are provided by separate projects financed through the Research and Development Framework Programmes (FP) of the EU. The first GMES Service Projects (GSPs) are now available in pre-operational mode. These services address the areas of land monitoring, marine monitoring, atmosphere monitoring, emergency response, and security:

- Land Monitoring (FP7 geoland2 project, http://www.gmes-geoland.info)
- Ocean Monitoring (FP7 MyOcean project, http://www.myocean.eu.org)
- Atmosphere Monitoring (FP7 MACC project, http://www.gmes-atmosphere.eu)
- Emergency Response (FP7 SAFER project, http://www.emergencyresponse.eu)
- Security (FP7 G-MOSAIC project, http://www.gmes-gmosaic.eu)

Of these five projects, MyOcean (cf. 2.2.8) is the most relevant to NETMAR as it deals with a similar thematic area (marine).

With the GMES architecture (Figure 2-3), the GMES Space Component Data Access (GSCDA) system is responsible for supplying harmonised access to Earth Observation (EO) data for the GMES Service Projects. GSCDA is managed by the European Space Agency (ESA) and funded through FP7. Within GSCDA, the Coordinated Data access System (CDS) is in charge of coordinating data flow to the GMES Service Projects. In particular, the EO DAIL (Earth Observation Data Access Integration Layer) provides an interface to the GMES Service Projects for ordering data, accessing data, etc.

The EO DAIL interface is a service-oriented architecture using Java EE (Enterprise Edition) and open standard specifications from standardisation bodies such as ISO, OASIS, W3C and OGC. Standards used include:

- ISO 19115, 19119, 19139
- OGC WMS, WCS, WFS, CSW
- OASIS BPEL

As well as its close association with GEOSS, GMES is also linked with INSPIRE (cf. GIGAS project in section 2.2.11). It is hoped that the three projects will cooperate on standards.

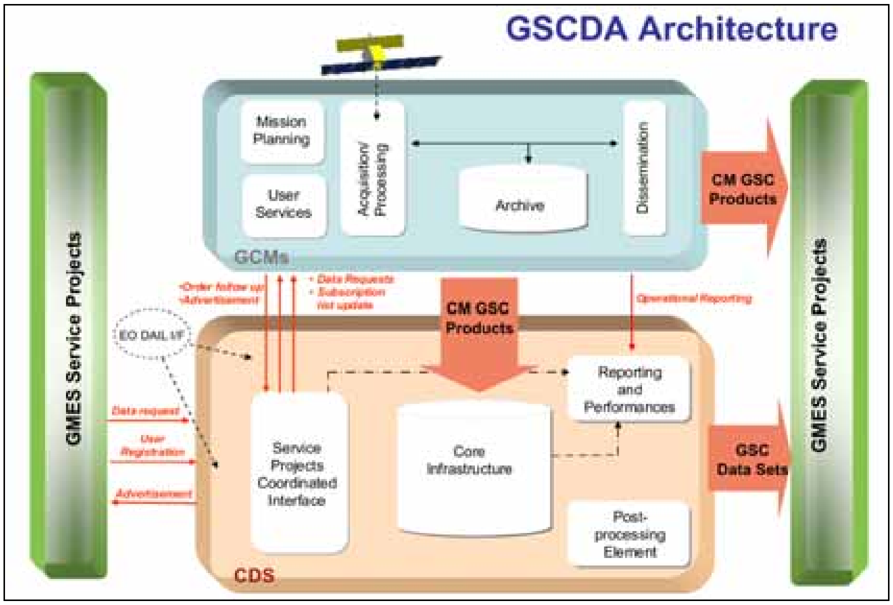

Figure 2-3 GSCDA Architecture
(source: http://www.thegigasforum.eu/cgi-bin/download.pl?f=345.pdf)

2.1.3 *WMO Information System (WIS)*

The WMO Information System (WIS) is a project within the World Meteorological Organization (WMO). It will provide an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centres and member countries in the framework of any WMO Programme. WIS is built on the existing Global Telecommunication System (GTS) and will use international industry standards for protocols, hardware and software.

WIS encompasses three types of data centres (Figure 2-4). For regional and global connectivity, the Global Information System Centres (GISCs) will collect and distribute information intended for routine global dissemination. In addition, GISCs serve as collection and distribution centres in their areas of responsibility and also provide entry points through portals and comprehensive metadata catalogues for any data request held within the WIS. The Data Collection or Production Centres (DCPCs), which are connected to the GISCs, will be responsible for the collection or generation of datasets, forecast products, processed or value-added information, and/or for providing archiving services. National Centres (NCs) will collect and distribute data on a national basis and will coordinate or authorise the use of the WIS by national users, normally under a policy established by the respective Permanent Representative (PR) with WMO [WMOIS].

The WIS implementation plan consists of two parts to be developed in parallel. The first part makes improvements to the existing GTS. The second part develops new information services for flexible data discovery, access and retrieval [WMOIP]. WMO has already created a core metadata profile based on the ISO 19115 standard called “WMO core profile of the ISO metadata standard”. In January 2010, the WMO signed a Memorandum of Understanding with the OGC. It is anticipated that this collaboration will support the implementation of the WIS.

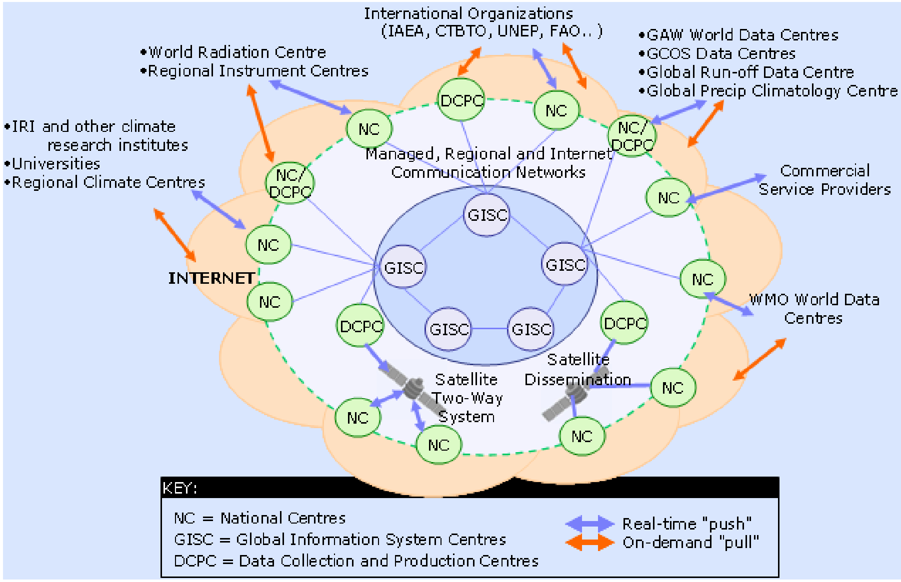

Figure 2-4 WMO Information System (WIS) data centres
(source: http://www.wmo.int/pages/prog/www/WIS/centres_en.html)

2.1.4 *INSPIRE Directive*

The INSPIRE (Infrastructure for Spatial Information in the European Community) Directive aims to establish a Spatial Data Infrastructure (SDI) framework within Europe [INSDI]. This infrastructure will be capable of seamlessly delivering integrated spatial information services to end-users in an interoperable way. Spatial information services include geographic data discovery, portrayal of geographic layers, overlay of geographic information from different sources, spatial and temporal analysis, etc. Target end-users of INSPIRE include policy-makers, planners and managers (at European, national, and local levels), organisations and citizens. While much spatial information is available at both local and national level, this information is difficult to exploit on a broader European level for a variety of reasons. Problems include data policy restrictions, lack of co-ordination, gaps in data availability, duplication of information collection, data fragmentation, lack of standards, and issues with identifying, accessing or using data that is already available. INSPIRE addresses both technical and non technical issues, ranging from technical standards and protocols, organisational issues, and data policies to the creation and maintenance of geographical information for a wide range of themes, starting with the environmental sector [INSPP]. The Directive entered into force on the 15th May 2007 and will be implemented in various stages, with full implementation required by 2019. INSPIRE is based on a number of common principles [INSAB]:

- Data should be collected only once and kept where it can be maintained most effectively.
- It should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications.
- It should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes.
- Geographic information needed for good governance at all levels should be readily and transparently available.
- Easy to find what geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used.

Figure 2-5 gives an overview of the INSPIRE architecture [INSTA]. The Directive has requirements related to metadata (for discovery and use), interoperability of spatial data sets and services, and network services. Network services to be operated are discovery, view, download, transformation, and invoke services. The spatial datasets are split and prioritised into themes listed in Annex I, II, and III of the Directive. The timetable for implementation is different according to theme. The Directive requires that common Implementing Rules (IR) [INSIR] are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). To assist implementation, technical guidance documents are provided which give detail concerning implementation of these rules.

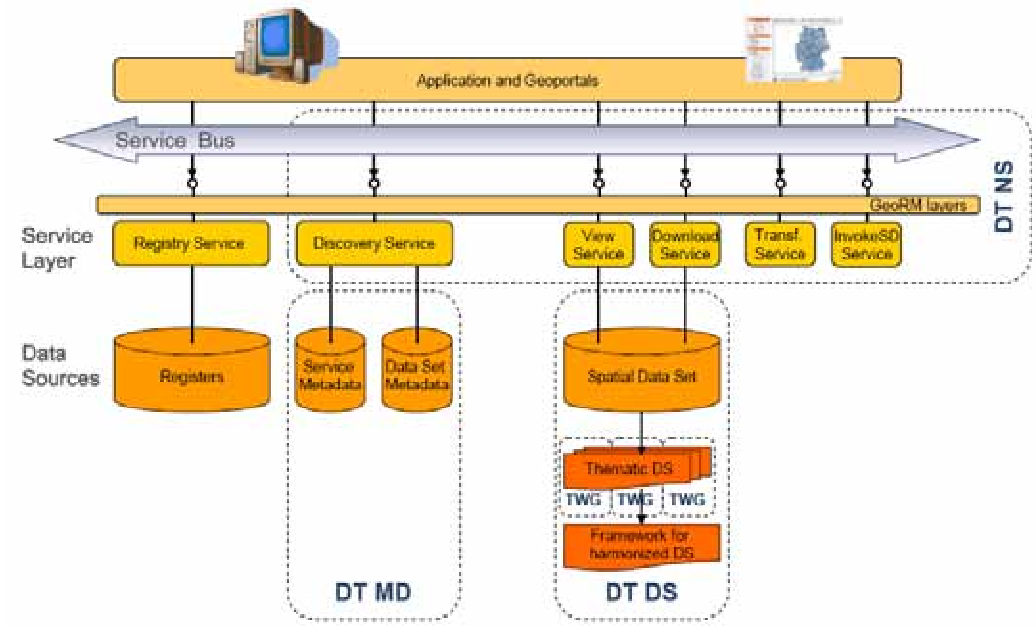

Figure 2-5 INSPIRE architecture
(source: http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/network/INSPIRETechnicalArchitectureOverview_v1.2.pdf)

For Metadata, technical guidelines are based on a profile of ISO 19115 and ISO 19119 [INSME].

For Network Services, technical guidelines consist of [INSNS]:

- **discovery services** using OGC CSW
- **view services** using OGC WMS
- **download services** using OGC WFS
- **transformation services** using Web Coordinate Transformation Service (WCTS) as an Application Profile of OGC WPS
- **invoke services** are expected to use OGC WPS when technical guidelines become available

The default communication protocol and binding technology proposed for INSPIRE network services is SOAP (using *document/literal* encoding style) [INSSO].

The spatial data themes referred to by INSPIRE are listed in Table 2-1. Data specification guidelines for Annex I themes are currently available. Data specification guidelines for Annex II and Annex III themes are currently under development. They are expected to become available for initial stakeholder testing in 2011 with a deadline for final completion by May 2012 [INSEI].

Annex I	Annex II	Annex III
Coordinate Reference Systems	Elevation	Statistical units
Geographical Grid Systems	Land cover	Buildings
Geographical Names	Orthoimagery	Soil
Administrative Units	Geology	Land use
Addresses		Human health and safety
Cadastral Parcels		Utility and governmental services
Transport Networks		Environmental monitoring facilities
Hydrography		Production and industrial facilities
Protected Sites		Agricultural and aquaculture facilities
		Population distribution - demography
		Area management / restriction / regulation zones and reporting units
		Natural risk zones
		Atmospheric conditions
		Meteorological geographical features
		Oceanographic geographical features
		Sea regions
		Bio-geographical regions
		Habitats and biotopes
		Species distribution
		Energy resources
		Mineral resources

Table 2-1 INSPIRE spatial data themes

2.1.5 *Shared Environmental Information System (SEIS)*

In January 2008, the European Commission proposed to create a Shared Environmental Information System for Europe (SEIS). It is a collaborative initiative of the European Commission and the European Environment Agency (EEA) to establish with the Member States an integrated and shared pan-European environmental information system. The proposal will offer a legal basis for an integrated and sustainable EU-wide eReporting System which will be built as a partnership between European Institutions (European Commission/EEA) and the Member States. The concept for the EU eReporting system is based on the SEIS principles of a decentralised system and builds on the experience with the implementation of the INSPIRE Directive and the U.S. EPA eReporting System. It will be composed of web-based national content registers providing access to the information at national level, and a web-portal operating at EU level. Member States will have the flexibility to build their national registers on a centrally operated content repository or to interconnect existing information systems and content repositories held in various locations. This system will better integrate all existing data gathering and information flows related to EU environmental policies and legislation. A major challenge is to organise the large amount of environmental data and information and to integrate these, where desirable, with existing social and economic data. This data should be made available together with tools that allow experts to do their own analyses and to communicate their results in ways which policy makers and the public can easily understand. At the same time, Member States and EU institutions need an efficient and modern reporting system to fulfil their legal obligations under EU and international environmental policies and legislation, thus avoiding duplicate, overlapping, and redundant reporting efforts. Figure 2-6 shows the existing fragmented reporting system against the proposed shared reporting system [SEIS].

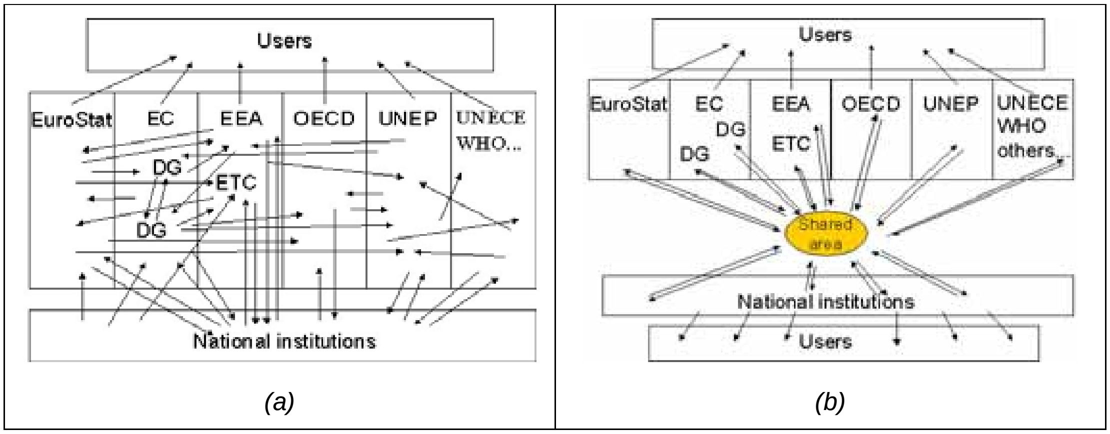

Figure 2-6 (a) existing fragmented system (b) proposed shared system (source: http://ec.europa.eu/environment/seis/why.htm)

2.1.6 *Single Information Space in Europe for Environment (SISE)*

A goal for the Single Information Space in Europe for the Environment (SISE) is to support national, regional, non-governmental organisations, and voluntary initiatives to make more accessible and reusable environmental information [SISE1]. SISE has policy links to *i2010 - A European Information Society for growth and employment*. The European Commission set i2010 as a framework for addressing the main challenges and developments in the Information Society and media sectors up to 2010. It promoted the positive contribution that ICT can make to the economy, society and personal quality of life. The first objective of i2010 was to establish a Single European Information Space offering affordable and secure high-bandwidth communications, rich and diverse content and digital services [i2010]. Consequently, during the preparation of FP7 Work Programmes, DG Information Society and Media (INFSO) proposed the development of a Single Information Space in Europe for the Environment (SISE). The aim of SISE has an ICT research vision to enable [Hreb09]:

- real-time connectivity between multiple environmental resources;
- seamless cross-system search;
- cross-border, multi-scale, multi-disciplinary data acquisition, pooling and sharing;
- service-chaining on the web, thereby stimulating data integration into innovative value-added web services.

Targets of SISE were specified during several workshops organised by the Commission in 2007 and 2008. The last workshop, “Towards a Single Information Space in Europe for the Environment (SISE)”, was organised by the ICT for Sustainable Growth Unit of DG INFSO. At the workshop, DG INFSO first presented their vision for the proposed SISE. Thereafter, the workshop participants presented trends in the following topics as they are central to implementing SISE [SISE2]:

- service-oriented architecture (SOA)
- web services
- process chaining and uncertainties
- real-time mapping and modelling
- controlled vocabularies
- data interoperability
- open standards
- open source software
- model driven communities
- web communities
- data visualisation
- SISE deployment models

The goal of the workshop was to provide an outline justification and prioritisation of future research or innovation actions with clear European added value. To support the efforts for integration of environmental information in Europe several projects are now in progress under FP7 "Objective ICT-2007.6.3: ICT for environmental management and energy efficiency" [Hreb09]. Examples projects under this objective include GENESIS (cf. section 2.2.9), GIGAS (cf. section 2.2.11), and ICT-ENSURE (a support action in the area of "ICT for Environmental Sustainability Research", http://ict-ensure.tugraz.at/en/index.php). Also, the FP7 "Objective ICT-2009.6.4 ICT for Environmental Services and Climate Change Adaptation" is addressing SISE. In fact, NETMAR is funded under this Objective. Other relevant projects under this Objective include ENVISION (cf. section 2.2.4) and UncertWeb (http://www.uncertweb.org).

The activities of SISE are seen as complementary to the implementation of the Shared Environmental Information System (SEIS, cf. section 2.1.5). Both SEIS and SISE rely on INSPIRE for providing the overarching Spatial Data Infrastructure (SDI) framework. At a policy level, SEIS is focused on the developing an environmental reporting application for the European Environment Agency, European Commission and EU member states. In contrast, SISE is talking a more bottom up approach which is more focussed on ICT research to achieve better integration of environmental information. Therefore, the outputs of ICT research concerning SISE are seen as essential for supporting the implementation of SEIS.

2.2 Projects

This section reviews relevant projects including projects funded by European Commission Framework programmes.

2.2.1 *EC FP6 ORCHESTRA*

The completed FP6 ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) integrated project (2004-2008) was funded by the European Commission whose overall aim was the design and implementation of an open, service-oriented software architecture as a contribution to overcome interoperability problems in the domain of risk management. Risk management activities often involve different organisations each having their own bespoke systems and services. ORCHESTRA is driven by the need to better consolidate such systems to help support citizen protection, security issues, disasters, and emergency management operations. Specific goals of ORCHESTRA are [ORCWS]:

- to design an open service-oriented architecture for risk management;
- to develop the software infrastructure for enabling risk management services;
- to deliver an infrastructure integrating spatial and non-spatial services for risk management;
- to validate the ORCHESTRA results in a multi-risk scenario;
- and to provide software standards for risk management applications.

In order to achieve these goals, ORCHESTRA defined a reference architecture that forms the basis for the implementation of service networks based on open standards. The Reference Model for the ORCHESTRA Architecture (RM-OA) document describes this architecture [RM-OA]. RM-OA provides a specification framework for system architects, information modellers and system developers. The ORCHESTRA Architecture is a platform-neutral (abstract) specification of the informational and functional aspects of service networks taking into account and evolving out of architectural standards and service specifications of ISO, OGC, W3C and OASIS [ORCBO]. The RM-OA document is described using ISO/IEC 10746 RM-ODP (Reference Model for Open Distributed Processing) where five viewpoints (enterprise, information, computational, engineering, and technology) are used to describe the architecture design. RM-OA is built upon a process model which follows an incremental, iterative approach for the analysis and design phases across several abstraction layers. ORCHESTRA distinguishes between an abstract service platform and a concrete service platform which may be implemented using W3C Web services, OGC services, etc. (cf. Figure 2-7).

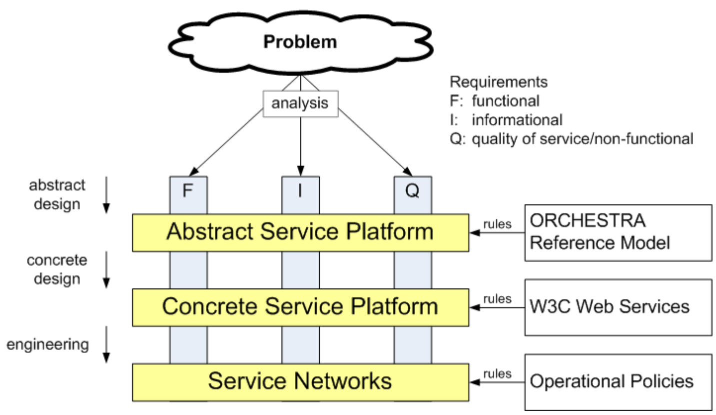

Figure 2-7 ORCHESTRA architecture approach
(source: http://www.eu-orchestra.org/docs/ORCHESTRA-Book.pdf)

ORCHESTRA Services, which are the building blocks for risk management applications, are specified in two different ways. First, a coarse abstract service description is given for each service in a human-readable text format by using a service description framework within the RM-OA document. Second, refined abstract specifications of these interfaces are described in separate specification documents using UML. These documents can be downloaded from http://www.eu-orchestra.org/publications.shtml. The ORCHESTRA Services can be broadly divided in two groups: ORCHESTRA Architecture (OA) Services and ORCHESTRA Thematic (OT) Services [RM-OA].

First, ORCHESTRA Architecture (OA) Services are generic, platform-neutral and independent of the application domain. These consist of OA Info-Structure Services (usually a required service) and OA Support Services (a supporting or valuing adding service.) OA Info-Structure Services types include [RM-OA]:

- Authorisation Service
- Authentication Service

- Catalogue Service
- Document Access Service
- Feature Access Service
- Map and Diagram Service
- Name Service
- Sensor Access Service
- Service Monitoring Service
- User Management Service

OA Support Service types include [RM-OA]:

- Annotation Service
- Coordinate Operation Service
- Format Conversion Service
- Gazetteer Service
- Ontology Access Service
- Schema Mapping Service
- Service Chain Access Service
- Thesaurus Access Service

Second, ORCHESTRA Thematic (OT) Services provide application specific functionality built on top of the OA Services. OT Services include [RM-OA]:

- Processing Service
- Simulation Management Services
- Sensor Planning Service
- Project Management Support Service
- Communication Service
- Calendar Service
- Reporting Service

RM-OA became an OGC Best Practice Document (OGC 07-097) in 2007.

2.2.2 *EC FP6 SANY Sensors Anywhere*

The completed FP6 SANY Sensors Anywhere project (2006-2009) was funded by the European Commission and focused on improving interoperability of in situ sensors and sensor networks to better support decision making applications. The main objectives of SANY are [SANOB]:

- to specify a generic open architecture for fixed and moving sensors and sensor networks capable of seamless ‘plug and measure’ and sharing of resources in virtual networks;
- to develop and validate reusable data fusion and decision support service building blocks and a reference implementation of the architecture;
- to closely work with end users and international organisations in order to assure that the outcome of SANY contributes to future standards;
- and to validate the project results, through development of three innovative risk management applications covering the areas of air pollution, marine risks and geo hazards.

The open architecture developed by the project is called SANY Sensor Service Architecture (SensorSA) and structured according to ISO/IEC 10746 RM-ODP viewpoints. SensorSA belongs to the family of service-oriented architectures (SOA). In fact, SANY adopted the general ORCHESTRA approach for specifying a service-oriented architecture and is, therefore, based on the Reference Model for the ORCHESTRA Architecture (RM-OA) - OGC Best Practice Document 07-097. SensorSA has a particular focus on the access, the management and the processing of information provided by sensors and sensor networks. While the architecture contains sensor-specific services it also provides a higher-level, functionally and semantically richer services to support environmental risk management applications. Furthermore, the SensorSA relates the basic concepts of a resource-oriented architecture (ROA) such as resources and their representations to the SOA concepts in order to gain flexibility in discovery tasks and mapping to underlying web services. Service interfaces are described in SensorSA using the following hierarchy [SenSA]:

1. OGC Sensor Web Enablement Services:
   a. Sensor Observation Service
   b. Sensor Planning Service
   c. Sensor Alert Service
   d. Web Notification Service

2. Access Control Services:
   a. Profile Management Service
   b. Identity Management and Authentication Service
   c. Policy Management and Authorisation Service
   d. Policy Enforcement Service

3. Mediation, Processing and Application Domain Services:
   a. Basic Interfaces
   b. Catalogue Service
   c. Document Access Service
   d. Feature Access Service
   e. Map and Diagram Service
   f. Ontology Access Interface
   g. Name Service
   h. Processing Service
   i. Schema Mapping Service
   j. Service Monitoring Service

2.2.3 *EC FP6 SWING*

The completed FP6 SWING project (2006-2009) was funded by the European Commission and its overall objective was to create a Semantic Web Service (SWS) framework for the geospatial domain. This framework consists of a set of tools and ontologies, which helps simplify the access to SWS technology and in this way, reduce the training required for applying this technology. The tools allow a user to perform basic tasks such as annotation, composition, discovery, and execution of web services. To evaluate the suitability of the framework, SWING also built an application that utilises the framework for decision support in mineral resource management. The SWING framework is outlined in Figure 2-8. This framework integrates [SWING]:

- MiMS (Mineral resources Management System): an end-user tool to use Geospatial SWS
- DEV: a UML developer tool to support the composition of new Geospatial SWS
- CAT: a service catalogue
- WSMX (Web Service Modelling eXecution environment): a state-of-the-art SWS platform

- ANNOT: an annotation tool that helps with the creation of the semantic annotations

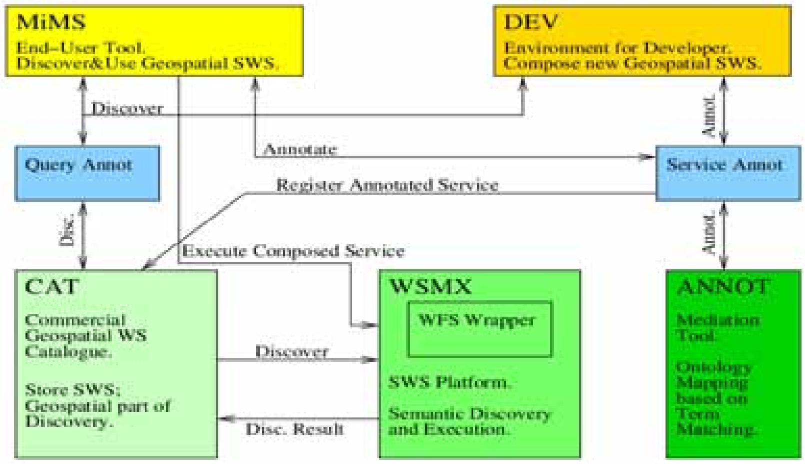

Figure 2-8 overview of the SWING framework
(source: http://www.eswc2008.org/demos/demo06.pdf)

2.2.4 *EC FP7 ENVISION*

The FP7 ENVISION project (2010-2013) is funded by the European Commission and is a follow-up to the FP6 SWING project, adopting and extending its results. The project aims to support non ICT-skilled users in the process of semantic discovery, and adaptive chaining and composition of environmental services. Innovations include [ENVIS]:

- web enabling and packaging of technologies for their use by non ICT-skilled users;
- support for migrating environmental models to be provided as Models-as-a-service (Maas);
- and the use of data streaming information for harvesting information for dynamic building of ontologies and adapting service execution.

The ENVISION Environmental Decision Portal supports the creation of web-based applications enabled for dynamic discovery and visual service chaining. The ENVISION Ontology Infrastructure provides support for visual semantic annotation tools and multilingual ontology management. The ENVISION Execution Infrastructure comprises a semantic discovery catalogue and a semantic service mediator based on a generic semantic framework and adaptive service chaining with data-driven adaptability. Scenario requirements and pilot applications focus on landslide hazard assessment and environmental pollution (oil spills) decision support [ENVIS].

2.2.5 *EC FP6 HUMBOLDT*

The Humboldt project (2006-2010) aims to facilitate cross-national harmonisation of spatial data and at supporting the implementation of the European INSPIRE Directive in applications related to GMES. The project is funded by the European Commission within FP6 and coordinated by Fraunhofer Institute for Computer Graphics, located in Darmstadt, Germany. 28 partners from 14 European countries collaborate on the development of IT solutions to support the harmonisation of spatial data to be used within Spatial Data Infrastructure (SDIs). The technical goal of HUMBOLDT is to support SDI enablement by providing the functionalities for covering the data harmonisation process as a whole. The HUMBOLDT framework has three tiers [HUMBT]:

1. HUMBOLDT Harmonisation Toolkit

2. HUMBOLDT Service Integration Framework
3. individual transformation or harmonisation services

For the first tier, the HUMBOLDT Harmonisation Toolkit, the following components are being developed:

- **HUMBOLDT GeoModel Editor**: a UML editor for creating UML application schemas.
- **HUMBOLDT Alignment Editor**: a tool to define conceptual schema transformations.

For the second tier, the HUMBOLDT Service Integration Framework, the following components are being developed:

- **Mediator Service (MS)**: for workflow execution.
- **Workflow Design and Construction Service (WDCS)**: for workflow construction.
- **Model Repository (MR)**: a conceptual schema and mappings repository.
- **Context Service (CS)**: for defining transformation products.
- **Information Grounding Service (IGS):** for the discovery of geospatial data services.

For the third tier, the following individual transformation or harmonisation services are being developed:

- **Conceptual Schema Translation Service**: a Web Processing Service (WPS) for transforming data from one application schema to another.
- **Edge Matching Service**: a Web Processing Service (WPS) that deals with inconsistencies in geometry.
- **Language Transformation Service**: a Web Processing Service (WPS) that allows to translate data from one natural language to another using thesauri.
- **Multiple Representation Merging Service**: A Web Processing Service (WPS) that provides facilities for the merging of spatial data sets.

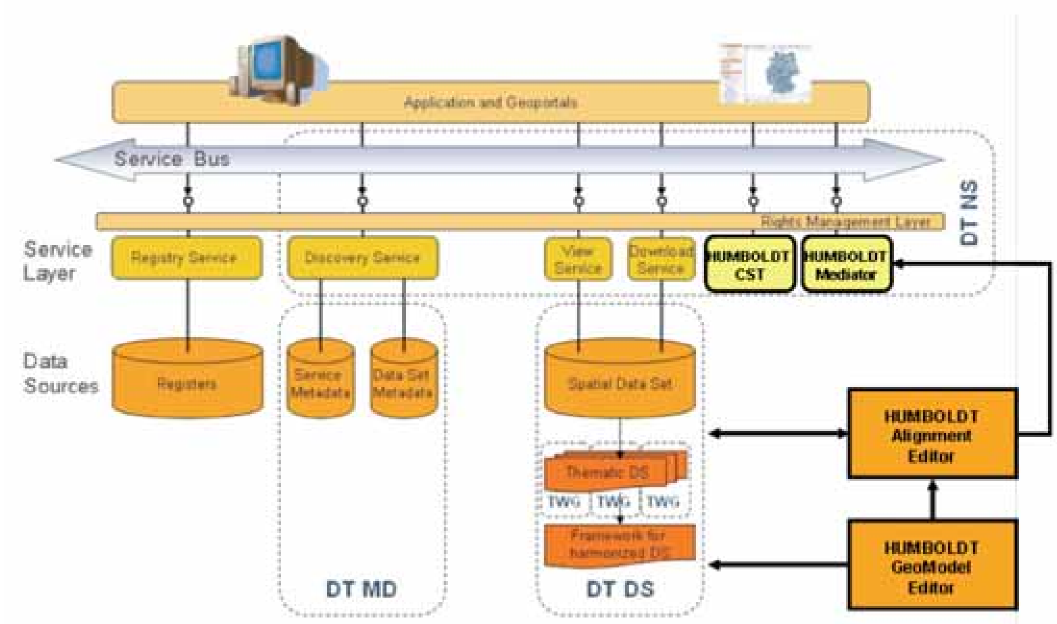

Figure 2-9 relationship of some of the HUMBOLDT components to the INSPIRE services architecture (source: http://www.esdi-humboldt.eu/files/ 1004-a11_5-d3_humboldt_annual_report_2009-fhg-igd-001-final.pdf)

A number of the HUMBOLDT components have been published at http://community.esdi-humboldt.eu. These are available as open source software, released under the LGPL 3.0 license. The relationship of some of the HUMBOLDT components to the INSPIRE services architecture is illustrated in Figure 2-12.

The Ocean scenario (http://www.esdi-humboldt.eu/scenarios/ocean.html) is one of 10 scenarios developed within HUMBOLDT. The primary objective of the Ocean scenario is to test the HUMBOLDT framework for its ability to solve data harmonisation issues in applications for assessing and managing oil/contaminant spill crises at sea.

2.2.6 *EC FP6 SeaDataNet*

The FP6 SeaDataNet Integrated research Infrastructure Initiative (I3) project (2006-2011) is funded by the European Commission. SeaDataNet provides a data management system adapted towards both the integration of fragmented observation systems and users' need for integrated access to data, metadata, products and services. SeaDataNet insures the long term archiving for a large number of multidisciplinary data (i.e. temperature, salinity, currents, sea level, chemical, physical, and biological properties) collected by many different sensors installed onboard research vessels, satellite and the various platforms of the marine observing system. SeaDataNet is a distributed infrastructure that provides transnational access to marine data, metadata, products and services through 40 interconnected Trans National Data Access Platforms (TAP) from 35 countries around the Black Sea, Mediterranean, North East Atlantic, North Sea, Baltic and Arctic regions. These include National Oceanographic Data Centres (NODC's) and Satellite Data Centres. Furthermore the SeaDataNet consortium comprises a number of expert modelling centres, SME's experts in IT, and 3 international bodies (ICES, IOC and JRC). SeaDataNet also develops added value regional data products such as gridded climatologies and trends, in partnership with scientific research laboratories. SeaDataNet provides harmonised access to the distributed databases via a central portal [SDN].

SeaDataNet has defined common standards for metadata and data formats, common vocabularies, quality flags, and quality control methods, which considers international standards such as ISO 19115, netCDF (CF), and best practices from IOC and ICES. SeaDataNet is also adding OGC viewing services for data products and ensuring compliance with the INSPIRE Directive. SeaDataNet maintains and provides discovery services via the following catalogues:

- CSR – Cruise Summary Reports of research vessels
- EDIOS – Locations and details of monitoring stations and networks / programmes
- EDMED – High level inventory of Marine Environmental Data sets collected and managed by research institutes and organisations
- EDMERP – Marine Environmental Research Projects
- EDMO – Marine Organisations

These catalogues are interrelated, where possible, to facilitate cross searching and context searching. They connect to SeaDataNet's Common Data Index (CDI) metadata. CDI makes possible data discovery and delivery. It gives detailed insight regarding available datasets at partners' databases and makes possible direct online access and delivery of these datasets from these data centres (cf. Figure 2-10) [SDN].

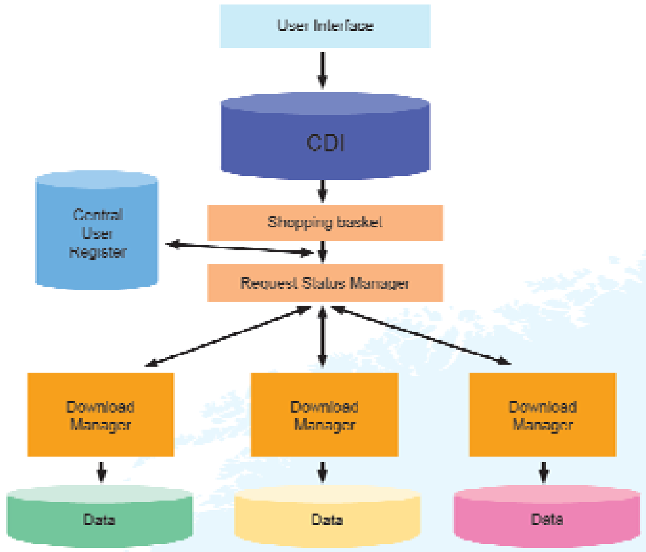

Figure 2-10 data discovery and access using CDI metadata (source: http://www.seadatanet.org/content/download/9054/54103/file/poster_seadatanet.pdf)

2.2.7 *EC FP6 ECOOP*

The FP6 ECOOP project (2007-2010) is funded by the European Commission. The overall aim of ECOOP is to "consolidate, integrate and further develop existing European coastal and regional seas operational observing and forecasting systems into an integrated pan-European system targeted at detecting environmental and climate changes, predicting their evolution, producing timely and quality assured forecasts, providing marine information services (including data, information products, knowledge and scientific advices) and facilitate decision support needs." This overall aim is being attained through the following actions [ECOOP]:

- integrate existing coastal and regional sea observing (remote sensing, in-situ) networks into a pan-European observing system;
- integrate existing coastal and regional sea forecasting systems into a pan-European forecasting system and assimilate pan-European observation database into the system;
- assess the quality of pan-European observing and forecasting system;
- advance key technologies for the current and next generation pan-European observing and forecasting system;
- develop and generate value-added products for detecting environment and climate change signals;
- integrate and implement a pan-European Marine Information System of Systems (EuroMISS) for general end user needs;
- develop methodology and demonstrate a European Decision Support System for coastal and regional seas (EuroDeSS) that responds to the needs from targeted end users, as emphasised in the GEOSS and GMES initiatives;
- and carry out technology transfer both in Europe and at intercontinental level; establish education and training capacities to meet the need for ocean forecasters.

ECOOP achieves its overall aim by implementing a Marine Information System of Systems (EuroMISS) and the European Decision Support System (EuroDeSS).

EuroMISS aims to provide integrated access to the ocean products both inside and outside ECOOP. EuroMISS is designed as a service-oriented architecture (SOA) (cf. Figure 2-11). The architecture does not strictly implement W3C standard web services (e.g. SOAP protocol) but instead uses web interfaces that are used widely in the ocean community and easy to set up. EuroMISS front-end services include data discovery (ISO 19115 metadata), view (e.g. WMS) and download (e.g. OPeNDAP, Dapper, FTP). EuroMISS consists of TACs (Thematic Assembly Centres) and MFCs (Monitoring and Forecasting Centres). A TAC gathers observation datasets (e.g. in-situ, remote sensing) while a MFC runs ocean numerical models. TACs and MFCs are regionally organised by ROOS (Regional Operational Oceanography System).

EuroDeSS aims to develop integrated services in support of marine environmental management in European coastal areas using the ocean products made available by EuroMISS services (cf. Figure 2-11). EuroDeSS does not aim to be a 'single pan-European decision support system'. Instead, EuroDeSS is aiming to provide better harmonisation regarding the way decision support systems for coastal seas are developed and deployed across Europe by embodying best practises (e.g. use of OGC standards) for similar decision support systems, and providing a framework for establishing local, regional and pan-European services for the coastal and shelf seas. The targeted decision support applications developed in EuroDeSS cover three key GMES/GEO marine service areas:

- Marine security (oil spill and search-and-rescue response support)
- Ecosystem health (eutrophication, harmful algal blooms)
- Fisheries assessment

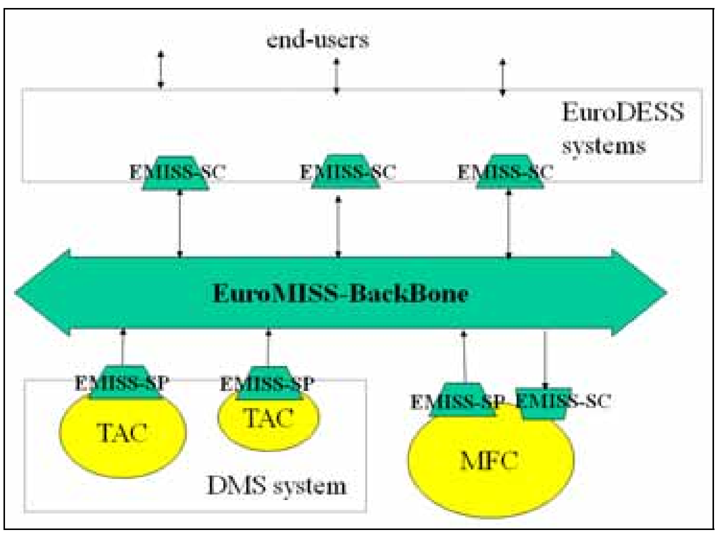

Figure 2-11 EUROMISS service-oriented architecture consisting of service providers and consumers (source: http://www.ecoop.eu/documents/presentations/02-ECOOP-EUROMISS.ppt)

2.2.8 *EC FP7 MyOcean*

MyOcean is an FP7 project (2009-2012) funded by the European Commission within the GMES Program. Its objective is to provide a Core Service for the Ocean. This means MyOcean is setting up pre-operational services for forecasts, analysis and expertise on ocean currents, temperature, salinity, sea level, primary ecosystems, and ice coverage. The production of observation and forecasting data is distributed through twelve production centres. There are five TACs (Thematic Assembly Centres) covering satellite and in situ observations and seven MFCs (Monitoring and Forecasting Centres) covering ocean forecasting in six European basins plus the global ocean. The interface with the external users (including web portal) and the coordination of the overall service is managed by a component called service desk. A transverse component called MIS (MyOcean Information System) aims at connecting the production centres and service desk together, manage the shared information for the overall system, and implement a standard INSPIRE interface for the external world. The categories of information to be shared are:

1. Ocean products:
   a. Metadata for discovery and system configuration management (e.g. product lifecycle: demonstration, operational, retired, ...)
   b. Images (view)
   c. Data (download)

2. System monitoring and assessment:
   a. Production inventory
   b. Sub-components (production centres, service desk, MIS) availability and reliability.
   c. User's transactions

3. In addition, ancillary information is required :
   a. Reference vocabularies (e.g. ocean variable names, …)
   b. Registered users and authorisations

From a MyOcean top-level system requirement definition, the required information flows have been defined. How each component (i.e. production centres, MIS, service desk) is involved has also been defined from top-level architecture work. From these requirements, working groups have been set up to define how technically speaking these interfaces will be implemented. These definitions rely on:

- MyOcean functional requirements;
- Work done on previous European projects (MERSEA, ECOOP, SeaDataNet, BOSS4GMES, MarCoast,...), European directives and interoperability requirement (INSPIRE, OGC, WIS, IOOS, IMOS, HMA,...) or pre-existing working group (e.g. OGC MetOceanDWG);
- Technical constraints at production centres (available infrastructures, requirements from pre-existing services, e.g. at national, European, or international level).

The chosen interface definitions (most of them among commonly agreed ocean or geo-spatial standards: netCDF-CF, OPeNDAP, OGC CSW, and OGC WMS) are described in architecture documents which are the basis for MyOcean system implementation. These documents, currently confidential, introduce MyOcean specific conventions agreed for internal interoperability within the system. Figure 2-12 illustrates the overall MyOcean architecture. Standard protocols, such as OGC WMS, OPeNDAP and FTP, are used for communication between the MyOcean subsystems. MyOcean is developing an INSPIRE compliant metadata profile which is being implemented using ISO 19139. This MyOcean metadata profile is currently a draft, and covers three types of (static) metadata:

- Product line metadata (maps to ISO 19115 metadata type “nonGeographicDataset”)
- Product specification metadata (maps to ISO 19115 metadata type “series”)
- Service metadata (maps to ISO 19115 metadata type “service”)

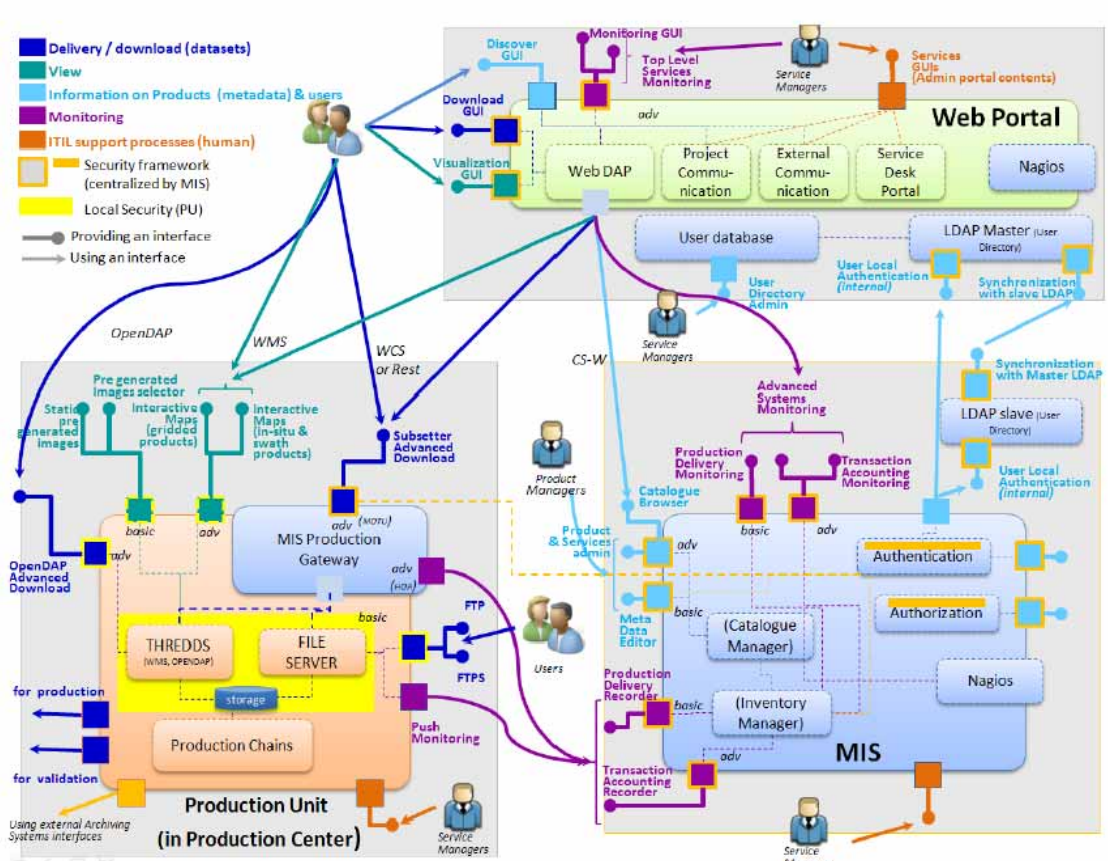

Figure 2-12 Overview of MyOcean architecture (courtesy of MyOcean)

2.2.9 *EC FP7 GENESIS*

GENESIS (GENeric European Sustainable Information Space for Environment) is an FP7 Integrated Project (2008-2011) whose primary objective is to “provide those involved in environmental management and health services in Europe with an efficient, web-based solution to monitor air and water quality” [GENa]. To achieve this, GENESIS will develop a generic system architecture based on SOA (service-oriented architecture) principles, comprised of a set of web services and web clients that can be integrated and customised in a generic portal framework [SPB09]. All software developed by GENESIS will be compliant with existing open web services and web-GIS standards from W3C, CEN, ISO, OGC and OASIS, and compatible with GEOSS and the INSPIRE Network Service architecture [INSNA]. Figure 2-13 illustrates the GENESIS architecture, which contains the following services and framework components:

- A set of metadata catalogue services adhering to the latest version of the CSW interfaces. These catalogue services will provide access to both environmental data sets (remote sensing, in situ, non-GIS) as well as services.
- A set of downloading services for accessing raster, vector and sensor data according to the latest version of the OGC WFS, WCS and SOS specifications.
- A set of services for data processing and combination, including the WPS standard but also using new approaches such as OpenMath [BCCD+04] for expressing scientific computations.
- A workflow engine allowing multiple services to be chained together to form new services.

- A set of communication services enabling other services exchange messages using an event driven approach.
- A security layer for authentication and authorisation, including user management.
- A generic portal framework termed GPPF (Generic Portal & Portlets Framework) based on JSR 286 [Hepper08].
- A set of tools or frameworks for integration and deployment of thematic portals and services.

GENESIS is currently developing six thematic pilots (http://genesis-fp7.eu/thematic_pilots):

- Air quality pilot in London (UK)
- Water Quality Pilot on Bodensee/Constance Lakes (Germany)
- Air quality pilot on Bavaria (Germany)
- Water quality pilot on Oder Estuary (Baltic Sea)
- Water quality pilot on Villerest Reservoir (France)
- Air and Coastal Water Quality Pilot on French Riviera

Each pilot system is described using the RM-ODP methodology [Put00] in a technical specification [DLR09] [SGH09] [ACRI09], incorporating those services and portal components from the GENESIS generic system architecture that are needed to fulfil the identified user requirements for the particular application. These pilots will demonstrate how the generic architecture and software tools can be customised to meet the needs of a specific thematic application. The experience from building the pilots will be used to refine the GENESIS generic architecture and enhance the functionality and performance of the developed tools and frameworks.

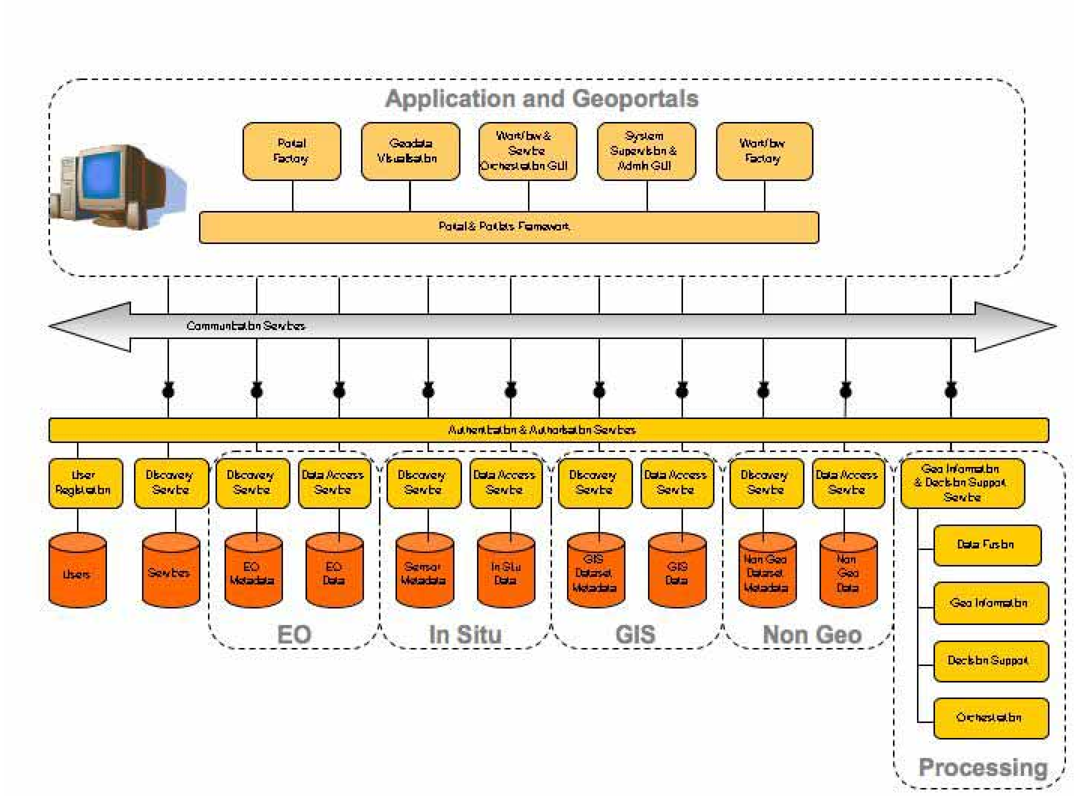

Figure 2-13 GENESIS system architecture
(source: http://genesis-fp7.eu/technologies/technology_integration)

2.2.10 *EC FP7 GENESI-DR*

Ground European Network for Earth Science Interoperations - Digital Repositories (GENESI-DR) is an FP7 project initiated in 2008 under ESA coordination. The project builds on the existing operational Earth observation infrastructure in Europe, and includes key Earth science centres for operational data acquisition, processing, archiving and distribution. The GENESI-DR consortium is comprised of national space agencies from Germany (DLR), Italy (ASI) and France (CNES); space and non-space data providers such as ENEA (Italy), Infoterra (UK), K-SAT (Norway), NILU (Norway), JRC (EU); and industry companies, such as Elsag-Datamat (Italy), CS (France) and TERRADUE (Italy) [FC10].

The aim of GENESI-DR is to offer a framework that allows scientists from different Earth Science disciplines to have access, to combine and to integrate all historical and present Earth-related data from space, airborne and in situ sensors available from all digital repositories distributed all over Europe. A web portal has been developed, providing “a single access point to Earth Science data”. In fact, all services made available by GENESI-DR provide open interfaces that can be individually accessed. Figure 2-13 gives an overview of the data currently federated through GENESI-DR. All metadata are free and publicly available. Metadata is compliant with INSPIRE Implementing Rules and uses OpenSearch protocol with Geo extensions for data and services discovery [PLB+08]. Data which are discoverable and accessible through GENESI-DR is archived at the data provider.

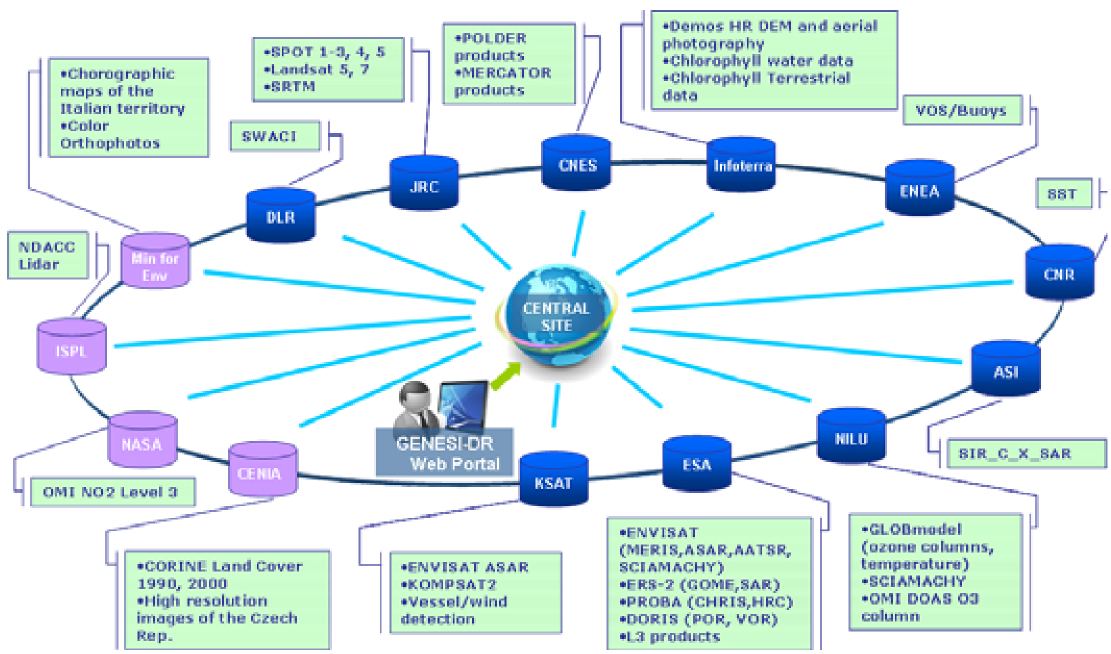

Figure 2-14 GENESI-DR federated Digital Resources and available dataset series (source http://portal.opengeospatial.org/files/?artifact_id=38175)

The GENESI-DR system architecture is based on SOA with services communicating through SOAP [W3C07] and REST [Fielding00] interfaces. The architecture is layered and organised in four horizontal layers and one cross-cutting layer (Figure 2-15) [PLB+08]. The lowest layer (number 4 in Figure 2-15) contains the digital resources such as data repositories that are available in the GENESI-DR system, and services for generating, publishing and updating metadata for these data. The layer above (number 3) contains a suite of web services for accessing the data and metadata resources through standard protocols, including among others multiple OGC protocols, OPeNDAP and Grid services. The core services layer (number 2) contains services for data discovery and access, service chaining and execution (including Grid services), as well as user management. The top layer (number 1) contains the user client services, and includes among others the GENESI-DR Web Portal and various data transfer clients. The cross-cutting layer (number 5) provides services for securing access to services and data, including authentication and authorisation, over a secure communication protocol (HTTPS or SOAP over HTPPS).

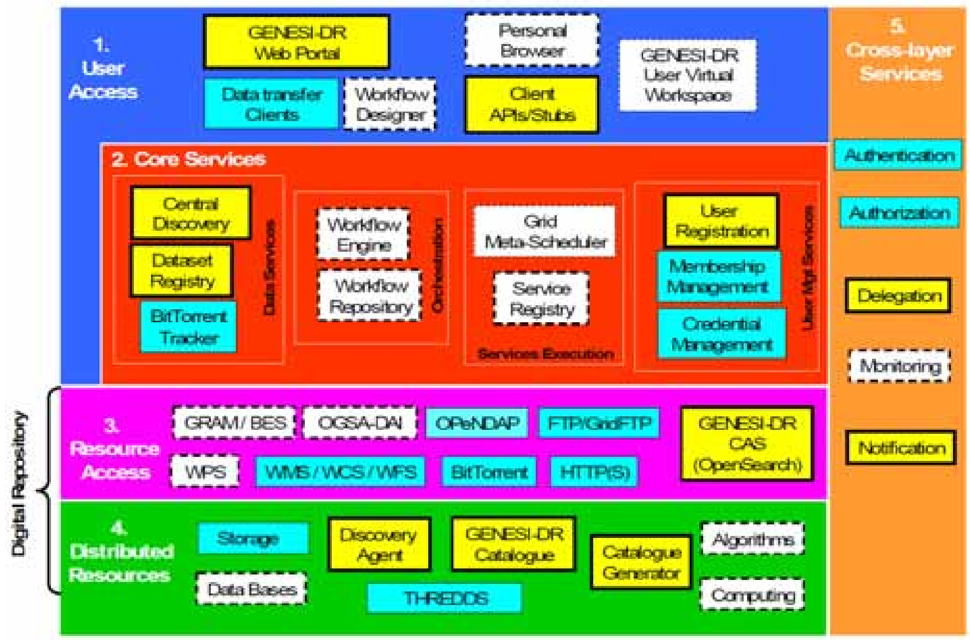

Figure 2-15 The GENESI-DR layered architecture
(source: http://www.genesi-dr.eu/documents/GENESI-DR-SA2-DEL-DSA2.1-v1.0.pdf)

2.2.11 *EC FP7 GIGAS*

GIGAS (GEOSS INSPIRE and GMES Action in Support) is an FP7 project (2008-1010) whose overall objective is to facilitate "a rapid adoption of standards, protocols and open architectures in support of INSPIRE, GMES and GEOSS initiatives" [GC09a]. As such the project is not developing an architecture by itself, but instead analysing and documenting the architectures originating from these three initiatives and selected FP6/FP7 projects (ORCHESTRA (section 2.2.1); SANY (section 2.2.2), GENESI-DR (section 2.2.10)) using a common methodology for system architecture design, RM-ODP [Put00]. In addition, GIGAS is performing a comparative analysis of these architectures to identify both possibilities for synergies as well as potential obstacles to interoperability between the systems and services developed in these initiatives and projects [GC09b].

The analysis and documentation of existing architectures and services in the chosen initiatives and projects is termed the "GIGAS Technology Watch", and addresses the following aspects of system development:

- Architecture
- Catalogue-Metadata-Discovery
- Data Access and Processing
- Data Harmonisation – Semantic Interoperability
- Cross-initiative Scenario
- User Management

Each of the investigated architectures is described by RM-ODP's five viewpoints: (1) the enterprise viewpoint, (2) the information viewpoint, (3) the computational viewpoint, (4) the engineering viewpoint, and (5) the technology viewpoint [GC09d]. This work has identified differences in among others, the underlying information model for the systems and in the realisation of a service-oriented architecture as well as the underlying services. Also, key concepts like "Service" may have different semantics in the different systems and GIGAS recommends further effort should be put into clarifying such differences to enable future interoperability between the systems.

The "Catalogue-Metadata-Discovery" theme is describing what OGC, ISO and OASIS (Organization for the Advancement of Structured Information Standards) standards are being used for storing and accessing metadata for datasets and services, and what versions of the protocols are used in each system (Table 3 and 4 in [GC09b]). Metadata and catalogue services are fundamental in any spatial data infrastructure, and while individual systems offer such services, many of them powerful, it is not possible to perform harmonised searches across the investigated systems yet.

Data access and processing services are realised using OGC and OASIS standards such as WMS (Web Map Service) and WMS Tiled (which is not included yet due to lack of an approved implementation specification) for map display, WPS (Web Processing Service) and BPEL (Business Processing Execution Language) workflows for data processing services, SPS (Sensor Planning Services) for scheduling and acquiring data from sensors, feature access services by WFS (Web Feature Service) and WCS (Web Coverage Service) for coverage access services. In addition, ordering is identified as one of the recurring services across the investigated systems, but with differing semantics and solutions in each initiative, and less mature protocols and implementation tools available.

The analysis of data harmonisation and semantic interoperability has focussed on identifying the opportunities and possible obstacles to achieving two key scenarios: (1) "the reuse of European data in a global context" and (2) "the cross-initiative scenario where a client accesses data from different initiatives in parallel". These two scenarios are then defined in more detail as specific scenarios including what data should be used, which provider(s) will supply the various data, which services to use, etc. [GC09c].

User management is defined differently in the investigated systems, even if there are also many similarities. For instance, the GMES CDS DAIL (Coordinated Data access System Data Access Integration Layer) is currently implementing user management handling based on industry standard technologies, while INSPIRE has identified some elements of user management as part of the "Network Services" development.

The GIGAS comparative analysis is ongoing and will lead to a set of recommendations for how the different initiatives can continue developing their systems in line with their plans while taking into account amendments that can facilitate interoperability with systems implemented by the other initiatives and relevant FP6/FP7 projects. These recommendations are currently in draft form [GC09e]. However, is it expected that this document will be finalised and made publicly available during summer or autumn 2010. With major players in INSPIRE, GMES and GEOSS as partners in GIGAS, these recommendations are foreseen to be adopted in these initiatives as well as in a number of projects developing environmental information systems. These recommendations will therefore be a valuable resource for NETMAR when designing the system architecture for the European Marine Information System (EUMIS).

2.2.12 *IODE Ocean Data Portal*

The Ocean Data Portal (ODP) aims to provide access to marine data from the NODCs (National Oceanographic Data Centres) of the IODE (International Oceanographic Data and Information Exchange) network. It allows for the discovery, evaluation (through visualisation and metadata review) and access to data. The IODE is working closely with the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) to ensure that ODP is interoperable with the WMO Information System (WIS) which will provide access to marine meteorological and oceanographic data and information. Different data standards and formats have evolved within the oceanographic community, thus, making data exchange complex. The IODE community has recognised standards are critical in defining how and what data is exchanged. The IODE, together with JCOMM, has initiated a standards process to better support the official approval and adoption of core standards by the marine meteorological and oceanographic communities [ODP].

The Ocean Data Portal architecture is illustrated in Figure 2-16. It uses web technologies to access non-homogeneous and geographically distributed marine data and information. The architecture consists of three main components [ODP]:

- Data Provider
- Integration Server
- ODP Services

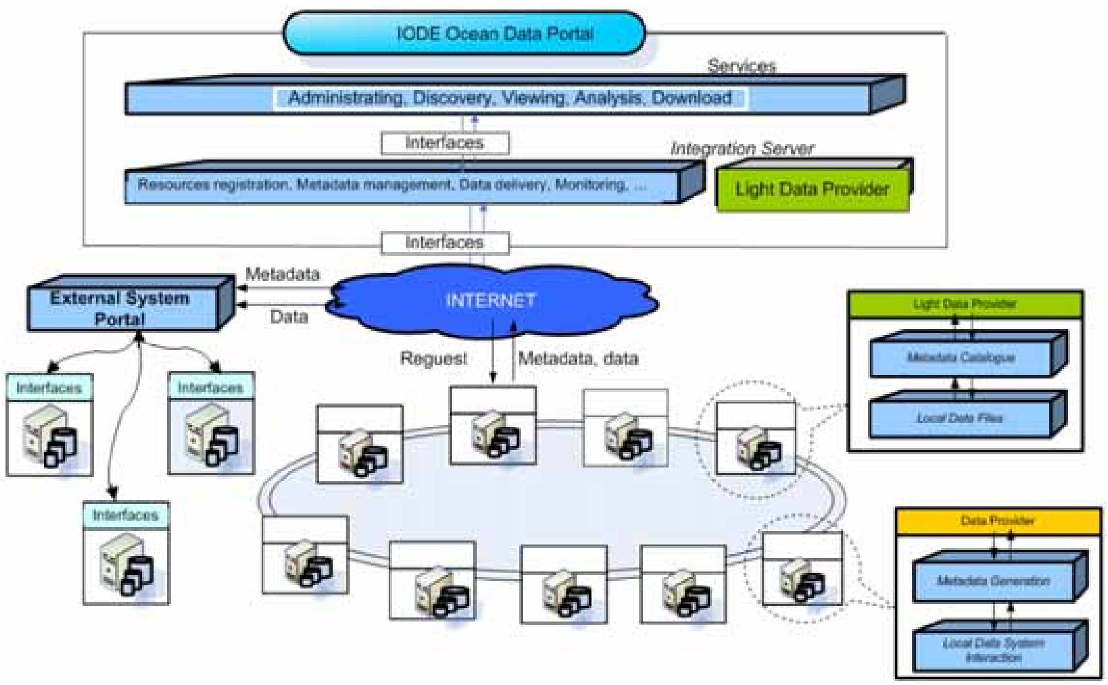

Figure 2-16 Ocean Data Portal V1 architecture
(source: http://www.oceandataportal.org/images/stories/odp/documents/brochure_ocean%20data%20portal_rev_sb_16022010.pdf)

The Data Provider component is installed at the data centre. It processes local databases and automatically generates discovery metadata and data transport files. This component uses OPeNDAP data structures. Metadata is presented in an XML format based on the ISO 19115 standard. However, a "light" version of the Data Provider component has recently been added, which does not need to be installed at the data centre. Instead, this "light" version enables registration of local datasets using existing metadata catalogues based on metadata standards including WIS (cf. section 2.1.3), CDI (cf. section 2.2.6), and MCP (Marine Community Profile).

The Integration Server component harvests discovery metadata from the Data Provider and provides access to distributed data held at the Data Provider. It can also interact with other systems through discovery metadata exchange, and provides additional functionally such as resource registration, status monitoring, etc.

The ODP Services component provides functionality including administration, discovery, viewing, analysis and download. Much of these services are integrated into a public web-based portal which includes a web mapping user interface, metadata and data search, data download and visualisation components. The data transport file formats available for download include netCDF (E2E convention), ASCII, and XML. In addition, ODP Services include a number of W3C web services and OGC web services (WMS).

2.2.13 *NOAA Observing System Monitoring Center*

The Observing System Monitoring Center (OSMC) system is a web-based tool to assist managers and scientists with monitoring the global in-situ ocean observing system, identifying problems in real-time, and evaluating the adequacy of the observations in support of ocean/climate state estimation, forecasting and research. The OSMC system provides data visualisation tools to identify the coverage of any given collection of platforms and parameters. OSMC is funded by the U.S. National Oceanic and Atmospheric Administration's (NOAA) Office of Climate Observation (OCO) [OSMC].

OSMC is primarily built of two components: a database of metadata, and tools to assist with the interpretation of this metadata. Metadata includes the times, locations, platform information, parameters measured, and web links to more information such as access or visualisation of the data. Metadata integration under OSMC consists of real-time and historical observations metadata. Real-time observations are primarily sourced from GTS observations. As GTS is a mature system, this proved a good starting point. Therefore, GTS was integrated into the OSMC first. Next, the focus has moved to the integration of archived observations metadata from Data Assembly Centers (DACs). This includes delayed-mode data which may be released months after the observations were taken. However, such data can be difficult to use because it is poorly integrated due to a lack of common standards. Therefore, OSMC is working in partnership with the DACs. As systems within the DACs mature, then OSMC can better integrate their metadata and data. The key to improved integration are the use of common standards such as netCDF-CF, OPeNDAP, SOS, etc. For example, OSMC are working with the U.S. Integrated Ocean Observing System (IOOS) to expose IOOS data through the OSMC system [OBRI08]. IOOS are using technologies such as SOS for in-situ observation data [IOOS].

2.2.14 *Ocean Biogeographic Information System*

The Ocean Biogeographic Information System (OBIS) was established by the Census of Marine Life program. It is an evolving strategic alliance of people and organisations who share a common vision to make marine biogeographic data from all over the world freely available over the Web. In June 2009, OBIS was adopted by the Intergovernmental Oceanographic Commission (IOC) of UNESCO, as one of its activities under its International Oceanographic Data and Information Exchange (IODE) [OBIS].

OBIS uses an XML-based data format called OBIS schema. It is an extension to the Darwin Core Version 2 standard. Darwin Core includes a glossary of terms intended to facilitate the sharing of information about biological diversity by providing reference definitions, examples, and commentaries. The Darwin Core is primarily based on taxa, their occurrence in nature as documented by observations, specimens, and samples, and related information [DARWIN]. The OBIS Schema contains some additional fields for holding information that the Darwin Core does not handle. Compliance with the OBIS data schema is enforced either by using a standard Excel spreadsheet layout or by using the open source DiGIR (Distributed Generic Information Retrieval) software. DiGIR is the software through which OBIS communicates with its distributed data providers. A high level overview of the DiGIR architecture is illustrated in Figure 2-17. When a user of the OBIS portal inputs and submits in a query, DiGIR sends that query to the distributed data providers. Here, each data provider translates the query into a local query on their internal database. The results are then sent back to the OBIS portal [OBIS].

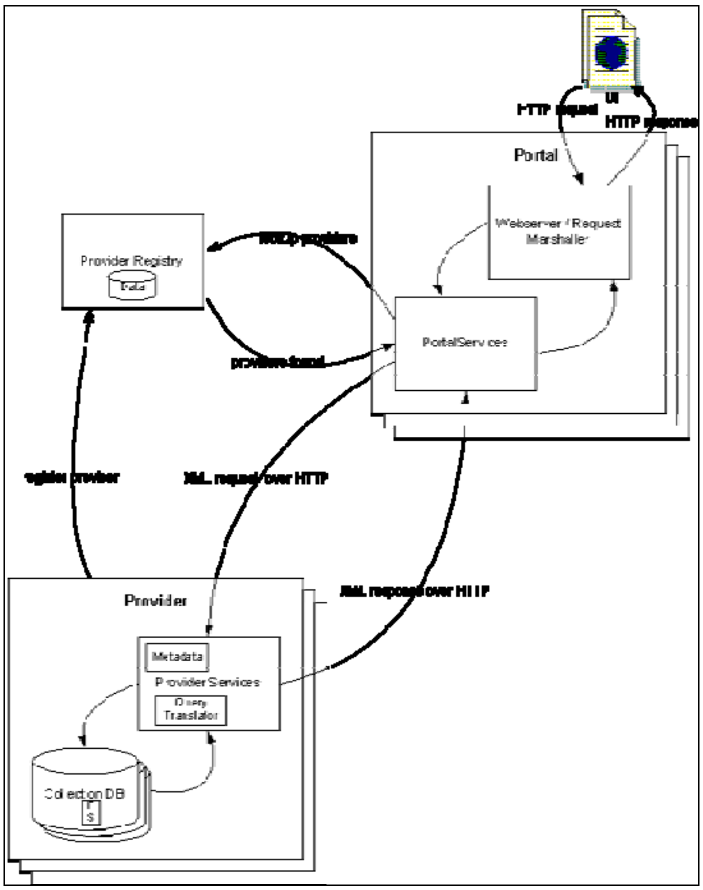

Figure 2-17 DiGIR high-level architecture version 1.0
(source: http://digir.sourceforge.net/gen/architecture_1_0.gif)

3 Service-oriented architecture principles and standards

This chapter summarises architecture solutions and standards, which were reviewed and referenced in the last chapter within the context of various initiatives and projects. It outlines SOA principles, and standards from the Internet Engineering Task Force (IETF), the World Wide Web Consortium (W3C), the Organization for the Advancement of Structured Information Standards (OASIS), ISO/TC 211 Geographic information/Geomatics, and the Open Geospatial Consortium (OGC).

3.1 Service-oriented architecture (SOA)

A service is defined in ISO 19119 as a "distinct part of the functionality that is provided by an entity through interfaces" [ISO19]. A service consists of a service provider and a service consumer. The service provider is a component/application that provides distinct information and/or functionality to consumer components/applications. The consumer accesses a service by binding to the service provider's interface. A service provider can also publish their interface in a service registry. This enables a service consumer to dynamically find a service and its endpoint, which is then used to bind to and invoke the service.

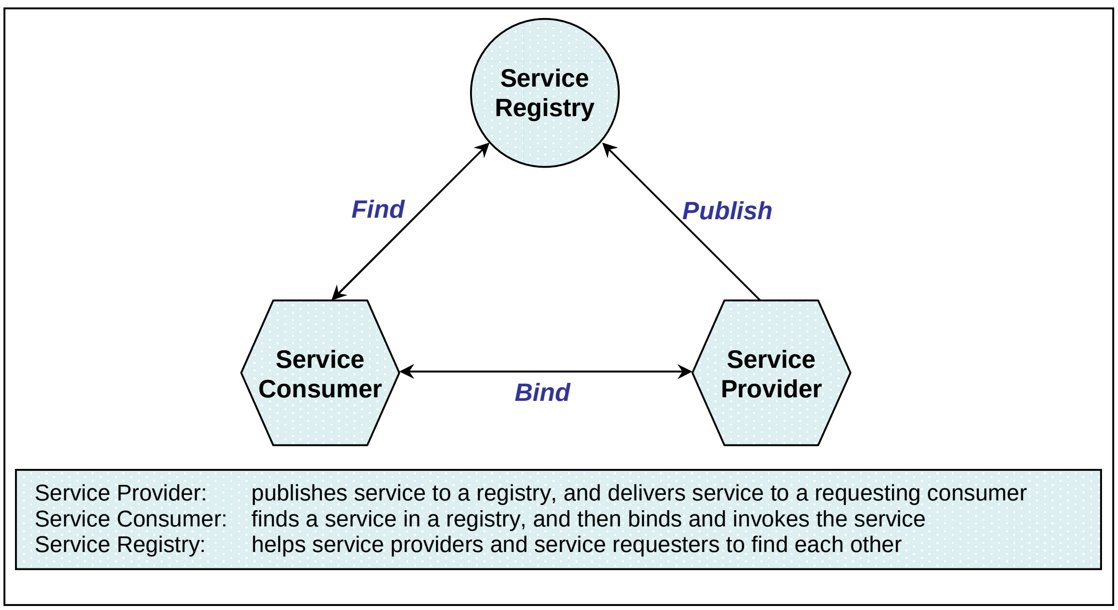

Figure 3-1 Service-oriented architecture

Because each service component or application is accessed via a well described interface, this encourages a loosely coupled architecture design. This enables service components and applications to be more reusable and interoperable in cost effective manner. Service-oriented architectures can be implemented using web services. This enables service components or applications to be accessible over the Internet in a distributed fashion. Web services can be implemented using bindings such as SOAP (Simple Object Access Protocol), Key-Value Pair (KVP), XML-RPC, etc. Such bindings are based on procedural style interfaces. An alternative binding approach is based on the resource-oriented architecture (ROA) style using REST. RESTful URLs rely purely on hyper-referenced and atomic resources. Typically, this is achieved by encoding the service operation parameters into the URL as path elements rather than, for example, as named KVP elements.

3.2 Internet Engineering Task Force (IETF)

The Internet Engineering Task Force (IETF) (http://www.ietf.org/) develops and promotes Internet standards, in particular the Internet Protocol Suite which makes up the backbone of the Internet. Internet protocol standards are published in technical reports called Request For Comments (RFC). IETF has published several protocol standards and best current practice protocols. Relevant protocols include [IETF]:

- HTTP (Hypertext Transfer Protocol)
- FTP (File Transfer Protocol)
- MIME (Multipurpose Internet Mail Extensions)

3.3 World Wide Web Consortium (W3C)

The World Wide Web Consortium (W3C) (http://www.w3c.org) mission "is to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web" [W3CMI]. W3C has published several recommendations which are consensus specifications. Relevant recommendations include [W3CST]:

- **Extensible Markup Language (XML)**
  XML is a well formed textual information format. XML is widely used as a means for the open exchange of a variety of data on the Web.

- **XML Schema**
  XML Schema is used describe the structure of the XML document, including any constraints and grammatical rules. The XML Schema Definition (XSD) language is typically used to specify an XML Schema.

- **XSL Transformation (XSLT)**
  XSLT is a stylesheet language used to transform an XML document into other XML documents.

- **XML Path Language (XPath)**
  XPath is a query language used to select nodes from an XML document.

- **SOAP**
  SOAP is an XML based messaging and remote procedure call specification that enables the exchange of information among distributed systems.

- **Web Services Description Language (WSDL)**
  WSDL is an XML language for describing Web services, and is often used in combination with SOAP.

- **Resource Description Framework (RDF)**
  RDF is defined by W3C as "a framework for representing information in the Web".

- **RDF Vocabulary Description Language: RDF Schema (RDF-S)**
  RDF Schema further extends RDF by enabling it to describe RDF vocabularies.

- **Simple Knowledge Organization System (SKOS)**
  SKOS provides a standard data model to represent knowledge such as thesauri, classification schemes, taxonomies, subject-heading systems, and taxonomies using the RDF.

- **Web Ontology language (OWL)**
  OWL is defined by W3C as "an ontology language for the Semantic Web with formally defined meaning". It has more facilities for expressing meaning and semantics than XML, RDF, and RDF-S, and thus OWL goes beyond these languages in its ability to represent machine interpretable content on the Web.

- **SPARQL (OWL)**
  SPARQL is a RDF query language.

3.4 Organization for the Advancement of Structured Information Standards (OASIS)

The Organization for the Advancement of Structured Information Standards (OASIS) (http://www.oasis-open.org) is a non-profit consortium that drives the development, convergence and adoption of e-business and web service standards. Relevant standards from OASIS include [OASIS]:

- **Universal Description, Discovery and Integration (UDDI)**
  UDDI enables organisations to publish and register their web services including contact information and the technical interfaces which may be used to access these web services.

- **Business Process Execution Language (BPEL)**
  Business Process Execution Language (BPEL), or Web Services Business Process Execution Language (WS-BPEL), defines a language for specifying business process behaviour based on Web Services.

3.5 ISO/TC 211 Geographic information/Geomatics

The International Organization for Standardization (ISO) (http://www.iso.org) is the most established and recognised developer and publisher of International Standards. ISO also publishes standards specific to geographic data through ISO Technical Committee 211 (ISO/TC 211) Geographic information/Geomatics (http://www.isotc211.org). ISO/TC 211 provides standards and technical reports for the methods, tools and services for managing, acquiring, processing, analysing, accessing and presenting geospatial data. It also provides a framework for developing interoperable spatial applications where geospatial data can be shared and exchanged between different systems. ISO/TC 211 develops the ISO 191XX series of standards. ISO/TC211 currently has approximately 60 international standards and technical reports. Many of these standards are both directly and indirectly relevant to NETMAR. Current standards and proposed standards include [ISOFS]:

- ISO 6709 – Standard representation of latitude, longitude and altitude for geographic point locations
- ISO 19101 – Reference model
- ISO 19103 – Conceptual schema language
- ISO 19104 – Terminology
- ISO 19105 – Conformance and testing
- ISO 19106 – Profiles
- ISO 19107 – Spatial Schema
- ISO 19108 – Temporal Schema
- ISO 19109 – Rules for application schema
- ISO 19110 – Methodology for feature cataloguing
- ISO 19111 – Spatial referencing by coordinates

- ISO 19112 – Spatial referencing by geographic identifies
- ISO 19113 – Quality principles
- ISO 19114 – Quality evaluation procedures
- ISO 19115 – Metadata
- ISO 19116 – Positioning services
- ISO 19117 – Portrayal
- ISO 19118 – Encoding
- ISO 19119 – Services
- ISO 19120 – Functional standards
- ISO 19121 – Imagery and gridded data
- ISO 19122 – Qualification and certification of personnel
- ISO 19123 – Schema for coverage geometry and functions
- ISO 19125 – Simple feature access
- ISO 19126 – Feature concept dictionaries and registers
- ISO 19127 – Geodetic codes and parameters
- ISO 19128 – Web map server interface
- ISO 19129 – Imagery, gridded and coverage data framework
- ISO 19130 – Imagery sensor models for geopositioning
- ISO 19131 – Data product specification
- ISO 19132 – Location-based services - Reference model
- ISO 19133 – Location-based services - Tracking and navigation
- ISO 19134 – Location-based services - Multimodal routing and navigation
- ISO 19135 – Procedures for item registration
- ISO 19136 – Geographic markup language (GML)
- ISO 19137 – Core profile of the spatial schema
- ISO 19138 – Data quality measures
- ISO 19139 – Metadata - XML Implementation Specification
- ISO 19141 – Schema for moving features
- ISO 19142 – Web Feature Service
- ISO 19143 – Filter encoding
- ISO 19144 – Classification systems
- ISO 19145 – Registry of representations of geographic point location
- ISO 19146 – Cross-domain vocabulary
- ISO 19147 – Transfer nodes
- ISO 19148 – Linear referencing
- ISO 19149 – Rights expression language for geographic information - GeoREL
- ISO 19150 – Ontology
- ISO 19151 – Logical location identification scheme
- ISO 19152 – Land Administration Domain Model (LADM)
- ISO 19153 – Geospatial Digital Rights Management Reference Model (GeoDRM RM)
- ISO 19154 – Standardization Requirements for Ubiquitous Public Access
- ISO 19155 – Place Identifier (PI) Architecture
- ISO 19156 – Observations and measurements
- ISO 19157 – Data quality
- ISO 19158 – Quality assurance of data supply
- ISO 19159 – Calibration and validation of remote sensing imagery sensors and data
- ISO 19160 – Addressing

3.6 Open Geospatial Consortium (OGC)

The Open Geospatial Consortium (OGC) defines standards and best practices, both for data models and for geospatial web services. It promotes interoperability in the fields of geographic data by defining standard interfaces and implementation guidelines for geospatial data and geo-processing services. The OGC develops two mains sets of standards at conceptual level (abstract specifications) and at implementation level (implementation specifications). Relevant OGC standards include:

- Catalogue Service for the Web (CSW)
- Web Map Service (WMS)
- Web Map Tile Service (WMTS)
- Web Feature Service (WFS)
- Web Coverage Service (WCS)
- Web Processing Service (WPS)
- Web Map Context (WMC)
- Geography Markup Language (GML)
- Sensor Observation Service (SOS)
- Symbology Encoding (SE)
- Styled Layer Descriptor (SLD)
- Filter Encoding Standard (FES)
- Keyhole Markup Language (KML)
- Geospatial Digital Rights Management (GeoDRM) Reference Model
- Uncertainty Markup Language (UnCertML) (currently a discussion paper)

Existing OGC web services support a mix of protocols and technology bindings. These bindings are [INSSO]:

- Key-Value-Pairs (KVP) via HTTP GET
- XML send via HTTP POST
- SOAP via HTTP POST

Also, some OGC specifications currently under development are considering the inclusion of RESTful bindings (e.g. WMTS).

Many OGC standards are relevant to NETMAR because this project is developing a network of services supporting the integration of satellite, in situ and numerical model data. Therefore, OGC standards concerning data discovery, data portrayal, data access, and data processing are discussed in more detail in chapters 4 to 7.

4 Data discovery standards and tools

This chapter outlines service standards and tools which enable discovery of geospatial data.

4.1 Metadata

4.1.1 *Overview*

Metadata is "data about data", and consists of information that describes content, quality, type, creation, condition of use, source and other characteristics about that geospatial dataset. In essence, metadata documents the dataset resource. Metadata falls into broad categories to answer the "what, why, when, who, where and how" questions about geospatial data. These questions include [SDI]:

- **What**: title and description of the dataset.
- **Why:** abstract detailing reasons for the data collection and its uses.
- **When:** when the dataset was created and the update cycles, if any.
- **Who:** originator, data supplier, and possibly the intended audience.
- **Where**: the geographical extent based on latitude/longitude coordinates, geographical names or administrative areas.
- **How:** how the dataset was produced and how to access the dataset.

Metadata may exist at the collection level (e.g. a satellite series), at a data product level (an image mosaic), at a data unit level (a vector dataset), a group of features of a given type (certain roads), or even at a specific feature instance (a single road) [SDI]. In these examples, metadata is used to describe geospatial data. In addition, metadata can also be used to describe geospatial services, which typically includes information on how to access and invoke such services.

4.1.2 *Standards*

In order for geospatial metadata to operate effectively between different organisations and data users, metadata must be compliant to international standards. Such standards provide a common structure and format to describe metadata. Standards enable improved metadata interoperability and integration, thus, facilitating more seamless sharing, searching, and discovery of metadata between organisations and users of geospatial data and services. Discovery metadata is the minimum amount of information that needs to be provided to help people find geospatial resources. Notable international metadata standards in use today include:

- ISO 19115 (Geographic information – Metadata)
- ISO 19119 (Geographic information – Services)
- ISO 19139 (Geographic information – Metadata – XML schema implementation)
- FGDC Content Standard for Digital Geospatial Metadata (CSDGM)
- Dublin Core

Governments and organisations are widely adapting the ISO 19115/19119 standards using the ISO 19139 XML implementation. While metadata entities and elements are well defined within the ISO standards, there is an extensive list of optional metadata elements on top of the mandatory metadata element set (ISO 19115 Core). It is left up to the system developer to define a specific information model or profile. There is no single metadata profile that fits all users' needs. Therefore, there is a need for metadata profiles to be adapted to support various regions, nations, organisations, and communities' needs.

Within the U.S., the FGDC metadata standard is the federal metadata standard that was developed in the 1990s. The FGDC model is currently being revised, where a U.S. Profile of ISO 19115 is being developed.

Within Europe, the INSPIRE Directive has defined a base metadata profile, which also builds on the underlying 19115 standard. However, full conformance to the ISO 19115 Core elements implies the provision of additional metadata elements which are not required by INSPIRE. Also, the conformance of an ISO 19115 metadata set to the ISO 19115 Core does not guarantee the conformance to INSPIRE. The exact relationship between the ISO 19115 Core and the INSPIRE core is detailed in the guideline report "INSPIRE Metadata Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119" [INSMI].

4.1.3 *Tools available*

A metadata editor is a program that is used for creating and editing metadata. It also contains utilities for pre-processing, post-processing, extracting, validating, and viewing metadata. Many metadata editors exist, some notable editors include:

- ESRI ArcCatalog (http://www.esri.com)
- GeoNetwork (http://geonetwork-opensource.org)
- INSPIRE Geoportal Metadata Editor (http://www.inspire-geoportal.eu)

4.1.4 *Recommendations*

It is recommend that NETMAR use ISO 19115 metadata to describe both dataset-series and datasets as appropriate, and use ISO 19119 to describe services. ISO 19115 and ISO 19119 should be implemented using the ISO 19139 XML implementation.

For static metadata it is recommended to use GeoNetwork as an editing tool, unless specific partners have special requirements and need to use an alternative tool. GeoNetwork is open source (GPL license) and supports ISO 19115/19119 and ISO 19139. For more dynamic metadata concerning data production, it is recommended that a data provider use a scripting/programming language of choice to automate metadata production.

It is recommended that NETMAR develops modular metadata rules for dataset-series and dataset (ISO 19115), and services (ISO 19119) based on minimum NETMAR requirements. Considerations for modular metadata rules include:

1. NETMAR semantic framework requirements (e.g. vocabularies, etc.);
2. NETMAR uncertainty propagation requirements (e.g. data quality parameters, etc.);
3. INSPIRE metadata profiles (i.e. a requirement within Europe);
4. ISO 19115 Core elements;
5. CSW - ISO Metadata Application Profile (cf. section 4.2).

For example, one set of rules may specifically deal with the metadata requirements for semantic frameworks, while another set of rules specifically deals with metadata requirements for uncertainty propagation. Use cases can then implement or extend a bespoke metadata profile and adapt relevant rule sets in order to implement particular NETMAR functionality (e.g. connect to semantic framework) or meet special metadata conformance needs (e.g. INSPIRE compliance). Such an approach is important at it gives more scope to plug-in multidomain use cases, and does not isolate any particular region or community who may have additional metadata requirements or constraints.

4.2 OGC Catalogue Service for the Web (CSW)

4.2.1 *Overview*

Catalog Services for the Web (CSW) is an OGC specification that defines common interfaces and operations to discover, retrieve and query metadata. It supports the ability to publish and search collections of metadata describing data, services, and related information objects [CSW202]. It enables a client application to search or query metadata in distributed catalogues. Query languages supported by CSW are CQL (Common Query Language) and OGC FILTER. Typically, CSW catalogues return an ISO 19115 or ISO 19119 metadata profile implemented using an ISO 19139 XML schema. Protocol bindings described in the standard include HTTP (KVP and SOAP), ISO 23950/ANSI Z39.50, and CORBA/IIOP.

While the interfaces and operations of OGC catalogue services are well defined, it is left up to the system developer to define a specific information model for the catalogue service implementation. This includes mandatory and optional metadata elements to be incorporated in the catalogue, supported query languages, available search terms, results, etc. Experience has shown there is no single solution for catalogue services that fits every user's needs. Therefore, there is a need for application profiles [CSWISO]. Base profiles exist for the search and retrieval of ISO 19115/19119 metadata. These profiles provide a basic set of information objects has to be supported by each catalogue instance. Profiles include the ISO Metadata Application Profile (version 1.0.0) and the ebRIM Profile (version 1.0.1). Both profiles support HTTP bindings using KVP or SOAP.

4.2.2 *Tools available*

The main open source CSW servers include:

- Constellation (http://constellation.codehaus.org)
- deegree (http://www.deegree.org)
- GeoNetwork (http://geonetwork-opensource.org)
- GI-cat (http://zeus.pin.unifi.it/cgi-bin/twiki/view/GIcat)

4.2.3 *Recommendations*

It is recommended to use CSW 2.0.2 - ISO Metadata Application Profile (version 1.0.0). This profile is required by INSPIRE, and also used in other projects such as MyOcean.

GeoNetwork open source is recommended as a dedicated CSW server, unless specific partners have special requirements and need to use an alternative tool. GeoNetwork is reliable, has a strong user community, and supports ISO 19115/19119, ISO 19139, and the ISO Metadata Application Profile.

In addition, it is recommended to further scope the capabilities of GI-cat as a tool for performing mediation of assorted catalogue services and dataset inventories, and exposing these through, among others, the ISO Metadata Application Profile interface.

5 Data portrayal standards and tools

This chapter outlines service standards and tools which enable portrayal and visualisation of geospatial data.

5.1 OGC Web Map Service

5.1.1 *Overview*

The OGC Web Map Service (WMS) standard supports the electronic retrieval of digital maps which portray geographic data. A WMS server produces maps that are rendered in a pictorial format such as PNG, GIF or JPEG, or occasionally as vector-based graphical elements in Scalable Vector Graphics (SVG) or Web Computer Graphics Metafile (WebCGM) formats [WMS13]. WMS is important because it provides a means to transform raw spatial data into a portrayal which can be used within decision support tools. WMS makes it possible to display, navigate, zoom in, zoom out, pan, or overlay spatial datasets and to display legend information. ISO has approved WMS (version 1.3.0) as international standard ISO 19128:2005.

The WMS specification provides very basic styling options by advertising a preset collection of visual portrayals for each available dataset. However, OGC Style Layer Descriptor (SLD) provides an extension to WMS and provides a mechanism for enabling a user to define their own dynamic styling rules regarding how to portray the underlying spatial data. SLD is based on a language called OGC Symbology Encoding (SE) [SLD]. This language can also be used to portray the output of WFS (cf. section 6.1) and WCS (cf. section 6.2) [SE].

A benefit of WMS is the fact that only a portrayal of raw data is sent from a WMS server to a WMS client. This fact can support better performance and copyright protection. It means that potentially large volumes of raw data do not need to be transported across the Internet to the WMS client. Instead, a relatively small image is transported to the requesting WMS client for visualisation. Because the image is relatively small, this enables interactive exploring of maps using client application functionality such zoom and pan. Also, because the actual data is not transported across the Internet from one organisation to another organisation, there are fewer issues regarding the copyright and protection of this data. On the other hand, the fact that WMS does not actually deliver raw data to client applications is also a limitation. While in many cases map imagery is sufficient, there are also many cases where client access to the actual data is necessary. In such cases, other standards and tools described in Chapter 6 should be considered.

The WMS specification contains optional support for multi-dimensional datasets. Options include the time and elevation dimensions, plus an option for other dimensions known as "sample dimensions". The sample dimension enables a WMS client to request a particular layer along one or more dimensional axes other than time or elevation. A potential problem with WMS is its handling of multi-dimensional data. Not all WMS servers support multi-dimensional datasets. Also, for WMS servers who fully or partially support multi-dimensional datasets, their implementations can slightly differ, thus, creating interoperability problems.

The WMS specification essentially deals with the portrayal of orthogonal maps. Portrayals of scientific data using time-series graphs, etc. are currently not formally addressed by WMS. However, the FP6 ORCHESTRA project proposed a WMS extension called "getDiagram" as a means of displaying a diagram.

To help address such issues, the OGC has community-orientated working groups who perform Interoperability Experiments (IEs). Such experiments promote OGC standards within a community and also give feedback to the OGC Standards Working Groups (SWG). For example, the Meteorology and Oceanography Domain Working Group (Met Ocean DWG) is conducting an Interoperability Experiment regarding the use of WMS, with the aim to demonstrate the benefits of using WMS and that anticipated problems (e.g. time handling) can be resolved [MODWG]. Met Ocean DWG will also address limitations concerning the use of SLD and SE applied to the portrayal of geophysical raster data such as satellite and model data.

The OGC Web Mapping Service (WMS) 1.4 SWG is active in finalising the new WMS 1.4 specification which includes multilingual support. Also, this SWG has finalised the Web Map Tile Service (WMTS) implementation standard which was officially released in April 2010. WMTS is a complementary approach to WMS for tiling maps. WMS focuses on rendering custom maps and is, therefore, an ideal solution for dynamic map generation. Instead, WMTS focuses on fast serving of static data constraining the bounding box and scales to discrete tiles. Therefore, WMTS makes it easier to improve scalability using caching, pre-rendering and clustering approaches [WMST]. OGC has also engaged in the development of community-based WMS profiles. These WMS Best Practice Application Profiles currently include the Earth Observation [WMSEO] and military [WMSMI] communities.

INSPIRE will use WMS 1.3.0 for its View Service implementation. INSPIRE also proposes to adopt multilingual support for WMS [INSVS].

5.1.2 *Tools available*

There are many WMS servers available. Some notable open source WMS servers include:

- Constellation (http://constellation.codehaus.org)
- deegree (http://www.deegree.org)
- GeoServer (http://geoserver.org)
- MapServer (http://mapserver.org)
- ncWMS (http://ncwms.sf.net)
- THREDDS Data Server (TDS) (http://www.unidata.ucar.edu/projects/THREDDS/)

5.1.3 *Recommendations*

It is recommended that NETMAR use WMS version 1.3 where possible. Because WMS is a well established standard many of the open source servers available are reliable. Therefore, the data providers should decide on the most appropriate WMS server to install or to continue to maintain an existing installation and infrastructure. The main caveat is support for multi-dimensional datasets. For example, in the case of ocean numerical model datasets using netCDF-CF data format, it is recommended to use ncWMS or THREDDS Data Server 4.2+ (which has integrated the ncWMS tool).

WMTS has recently become an official OGC standard. Open source implementation of this standard should be further scoped when they become available.

6 Data access standards and tools

This chapter outlines service standards and tools which enable direct access to geospatial data.

6.1 OGC Web Feature Service (WFS)

6.1.1 *Overview*

The OGC Web Feature Service (WFS) standard supports the electronic retrieval of geographic data as discrete "features". Examples of features include a point feature (e.g. buoy), a line feature (a ship's track), and a region feature (e.g. an oil slick). These features can have attributes, such as sea temperature along a ship's track, which will be returned along with the geographic information. WFS clients may select features from a feature based on spatial constraints and any other criteria attributes. Unlike WMS which returns static maps in an image format, WFS returns meaningful data (including geographic information) in Geography Markup Language (GML). GML is an XML grammar defined by the OGC to express geographical features. GML can be used to develop domain specific (or application specific) GML application schemas. While still at an early stage, domain specific GML application schemas are recognised as important and are starting to be developed by various user communities. For example, the Climate Science Modelling Language (CSML, http://csml.badc.rl.ac.uk) is a relevant GML application schema concerning marine data. WFS itself is a fairly mature standard supported by a number of tools. The current version is WFS 1.1.0 (also ISO 19142). A WFS version 2.0 is currently under development. INSPIRE technical guidelines recommended to implement the direct data access services using the WFS 1.1.0 and OGC Filter Encoding (FE) 1.1 (also ISO 19143).

6.1.2 *Tools available*

The OGC maintains a list of WxS servers together with their level of compliance with the standards at http://www.opengeospatial.org/resource/products. In this survey we have concentrated on open source software as one of the aims of NETMAR is to produce tool-chains that may be freely used in other projects. However, it is recognised that some data providers will have an existing GIS infrastructure using proprietary tools. The following open source tools have been identified:

- deegree (http://www.deegree.org)
- GeoServer (http://geoserver.org)
- MapServer (http://mapserver.org)

6.1.3 *Recommendations*

GeoServer is the OGC reference implementation for WFS. GeoServer is also available under an open source licence. It is a stable and mature product and, with version 2 now released, it supports application schemas. It is recommended that GeoServer be used by partners unless specific requirements that it cannot support are identified.

MapServer was originally developed by the University of Minnesota ForNet project in cooperation with NASA, and the Minnesota Department of Natural Resources. It is now managed by OSGeo and is available under an open source licence. MapServer is primarily a Web Map Server and only provides basic WFS capabilities, there is no transactional capability. If an organisation already has it installed and does not wish to install another server then MapServer could be used for WFS if it could provide the feature set required.

Deegree2 WFS is part of a family of web services which include WMS, WCS and WPS. It is powerful and flexible but complex. A new version, deegree3, is in development.

Within NETMAR, WFS services will be used to provide reference data such as coastlines, in situ measurements, and ship tracks. In order to fulfil the aims embodied in the NETMAR paradigm the simple model must be extended to incorporate semantic metadata and uncertainty estimates associated with the data. We envisage that this would be achieved by incorporating links to extended semantic and uncertainty data within the standard WFS payload. This would retain compatibility with current applications whilst allowing the additional information to be used within the semantic framework. This removes the requirement for a NETMAR GML application schema allowing a more organic approach.

6.2 OGC Web Coverage Service (WCS)

6.2.1 *Overview*

The OGC Web Coverage Service (WCS) standard supports the electronic retrieval of geographic data as discrete "coverages". A common example of a coverage is a regular grid (e.g. a 2D raster dataset, a 4D gridded dataset, etc.). The WCS standard enables WCS clients to choose portions of a server's geographic data holdings based on spatial constraints and other criteria. Similar to WFS, WCS returns the original geographic data. The format of the geographic coverage data returned includes, among others GML, geoTIFF and netCDF-CF [WCS11]. Community schemas and conventions for retrieved data encodings are important to improve semantic data interoperability between WCS servers (e.g. application schemas for GML coverage, CF convention for netCDF format, etc). WCS 1.1.2 is the currently the latest official version. However, the proposed WCS version 2.0 is being finalised. WCS 2.0 contains a core WCS specification which includes a GML 3.2.1 Application Schema for WCS. Based on this WCS 2.0.0 core interface standard, several extensions are proposed. These include [WCSCE]:

- Data model extensions (e.g. specialisation of coverage for time-series, map imagery, etc.)
- Service model extensions (e.g. scaling and interpolation, transactional services (WCS-T), Web Coverage Processing Service (WCPS), etc.)
- Protocol extensions (bindings such as HTTP GET/KVP, POST/XML, SOAP, etc.)
- Format encoding extensions (GML, netCDF, geoTIFF, etc.)
- Usability extensions (multilingual support, etc.)

6.2.2 *Tools available*

The main open source WCS servers include:

- deegree (http://www.deegree.org)
- Constellation (http://constellation.codehaus.org)
- GeoServer (http://geoserver.org)
- MapServer (http://mapserver.org)
- THREDDS Data Server (TDS) (http://www.unidata.ucar.edu/projects/THREDDS/)

6.2.3 *Recommendations*

Data providers should decide on the most appropriate WCS server to install or to continue to maintain an existing installation and infrastructure. However, GeoServer is a reference implementation for WCS 1.1. MapServer is also another reliable option and the THREDDS

Data Server is an alternative especially for gridded numerical ocean model data encoded in netCDF-CF. Constellation is still under development, while deegree is currently complex to configure. Otherwise, the OPeNDAP protocol (cf. section 6.4) is a good alternative to WCS. OPeNDAP is currently a better supported method for serving gridded data within the meteorology and oceanography communities.

6.3 OGC Sensor Web Enablement (SWE)

6.3.1 *Overview*

Within the Sensor Web Enablement (SWE) initiative, the enablement of sensor webs and networks is being pursued through the establishment of several encodings for describing sensors and sensor observations, and through several standard interface definitions for web services. Sensor Web Enablement standards that have been built and prototyped by members of the OGC include the following pending OpenGIS specifications:

1. Observations & Measurements Schema (O&M) – Standard models and XML Schema for encoding observations and measurements from a sensor, both archived and real-time.

2. Sensor Model Language (SensorML) – Standard models and XML Schema for describing sensors systems and processes; provides information needed for discovery of sensors, location of sensor observations, processing of low-level sensor observations, and listing of taskable properties.

3. Transducer Markup Language (TransducerML or TML) – The conceptual model and XML Schema for describing transducers and supporting real-time streaming of data to and from sensor systems.

4. Sensor Observations Service (SOS) - Standard web service interface for requesting, filtering, and retrieving observations and sensor system information. This is the intermediary between a client and an observation repository or near real-time sensor channel.

5. Sensor Planning Service (SPS) – Standard web service interface for requesting user-driven acquisitions and observations. This is the intermediary between a client and a sensor collection management environment.

6. Sensor Alert Service (SAS) – Standard web service interface for publishing and subscribing to alerts from sensors.

7. Web Notification Services (WNS) – Standard web service interface for asynchronous delivery of messages or alerts from SAS and SPS web services and other elements of service workflows.

The Sensor Observation Service (SOS) specification of the OGC's SWE initiative defines a web service interface to distribute sensor data and specifically "observation" data. The current SOS specification is supposed to define a common model for all sensors, sensor systems and their observations. The approach shall be applicable and consistent for all sensor systems including remote, in-situ, fixed and mobile sensors. It specifies an interface which allows to access data gathered by individual sensors, sensor platforms, networked constellations of sensors in real-time, archived or simulated environments in a standardised way [OSIRIS].

The web service interface of the SOS defines several operations. These operations are divided into three profiles (Table 6-1) [OSIRIS].

Core	Transactional	Enhanced
GetCapabilities DescribeSensor GetObservation	RegisterSensor InsertObservation	GetObservationById GetResult GetFeatureOfInterest GetFeatureOfInterestTime DescribeFeatureType DescribeObservationType DescribeResultModel

Table 6-1 SOS operations

The core profile includes the three mandatory operations GetCapabilities for requesting a description of the service and the offered sensor data, DescribeSensor for retrieving the metadata documents of the sensors and GetObservation for querying observations of certain sensors or phenomena using any combination of temporal, spatial and value filters.

The RegisterSensor operation of the optional transactional profile enables sensor producers to register new sensors. Afterwards the InsertObservation operation allows the integration of new observations produced by registered sensors.

The enhanced profile offers seven additional optional operations: GetObservationById, GetResult, GetFeatureOfInterest, GetFeatureOfInterestTime, DescribeFeatureOfInterest, DescribeObservationType, and DescribeResultModel. The GetObservationById operation for example can be used to request observations by their ID. The GetResult operation makes it possible to retrieve only results of observations without their metadata.

6.3.2 *Tools available*

The main open source SWE servers include:

- 52°North (http://52north.org)
- Constellation (http://constellation.codehaus.org)
- MapServer (http://mapserver.org)

6.3.3 *Recommendations*

One NETMAR data provider plans to install SWE services. They will use Constellation as it fits with their internal GIS infrastructure. Any other NETMAR data provider interested in deploying SWE services should, at first, consult this data provider regarding their experiences gained from deploying SWE services using Constellation.

6.4 OPeNDAP

6.4.1 *Overview*

OPeNDAP (Open-source Project for a Network Data Access Protocol) is a commonly used protocol to distribute and access data via Internet (http://www.opendap.org), which evolved from DODS (Distributed Oceanographic Data System). One of the main benefits of OPeNDAP is that many different data analysis clients can directly access OPeNDAP data removing the need to convert the data to the client format or to import foreign data. Examples of such clients include Ferret, Grads and LAS (Live Access Server).

OPeNDAP is a data access protocol that encapsulates the actual data storage and delivery mechanism from the user. Although the most commonly used data format with OPeNDAP is netCDF (http://www.unidata.ucar.edu/software/netCDF/) there is in principle no restriction in what format can be used. For example, there are also other data handlers for other standard formats such as HDF (http://www.hdfgroup.org/). It is also possible to use the so-called Free Form Handler (http://www.opendap.org/download/ff_server.html) to distribute data stored in a non-standard format. The simplest client for accessing OPeNDAP data is a web browser, where you can download either an ASCII or NetCDF file containing the data values for the selected parameters within a given geographic area and time range. However, an OPeNDAP server like THREDDS (Thematic Realtime Environmental Distributed Data Services) (http://www.unidata.ucar.edu/projects/THREDDS/) can also be used to deliver data to a web-GIS using, for example, the WCS protocol.

6.4.2 *Tools available*

The major open source data servers supporting the OPeNDAP protocol are:

- THREDDS Data Server (TDS) (http://www.unidata.ucar.edu/projects/THREDDS/)
- HYRAX (http://opendap.org/download/hyrax.html)
- Dapper (http://www.epic.noaa.gov/epic/software/dapper)
- GrADS Data Server (GDS) (http://grads.iges.org/grads/gds/index.html)

There are also a number of clients available that can display data provided through OPeNDAP services. Table 6-2 lists some of these clients.

OPeNDAP Client	Online information	Client type
ncBrowse	http://www.epic.noaa.gov/java/ncBrowse	desktop tool
ncView	http://meteora.ucsd.edu/~pierce/ ncview_home_page.html	desktop tool
GrADS	http://www.iges.org/grads	desktop tool
Environmental Data Connector	http://www.pfeg.noaa.gov/products/EDC/ index.html	ArcGIS plugin or standalone desktop tool
Ferret	http://ferret.wrc.noaa.gov/Ferret	command line
loaddap	http://opendap.org/download/ml-structs.html	Matlab toolbox
MATLAB OPeNDAP Ocean Toolbox	http://www.oceanographicdata.org/toolbox	Matlab toolbox
Live Access Server (LAS)	http://ferret.pmel.noaa.gov/Ferret/LAS	web-based
DChart	http://www.dchart.org	web-based
ncWMS/Godiva2	http://ncwms.sf.net	web-based

Table 6-2 OPeNDAP clients

The OPeNDAP website maintains a list of available servers and clients at:

- http://opendap.org/faq/whatServers.html
- http://opendap.org/faq/whatClients.html

6.4.3 *Recommendations*

All OPeNDAP data servers listed above are open source and available for multiple computer platforms. THREDDS Data Server is the most commonly deployed OPeNDAP server in the marine scientific community for gridded data, while Dapper is now starting to gain more widespread use for in situ observation data. The FP7 MyOcean project has decided to use THREDDS for deploying gridded OPeNDAP services. MyOcean are also developing a new tool for the deployment of OPeNDAP services for in situ observation data, which will use the Dapper conventions (http://www.dchart.org/documentation/metadata). Also, the Godiva2 web-GIS client (http://behemoth.nerc-essc.ac.uk/ncWMS/godiva2.html) has been selected as the default GIS viewer for MyOcean. For OPeNDAP services within NETMAR, we recommend THREDDS for gridded data and Dapper for in situ observation data.

7 Data processing standards and tools

This chapter outlines data processing standards and tools. In certain cases, it is required to combine several "simple services" (i.e. data discovery, portrayal, and access services) to produce a new dataset. Such a "complex service" will typically involve further processing of the data obtained from these simple services. The service provider can choose to implement data processing services on a single computer, a high performance computing system such as cluster computing, a Grid computing infrastructure, etc.

7.1 OGC Web Processing Service (WPS)

7.1.1 *Overview*

The OGC Web Processing Service (WPS) standard provides a framework and rules for standardising inputs and outputs for geospatial processing services. A processing service may offer algorithms ranging from simple processes (e.g. calculations such as subtracting one set of spatially referenced numbers from another) to complicated processes (e.g. a global climate change model). The WPS standard also defines how a client can request the execution of a process, and how the output from the process is handled. It defines an interface that facilitates the publishing of geospatial processes and clients' discovery of and binding to these processes [WPS10]. WPS 1.0.0 is the current version. The WPS 2.0 Working Group (WPS2.0 SWG) is currently working on the next version of the WPS standard. A number of change requests have been submitted to OGC which include [WPSWG]:

- Support for asynchronous process management
- Merging with Sensor Planning Services (SPS)
- Support for Sensor Model Language (SensorML)
- Division into a WPS core interface and WPS extensions

Based on the INSPIRE network services architecture overview, INSPIRE has two types of services that fall into the category of Web Processing Services [INSNA]:

- Transformation Services
- Invoke Spatial Service Services

7.1.2 *Tools available*

The main open source WPS servers include:

- 52°North (http://52north.org)
- deegree (http://www.deegree.org)
- PyWPS (http://pywps.wald.intevation.org)

7.1.3 *Recommendations*

WPS is a fast evolving technology. Both 52°North and PyWPS are up to date with current standards. PyWPS is recommended as it supports WPS version 1.0.0, and has a low footprint making it easy to install. Python is considered a good choice of implementation language as it is very easy to develop new processing modules. A number of partners have prior experience with PyWPS and this will facilitate further development.

It must also be stressed that no existing WPS is engineered to work with semantic/uncertainty metadata and part of the NETMAR project would involve developing extensions which would allow this metadata to be incorporated in processing chains and passed to other components. It is important that compatibility is maintained between the NETMAR WPS development and current standards in order to ensure that individual components can be reused outside of the full NETMAR system.

8 Service chaining standards and tools

This chapter outlines service chaining standards, workflow engines and tools. NETMAR's service chaining subsystem will specifically make it easier to construct complex services on demand. A graphical editor chaining will be created which will allow users to define their own workflows by combining various simple services (i.e. data discovery, portrayal and access services) and data processing services (i.e. WPS processes) offered by the NETMAR service network.

8.1 Overview

A service chain is defined in ISO 19119 as "a sequence of services where, for each adjacent pair of services, occurrence of the first action is necessary for the occurrence of the second action" [ISO19]. From a user perspective, service chaining is the linking together of standardised data and processing services into a workflow to produce results that are not predefined by the service providers.

8.2 Standards

Typical methodologies for describing the workflow are Business Process Execution Language (BPEL) [OAS07], the most common, and the XML Process Definition Language (XPDL) [WMFC08] using Business Process Modelling Notation (BPMN) [OMG10] as a visual representation. However the field of scientific service chaining is evolving quickly and there is no consensus at present. Many tools use their own internal representation.

8.2.1 *Business Process Execution Language (BPEL)*

The Business Process Execution Language (BPEL) is an XML-based orchestration language used to specify business processes. It has been adopted as an OASIS standard, WS-BPEL 2.0. BPEL is not a programming language at all and does not have a graphical representation. Mappings from graphical languages such as the Business Process Modeling Notation (BPMN) to BPEL are available, as are more conventional programming language representations such as BPELscript (http://www.bpelscript.org) and SimPEL (http://ode.apache.org/simpel.html)

8.2.2 *Business Process Modelling Notation (BPMN)*

The Business Process Modelling Notation (BPMN) is a standard for business process modelling, and provides a graphical notation for specifying business processes in a Business Process Diagram (BPD), based on a flowcharting technique very similar to activity diagrams from Unified Modelling Language (UML). BPMN 2 is currently under development (http://www.omg.org/spec/BPMN/2.0/Beta1/PDF). The BPMN specification also provides a mapping between the graphics of the notation to the underlying constructs of execution languages, particularly BPEL however XPDL is the preferred method for serializing BPMN.

8.3 Tools available

8.3.1 *Taverna workbench*

Taverna (http://www.taverna.org.uk) is a set of tools created by the myGrid project for designing and executing workflows. It is aimed at the non-technical, scientific user. It provides a simple, graphical, interface for creating workflows and an engine to run them (locally on the users system). Taverna 2 is being extensively developed and a standalone server will be released shortly to allow Taverna workflows to be run on a remote server.

8.3.2 *Kepler*

Kepler (https://kepler-project.org) is similar to Taverna in being designed for scientific workflows. Kepler provides a graphical user interface and a runtime engine that can execute workflows either from within a graphical interface or from a command line. A web service has been developed (https://code.kepler-project.org/code/kepler/trunk/modules/webservice/) and an Ajax workflow editor has been developed for the Science Pipes project (http://info.sciencepipes.org), however its license status is unclear.

8.3.3 *LONI Pipeline*

The LONI Pipeline (http://pipeline.loni.ucla.edu/) consists of a graphical interface and a simple workflow engine. The engine can run standalone processes locally or on a remote server via a LONI Pipeline instance. It is primarily designed for quick workflow development for Neuroimaging research. It is not clear how it would integrate with a WPS based processing system.

8.3.4 *VisTrails*

VisTrails (http://www.vistrails.org) is an open source scientific workflow and provenance management system developed at the University of Utah that provides support for data exploration and visualization. It provides a graphical interface and local server engine. It is not clear how it would integrate with a WPS based processing system.

8.3.5 *Enhydra*

Enhydra (http://www.enhydra.org) is a full suite of java based workflow and application server products. It uses XPDL as its native format.

8.3.6 *Intalio Works*

Intalio Works (http://www.intalioworks.com/products/bpm/opensource-edition/) is built around the Apache ODE BPEL engine and Eclipse BPEL editor.

8.3.7 *Bonita*

Bonita (http://www.bonitasoft.com/products/BPM__workflow_overview.php) is a BPMN based workflow system.

8.3.8 *jBPM*

jBPM (http://www.jboss.org/jbpm) is a Java based workflow system with a multilanguage capability. It can use its on native language, jPDL (jBPM Process Definition Language), or standard based languages such as BPEL or BPMN. It includes a web based graphical process editor based on the open source Oryx modelling tool. The engine can be deployed on any Java servlet environment (such as Tomcat).

8.4 Recommendations

Kepler and Taverna address similar use cases and are most directly relevant to the NETMAR use cases. The Science Pipes project has developed an Ajax chaining editor for

Kepler but it is not clear if this available outside of this project, however it provides a good example of what we should aim for in the NETMAR chaining editor. The Taverna Roadmap suggests that there might be a Web2.0 interface in the “next generation” of Taverna but this is only planned for alpha at the end of the year. Enhydra and Intalio Works are fully fledged web application systems with multiple components allowing a powerful system to be built, however they bring extra complexity with that power and are not focused on scientific workflow. jBPM is a very powerful and popular system orientated towards the business world and provides all components needed by NETMAR although some further enhancements would be required. Other systems (LONI Pipeline, VisTrails and Bonita?) are more suited to local use rather than a web services approach. At this stage we cannot make firm recommendations and suggest that further investigation and trials are made of the most promising systems.

9 Portal standards and tools

This chapter outlines web portal standards and portal frameworks. A portal framework will be used to integrate all client-side subsystems of NETMAR (i.e. service discovery and access, service composition, and GIS viewer with decision-support) into a coherent portal. These client-side subsystems will consume and utilise the various services offered by NETMAR service network.

9.1 Terminology and standards

9.1.1 *Definition of terms*

A ***portal*** is a web application that aggregates information from multiple sources and presents it in a uniform manner [Sar10]. A portal may also update the information held by these other sources. In addition, a portal typically offers functionality such as personalisation and customisation of the user interface, as well as authentication of the users.

Portals can be categorised as vertical or horizontal portals. A ***vertical portal*** (aka ***vortal***) is a "specialised website that serves as an entry point to a specific market or industry niche, subject area, or interest" (http://www.businessdictionary.com/definition/vertical-portal.html). A horizontal portal, on the other hand, is a "specialised website (portal) that serves as an entry point to several firms in the same industry or to the same type of suppliers" (http://www.businessdictionary.com/definition/horizontal-portal.html).

In a portal, each web page is comprised of a set of "mini web applications" [Sar10], each called a ***portlet***, that is responsible for generating a particular part of the page. This means a portlet can be seen as a "pluggable user interface component" ([Sar10], section 1.3) as it generates a separate window on the ***portal page***. A portlet may for example display a calendar, possibly with the user's appointments marked, or an RSS feed from an online news site. Each portal may offer the possibility of personalisation and customisation, e.g. changing the number of articles shown inside a news portlets of changing the news site from which the portlet extracts its content. Portlets may also be "linked" to one another such that the content displayed by one portlet is controlled by another portlet. An example of this would be a portlet allowing selection of a city from a map-based GUI, where the selected city is provided to two other portlets, one displaying the latest weather forecast and one offering access to a hotel booking service for the chosen city.

Each portlet needs a runtime environment, i.e. an application server that hosts it, allows it to execute in a secure manner and maintains its state (data) as long as the portlet is running. Such an application server is called a ***portlet container***, and is responsible for managing portlet instances and sending the GUI (Graphical User Interface) fragment generated by each portlet to the ***portal server***, which is responsible for sending user requests from the portal pages to the portlet container and updating the aggregated content in the portal when responses are received.

9.1.2 *Standards for web portals*

During the 1990s web portals started to emerge, and by the end of the decade a number of vendors were offering software tools for setting up enterprise portals. However, different vendors had implemented different APIs for portlet development and communication, prohibiting exchange of components and thereby increasing the development costs. Major vendors therefore initiated a standardisation process to alleviate this problem. The first version of the Java Portlet Specification (JSR 168) was completed in 2003 [AH03]. This specification was implemented by both commercial vendors as well as open source vendors, resulting in a number of tools for portlet containers and servers. As tools became available, developers started writing portlets that utilised the new standards, for a wide range of applications areas.

While JSR-168 for the first time provided a common portal API, it had several shortcomings. The development of a new version of the standard thus started in January 2006, and resulted in the Java Portlet Specification Version 2.0 (JSR 286) in 2008 [Hepper08]. This specification offered several new capabilities, including, among others, mechanisms for coordination between portlets implemented by different vendors and deployed in different WAR files, dynamic serving of resources, resource URLs, improved facilities for caching resources, easier use of Ajax and extending the portlet programming model to make it almost as powerful as the servlet programming model [HK08]. JSR 286 is backwards compatible with JSR 168, and most portal containers support both specifications.

Both JSR 168 and JSR 286 defined the API for portlets running in the same portlet container, but also allowed for portlets to communicate with remote portlets through the WSRP (Web Services for Remote Portlets) standard [KLR03]. WSRP defines portlets as SOAP-based web services that run distributed, but exchange messages using a common protocol. With WSRP, portal developers can utilise portlets running in a remote portlet container as if they were running in the local portlet container, without spending any additional effort on programming [Castle05].

9.2 Tools available

9.2.1 *Liferay*

Liferay (http://www.liferay.com/) is an open source enterprise portal with support for JSR-286 and which is licensed under the MIT open source license [Laurent04]. The Liferay Community Edition is available for free, and comes bundled with 60+ different portlets and widgets offering commonly used functionality like calendars, blogs, message boards, wikis, document library, and many more. Liferay can be installed in a number of application servers, including Tomcat, GlassFish, JBoss and WebShere [Sezov09]. Liferay has a rich user management model, with roles that control user permissions, and different mechanisms for grouping users.

9.2.2 *uPortal*

uPortal (http://www.jasig.org/uportal) is an open source enterprise portal framework developed for higher education. It is free, and is licensed under New BSD License. It offers a number of portlets pre-packaged with the installation, among others, a calendar, Google maps and translation, dictionary/thesaurus, facebook, announcements, proxy CAS (Central Authentication Service. There are also additional community provided portlets available (see http://www.jasig.org/portlets). According to the uPortal web site, it only supports JSR 168 in its current version (3.2.0).

9.2.3 *Gridsphere*

Gridsphere (http://swik.net/gridsphere) is a portal framework based on JSR-168. At present, the original web site, http://www.gridsphere.org/, is not available and it is not known if the framework will be maintained in the future.

9.2.4 *The eXo Platform*

The eXo Platform (http://www.exoplatform.com/portal/public/website/) is a platform for development of web portals, and can be integrated in a number of application servers, including Tomcat and JBoss. The eXo Platform is comprised of a set of Core and Extended Services. The Core Services include GateIn, eXo Portal and WebOS. The eXo Portal (http://www.exoplatform.com/portal/public/website/product/exo-products/portal) supports JSR -168, JSR-286 and WSRP 2. GateIn is the portal framework and WebOS the portal user interface. The Extended Services include a set of collaboration tools, content and knowledge management services, among others, mail and calendar services, document sharing, and forums. The software is licensed under the GNU Affero General Public License (GNU AGPL) (http://www.gnu.org/licenses/agpl-3.0.html). It is a commercial product, but does offer community distributions.

9.2.5 *Apache Jetspeed 2*

Apache Jetspeed 2 (http://portals.apache.org/jetspeed-2/) is an open source portal development framework that is compliant with JSR-286 (since version 2.2.0). It uses the Pluto (http://portals.apache.org/pluto/), the Reference Implementation of the Java Portlet Specification, as its portlet container. A limited number of portlets are available (http://portals.apache.org/applications/), including, among others, RSS feeds, Google Maps, file display and Flash object display. Jetspeed 2 is licensed under the Apache License (version 2.0). The Jetspeed framework is also used by a commercial company, Hippo, that offer a portal solution (http://www.onehippo.com/en/products/portal) as well as a CMS (Content Management System) based on Jetspeed.

9.2.6 *JBOSS Enterprise Portal Platform*

JBOSS Enterprise Portal Platform (http://www.jboss.com/products/platforms/portals/) is a portal development platform based on open standards. It is compliant with JSR-168, JSR-286 and WSRP 1.0. The JBOSS Enterprise Portal Platform is a commercial product and licensed under GNU Lesser General Public License v2.1.

9.2.7 *IBM WebSphere Portal*

IBM WebSphere Portal (http://www-01.ibm.com/software/websphere/portal/) is a portal development framework that offers a wide range of functionality. It is compliant with JSR-168, JSR 286 and WSRP 2.0 [Thom08]. The IBM WebSphere Portal is a commercial product.

9.2.8 *Non-Java based portals*

The term portlet is also used to denote components for generating parts of a web page by portal frameworks implemented in other programming languages than Java. For instance, Django (http://www.djangoproject.com/) and Plone (http://plone.org/) both support portlets written in Python to compose web pages. These portal frameworks come bundled with a number of predefined portlets, which the system administrator can install for specific portals.

Django portlets can be integrated by use of a Django plugin named django-portlets (http://packages.python.org/django-portlets/), which offers a generic portal engine. In Plone, a portlet is comprised of a page template and a Python script, and since version 3, Plone includes a new portlet engine which offers more features and higher performance. However, there is no standard for portlets written in Python. Despite the lack of standards, is it reported that a Python portlet can be integrated in a JSR-168/286 compliant portal like

Liferay[1] using Jython (http://www.jython.org/), which allows developers to compile Python code into Java byte code. We recommend that further investigations and trials are carried out to verify this for the portal framework chosen for this project.

9.3 Recommendations

Based on our preliminary investigation, Liferay seems to be well suited for the NETMAR project. Besides extensive user management capabilities and portal administration tools, it offers a wide range of pre-packaged portlets, a free community edition and is licensed under the MIT open source license. Apache Jetspeed 2 is another possible alternative, also offering an open source license and with an active development community. uPortal is targeted at e-learning, and while it offers some relevant portlets, it only supports JSR-168. For Gridsphere there is no access to its web site at present, and hence it cannot be evaluated. The eXo Platform, JBOSS Enterprise Portal Platform and IBM WebSphere Portal are all comprehensive portal development frameworks offering extensive functionality. While rich in functionality, these platforms may be too complex for our purposes. It is recommended to investigate the use of Liferay and Apache Jetspeed 2 further before making a final decision on the selection of portal development framework for the NETMAR project.

[1] http://www.liferay.com/community/wiki/-/wiki/Main/Scripting%20languages%20to%20develop%20portlets (Liferay Wiki)

10 Conclusions

This report has reviewed initiatives, projects, and technologies addressing the area of system architectures for distributed Environmental Information Systems (EIS), and gives initial direction towards the NETMAR architecture specification.

It is recommended to use ISO/IEC 10746 RM-ODP (Reference Model for Open Distributed Processing) to describe the NETMAR architecture. It is also recommended that NETMAR architecture follows the experiences and best practice approaches taken by projects such as ORCHESTRA and SANY for specifying service-oriented (SOA) architectures. These projects use a process model which follows an incremental, iterative approach for analysis and design. Four versions of the NETMAR architecture are planned. It is planned that the final version will become a public and authoritative specification at the end of the project.

NETMAR is developing a network of services supporting the integration of marine environmental data such as satellite, in situ, and numerical models. It is recommended that NETMAR's architecture design be driven by service-oriented architecture design principles, and use open standards from the IETF, W3C, OASIS, ISO/TC 211, and OGC. OGC standards are particularly important for implementing the NETMAR service network. A number of tools supporting these protocols have been reviewed. Table 10-1 lists the recommended tools for NETMAR.

To enable easy plug-in of multidomain and multilingual use cases, it is recommended that the NETMAR system architecture should be pragmatic, e.g. no or minimal modification of standards, incorporation of semantics into metadata via controlled vocabularies using a simple URI. The exact relationship between the semantic framework, uncertainty propagation, and other NETMAR subsystems needs to be further defined in context of CSW, WMS, WFS, WCS, SWE, OPeNDAP, and WPS services. In conjunction with use cases requirements, this will be defined in the NETMAR architecture specification using an incremental, iterative approach.

It is anticipated that metadata will play an important role in the NETMAR system. It is recommended that NETMAR develops modular metadata rules for dataset-series and dataset (ISO 19115), and services (ISO 19119) based on minimum NETMAR requirements. Considerations for modular metadata rules include semantic framework and uncertainty propagation requirements, and INSPIRE, ISO 19115 Core, and CSW ISO Metadata Application Profile conformance. For example, one set of rules may specifically deal with the metadata requirements for semantic frameworks, while another set of rules specifically deals with metadata requirements for uncertainty propagation. Use cases can then implement or extend a bespoke metadata profile and adapt relevant rule sets in order to implement a particular NETMAR functionality (e.g. connect to semantic framework) or meet special metadata conformance needs (e.g. INSPIRE compliance).

NETMAR will deploy CSW, WMS, WFS, WCS, SWE, OPeNDAP, and WPS services to build the NETMAR service network. This report has made initial recommendations regarding open source frameworks and tools for deploying these services. However, these recommendations must be seen in light of the current capabilities of the tested tools and the requirements of the planned NETMAR services. All tools appear to have strong and active development groups at present. Thus, new and enhanced functionalities can be expected at regular intervals, and it is therefore advised to consult the tool's homepage for updated information on the latest developments.

NETMAR's service chaining subsystem will specifically make it easier to construct complex services on demand. A graphical chaining editor will be created which will allow users to define their own workflows by combining various simple services (i.e. data discovery, portrayal and access services) and data processing services (i.e. WPS processes) offered by the NETMAR service network. However, at this stage we cannot make firm recommendations and suggest that further investigation and trials are made of the most promising chaining editor system. Workflow construction and execution experiences in projects such as HUMBOLDT are important to follow-up on.

NETMAR will use a portal framework to integrate all client-side subsystems of NETMAR (i.e. service discovery and access, service composition, and GIS viewer with decision-support) into a coherent portal. These client-side subsystems will consume and utilise the various services offered by NETMAR service network. It is recommended to investigate the use of Liferay and Apache Jetspeed 2 further before making a final decision on the selection of portal development framework for the NETMAR project.

NETMAR is expected to contribute to the Single Information Space in Europe for the Environment (SISE), and in turn support the development of the Shared Environmental Information System (SEIS). Because NETMAR covers the thematic area of marine data, NETMAR should aim to demonstrate the concept of a Single Information Space in Europe for the Marine Environment (SISME) using different use cases. Other FP7 projects such as GIGAS, ENVISION and UncertWeb are also contributing to the Single Information Space in Europe for the Environment. It is recommended to further scope recommendations and innovations in these projects.

NETMAR is expected to support the implementation of the INSPIRE Directive. It is therefore recommended that the NETMAR architecture specification follows the INSPIRE technical guidelines and implementation rules, which include, among others, using OGC CSW for discovery services, OGC WMS for view services and OGC WFS for download services. As INSPIRE guidelines and implementation rules are updated during the course of the NETMAR project, it is also necessary to incorporate these changes into the NETMAR system architecture if and as appropriate.

The FP7 MyOcean and the FP6 SeaDataNet projects are key European projects concerning marine data. Because NETMAR also covers the thematic area of marine data, it is recommended that NETMAR, where possible, seek to converge with and compliment appropriate elements of these projects (e.g. common vocabularies).

Protocol/Subsystem	**Recommended tool**
CSW	GeoNetwork
WMS	GeoServer or MapServer (if required by service provider)
WFS	GeoServer
WCS	GeoServer, MapServer of THREDDS Data Server
SWE	Constellation
OPeNDAP	THREDDS Data Server/Dapper (server); DChart/ncWMS (client)
WPS	PyWPS
Workflow engine	None (further investigation and trials are needed)
Portal framework	Liferay or Apache Jetspeed 2

Table 10-1 Recommended tools for NETMAR protocols and subsystems.

11 References

[ACRI09] ACRI, 2009. D8100.3- Coastal Water and Air Quality Thematic Pilot Specification Document. GENESIS Deliverable D8100.3, issue 1.0, 15/07/2009. Online at http://genesis-fp7.eu/publications (accessed 6 April 2010).

[AH03] Abdelnur, A. and S. Hepper, 2003. Java Portlet™ Specification Version 1.0. Online at http://jcp.org/aboutJava/communityprocess/final/jsr168/index.html (accessed 12 April 2010).

[BCCD+04] Buswell, S., O.Caprotti, D.P.Carlisle, M.C.Dewar, M.Gaëtano and M.Kohlhase (editors), 2004. The OpenMath Standard 2.0. The OpenMath Society, June 2004. Online at http://www.openmath.org/standard/om20-2004-06-30/omstd20.pdf (accessed on 6 April 2010).

[BODC10] British Oceanographic Data Centre, 2010. Review of available ontology tooling. NETMAR Deliverable D3.2. Revision 1, 19 May 2010.

[Castle05] Castle, B., 2005. Introduction to Web Services for Remote Portlets. In IBM developerWorks, 15 April 2005. Online at http://www.ibm.com/developerworks/library/ws-wsrp/ (accessed on 7 April 2010).

[CMRC10] Coastal and Marine Resources Centre, 2010. Review of Semantic Frameworks. NETMAR Deliverable D4.1. Revision 1, 9 June 2010.

[CSW202] OpenGIS Catalogue Service Specification, Version 2.0.2, OGC 07-006r1. Online at http://portal.opengeospatial.org/files/?artifact_id=20555 (accessed on 22 April 2010).

[CSWISO] OpenGIS Catalogue Services Specification 2.0.2 - ISO Metadata Application Profile, Version 1.0.0, OGC 07-045. Online at http://portal.opengeospatial.org/files/?artifact_id=21460 (accessed on 1 June 2010).

[DARWIN] Darwin Core, Biodiversity Information Standards. Online at http://www.tdwg.org/standards/450/ (accessed on 16 June 2010).

[DLR09] DLR, 2009. D2100.3- Air Quality Thematic Pilot Specification Document. GENESIS Deliverable D2100.3, issue 1.0, 15/07/2009. Online at http://genesis-fp7.eu/publications (accessed 6 April 2010).

[ECOOP] ECOOP project summary. Online at http://www.ecoop.eu/summary.php (accessed 19 April 2010).

[ENVIS] ENVISION FactSheet. Online at http://cordis.europa.eu/fp7/ict/sustainable-growth/envision.pdf (accessed 13 April 2010).

[FC10] Fusco, L., Cossu, R., 2010. GENESI-DR interoperability with GEOSS-CGI and CGI component evolution and integration analysis in GEOSS Architecture Implementation Pilot - Phase 3 (AIP-3). Online at http://portal.opengeospatial.org/files/?artifact_id=38175 (accessed 2 June 2010).

[Fielding00] Fielding, R., 2000. Architectural Styles and the Design of Network-based Software Architectures. Doctoral dissertation, 2000. Online at http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm (accessed 2 June 2010).

[GC09a] GIGAS Consortium, 2009a. GIGAS Technology Watch Report Summary Technical Note. Deliverable reference D2.2b, revision 103, 10.12-2009. Online at http://www.thegigasforum.eu/cgi-bin/download.pl?f=354.pdf (accessed 26 March 2010).

[GC09b] GIGAS Consortium, 2009b. GIGAS Comparative Analysis Technical Note. Deliverable reference D2.3b, revision 200, 14-12-2009. Online at http://www.thegigasforum.eu/cgi-bin/download.pl?f=359.pdf (accessed 26 March 2010).

[GC09c] GIGAS Consortium, 2009c. GIGAS Cross-Initiative Scenarios. Deliverable Reference D2.2b, revision 104. Online at http://www.thegigasforum.eu/cgi-bin/download.pl?f=350.pdf (accessed 26 March 2010)

[GC09d] GIGAS Consortium, 2009d. GIGAS Technology Watch Report Architecture Technical Note. Deliverable reference D2.2b, version 103, 15-11-2009. Online at http://www.thegigasforum.eu/cgi-bin/download.pl?f=345.pdf (accessed 26 March 2010).

[GC09e] GIGAS Consortium, 2009e. GIGAS Comparative Analysis Annex. Deliverable reference D2.3b (Annex), version 200, 14-12-2009. Online at http://www.thegigasforum.eu/cgi-bin/download.pl?f=360.pdf (accessed 30 March 2010).

[GENa] GENESIS Brochure. Online at http://genesis-fp7.eu/publications (accessed 6 April 2010).

[GEO09] GEO 2009-2011 WORK PLAN. Online at http://www.earthobservations.org/documents/work%20plan/geo_wp0911_rev2_091210.pdf (accessed 08 April 2010)

[GEO10] GEOSS Architecture Implementation Pilot (AIP). Online at http://www.earthobservations.org/documents/cfp/20100129_cfp_aip3_architecture.pdf (accessed 02 June 2010)

[Hepper08] Hepper, S., 2008. JavaTM Portlet Specification Version 2.0. Online at http://jcp.org/aboutJava/communityprocess/final/jsr286/index.html (accessed 6 April 2010).

[HK08] Hepper, S. and O. Köth, 2008. What's new in the Java Portlet Specification V2.0 (JSR 286). IBM developers Work, 18 March 2008. Online at http://www.ibm.com/developerworks/websphere/library/techarticles/0803_hepper/0803_hepper.html (accessed 7 April 2010).

[Hreb09] H ebí eka, J., Pillmannb, W. 2009, Shared Environmental Information System and Single Information Space in Europe for the Environment: Antipodes or Associates?, Opportunities of SEIS and SISE: Integrating Environmental Knowledge in Europe, European conference of the Czech Presidency of the Council of the EU TOWARDS eENVIRONMENT. Online at http://www.epractice.eu/files/SEIS%20and%20SISE%20for%20the%20Environment_Antipodes%20or%20Associates.pdf (accessed 19 April 2010).

[HUMBT] Open Source HUMBOLDT Software. Online at http://www.esdi-humboldt.eu/home/open-source.html (accessed 28 April 2010).

[i2010] i2010 - A European Information Society for growth and employment. Online at http://ec.europa.eu/information_society/eeurope/i2010/index_en.htm (accessed 19 April 2010).

[IETF] Internet Engineering Task Force, Official Internet Protocol Standards. Online at http://www.rfc-editor.org/rfcxx00.html. (accessed 19 April 2010).

[INSAB] About INSPIRE, Online at http://inspire.jrc.ec.europa.eu/index.cfm/pageid/48 (accessed 15 April 2010)

[INSDI] Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Online at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:EN:PDF (accessed 15 April 2010)

[INSEI] Call for Expression of Interest for participation in development of INSPIRE data specifications for Annex II & III Data Themes. Online at http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/Call_Annex_II_III.pdf (accessed 31 May 2010)

[INSIR] INSPIRE Implementing Rules, Online at http://inspire.jrc.ec.europa.eu/index.cfm/pageid/47 (accessed 15 April 2010)

[INSME] INSPIRE Metadata, Online at http://inspire.jrc.ec.europa.eu/index.cfm/pageid/101 (accessed 15 April 2010)

[INSMI] Drafting Team Metadata and European Commission Joint Research Centre, 2009, INSPIRE Metadata Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119, Version 1.1. Online at http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/metadata/MD_IR_and_ISO_20090218.pdf (accessed 20 April 2010)

[INSNA] Network Services Drafting Team, 2008. Network Services Architecture (Version 3.0). Online at http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/network/D3_5_INSPIRE_NS_Architecture_v3-0.pdf (accessed 6 April 2010).

[INSNS] INSPIRE Network Services. Online at http://inspire.jrc.ec.europa.eu/index.cfm/pageid/5 (accessed 15 April 2010)

[INSPP] Smits, P. C., Düren, U., Østensen, O., Murre, L., Gould, M., Sandgren, U., Marinelli, M., Murray, K., Pross, E., Wirthmann, A., Salgé, F., Konecny, M., 2002, INSPIRE Architecture and Standards Position Paper, European Commission, Joint Research Centre, JRC-Institute for Environment and Sustainability, Ispra, European Commission, Online at http://inspire.jrc.it/reports/position_papers/inspire_ast_pp_v4_3_en.pdf (accessed 15 April 2010)

[INSSO] Lucchi, R., Millot, M., Kanellopoulos, I., 2008, SOAP HTTP Binding Status - Survey on OGC and ORCHESTRA specifications relevant for the INSPIRE Network Services, Online at http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/network/SOAP_binding_survey.pdf (accessed 26 April 2010)

[INSTA] Data Specifications, Network Services and Metadata Drafting Team members, 2007, INSPIRE Technical Architecture – Overview, Online at http://inspire.jrc.ec.europa.eu/reports/ImplementingRules/network/INSPIRETechnicalArchitectureOverview_v1.2.pdf (accessed 15 April 2010)

[INSVS] Network Services Drafting Team, 2009, Implementing INSPIRE View Services. Online at http://inspire.jrc.ec.europa.eu/documents/Network_Services/Technical%20Guidance%20View%20Services%20v%202.0.pdf (accessed 21 April 2010)

[IOOS] De La Beaujardière, J., NOAA IOOS Data Integration Framework: Draft Architecture and Recommended Services. Online at http://ioos.gov/library/dif_overview_102908.pdf (accessed 17 June 2010)

[ISO19] ISO/TC-211, ISO 19119 Geographic information - Services. 2005.

[ISOFS] ISO/TC-211 Fact Sheets and Overview Documents. Online at http://www.isotc211.org/Outreach/Overview/Overview.htm (accessed 19 April 2010)

[KLR03] Kropp, A., Leue, C. and R. Thompson (editors), 2003. Web Services for Remote Portlets Specification Version 1.0. Approved as an OASIS (Organization for the Advancement of Structured Information Standards) standard August 2003.

[Laurent04] Laurent, St. Andrew M., 2004. Understanding open source & free software licensing. O'Reilly, 2004. ISBN 0-596-00581-4.

[LJL+10] Loubrieu, T., T. Jolibois, O. Lauret, C. Camel, F. Blanc, N. Cros, M. Price, J. Blower, Y. Barzic, B. Hakansson, T. Hamre, P. Tricket and G. Manzella, 2010. MyOcean Information System architecture and technical interfaces. Presentation at IMDIS 2010, March 2010.

[MODWG] OGC Meteorology and Oceanography Domain Working Group. Online at http://external.opengeospatial.org/twiki_public/bin/view/MetOceanDWG/WebHome (accessed 21 April 2010).

[OAS07] Web Services Business Process Execution Language Version 2.0. Online at http://docs.oasis-open.org/wsbpel/2.0/wsbpel-v2.0.pdf. (accessed 22 April 2010)

[OASIS] OASIS Standards. Online at http://www.eu-orchestra.org/project_status.shtml. (accessed 19 April 2010)

[OBIS] OBIS. Online at http://www.iobis.org/about. (accessed 16 June 2010)

[OBRI08] O'Brien, K., Hankin, S., Habermann, T., Kern, K., Schweitzer, R., Little, M., Snowden, D., Cartwright, J., Larocque, J., Li, J., Malczyk, J., Manke, A, 2008. Moving Toward Climate Data Integration: The Observing System Monitoring Center, American Geophysical Union, Fall Meeting 2008. Online at http://www.osmc.noaa.gov/OSMC_AGU_2009.ppt. (accessed 17 June 2010)

[ODP] Overview of the IODE/JCOMM Ocean Data Portal. Online at http://www.oceandataportal.org/images/stories/odp/documents/brochure_ocean%20data%20portal_rev_sb_16022010.pdf. (accessed 16 June 2010)

[OMG10] Business Process Maturity Model (BPMM), Version 1.0, Object Management Group. Online at http://www.omg.org/spec/BPMM/1.0/PDF (accessed 22 April 2010)

[ORCBO] ORCHESTRA: an open service architecture for risk management. Online at http://www.eu-orchestra.org/docs/ORCHESTRA-Book.pdf. (accessed 26 April 2010).

[ORCWS] ORCHESTRA: Project Status and Latest Developments. Online at http://www.eu-orchestra.org/project_status.shtml. (accessed 16 April 2010).

[OSIRIS] OSIRIS Architecture Specification and Justification, Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors (OSIRIS). Online at http://tws01.terranovaws.it/osiris/doc/OSIRIS-WP6000-DEL-0037-Archi%20Spec%20and%20Justification.pdf. (accessed 22 April 2010).

[OSMC] Observing System Monitoring Center website. Online at http://www.osmc.noaa.gov/. (accessed 17 June 2010).

[PLB+08] Pacini, F., Lankester, T., Burger, A., Goncalves, P., Brito, F., Jokulsson, G., 2008. DSA2.1 Architectural Design, GENESI-DR Deliverable DSA2.1. Online at http://www.genesi-dr.eu/documents/GENESI-DR-SA2-DEL-DSA2.1-v1.0.pdf. (accessed 02 June 2010).

[Put00] Putman, Janis R., 2000. Architecting with RM-ODP. Prentice Hall (October 16, 2000).

[RM-OA] Usländer, T.: Reference Model for the ORCHESTRA Architecture (RM-OA) V2 (Rev 2.1). Open Geospatial consortium Inc. 10 August 2007. Online at http://portal.opengeospatial.org/files/index.php?artifact_id=23286 (accessed 16 April 2010).

[SANOB] SANY objectives. Online at http://www.sany-ip.eu/about_sany/objectives (accessed 16 April 2010).

[Sar10] Sarin, A., 2010. Portlets in Action. MEAP (Manning Early Access Program) version.

[SDI] Wilson, M., 2009, Chapter Three: Metadata -- Describing geospatial data, Spatial Data Infrastructure Cookbook 2009. Online at http://memberservices.gsdi.org/files/?artifact_id=655 (accessed 20 April 2010)

[SDN] Schaap, D., 2008, SeaDataNet: A Pan-European Infrastructure for Ocean and Marine Data Management

[SE] OGC Symbology Encoding Implementation Specification, version 1.1.0 (revision 4), OGC 05-077r4. Online at http://portal.opengeospatial.org/files/?artifact_id=16700 (accessed 21 April 2010)

[SEIS] Shared Environmental Information System (SEIS). Online at http://ec.europa.eu/environment/seis/index.htm (accessed 19 April 2010).

[SenSA] SANY D2.3.4 Specification of the Sensor Service Architecture V3. Online at http://www.sany-ip.eu/filemanager/active?fid=333 (accessed 16 April 2010).

[Sezov09] Sezon, R. L., 2009. Liferay Portal Administrator's Guide.

[SGH09] SGH, 2009. D3100.3- Fresh Water Quality Thematic Pilot Specification Document. GENESIS Deliverable D3100.3, issue 1.0, 15/07/2009. Online at http://genesis-fp7.eu/publications (accessed 6 April 2010).

[SISE1] Single Information Space in Europe for Environment (SISE), INSPIRE Forum. Online at http://inspire-forum.jrc.ec.europa.eu/pg/groups/10035/single-information-space-in-europe-for-environment-sise/ (accessed 19 April 2010).

[SISE2] Towards a Single Information Space for the Environment in Europe, Experts Consultation Workshop. Online at http://cordis.europa.eu/fp7/ict/sustainable-growth/workshops/ws-20080215_en.html (accessed 19 April 2010).

[SLD] OGC Styled Layer Descriptor Profile of the Web Map Service Implementation Specification, version 1.1.0 (revision 4), OGC 05-078r4. online at http://portal.opengeospatial.org/files/?artifact_id=22364 (accessed 21 April 2010)

[SPB09] Spacebel s.a., 2009. D6100.6 - Technology Integration - Executive Summary. GENESIS Deliverable D6100.6, issue 2.0, 27/11/2009. Online at http://genesis-fp7.eu/publications (accessed 6 April 2010).

[SWING] Semantic Web-Service Interoperability for Geospatial Decision Making. Online at www.swing-project.org/deliverables/document/55 (accessed 13 April 2010).

[Thom08] Thompson, R. (editor), 2008. Web Services for Remote Portlets Specification v2.0. OASIS Standard , 1 April 2008. Online at http://docs.oasis-open.org/wsrp/v2/wsrp-2.0-spec-os-01.pdf (accessed 11 March 2010).

[W3C07] World Wide Web Consortium, 2007. SOAP Version 1.2 Part 1: Messaging Framework (Second Edition). W3C Recommendation 27 April 2007. Online at http://www.w3.org/TR/soap12-part1 (accessed 2 June 2010).

[W3CMI] W3C Mission, Online at http://www.w3.org/Consortium/mission.html (accessed 12 April 2010)

[W3CST] W3C Standards, Online at http://www.w3.org/standards/ (accessed 19 April 2010)

[WCS11] OGC Web Coverage Service (WCS) Implementation Specification, version 1.1.2, OGC 07-067r5, Online at http://portal.opengeospatial.org/files/?artifact_id=27297 (accessed 22 April 2010)

[WCSCE] OGC WCS 2.0 Overview: Core and Extensions (proposed), version (TBC), Online at http://portal.opengeospatial.org/files/?artifact_id=36266&version=2&format=pdf (accessed 22 April 2010)

[WMFC08] Process Definition Interface -- XML Process Definition Language (XPDL), Workflow Management Coalition Workflow Standard, Version 2.1a, Document Number WFMC-TC-1025, Online at http://www.wfmc.org/Download-document/WFMC-TC-1025-Oct-10-08-A-Final-XPDL-2.1-Specification.html (accessed 22 April 2010)

[WMOIS] WMO SECRETARIAT, 2010, PROJECT AND IMPLEMENTATION PLAN WMO INFORMATION SYSTEM “Managing and Moving Weather, Water and Climate Information in the 21st Century”. Version 1.2.0. February 8, 2010. Online at http://www.wmo.int/pages/prog/www/WIS/documents/WIS-ProjectPlan-v1-2.doc (accessed 21 April 2010)

[WMOIP] WIS Implementation Plan. Online at http://www.wmo.int/pages/prog/www/WIS/implementation_plan_en.html (accessed 27 April 2010)

[WMS13] OGC Web Map Service (WMS) Implementation Specification, version 1.3.0, OGC 06-042, Online at http://portal.opengeospatial.org/files/?artifact_id=14416 (accessed 21 April 2010)

[WMSEO] OGC Web Map Services - Application Profile for EO Products, version 0.3.3, OGC 07-063r, Online at http://portal.opengeospatial.org/files/?artifact_id=30912 (accessed 21 April 2010)

[WMSMI] OGC DGIWG WMS 1.3 Profile and systems requirements for interoperability for use within a military environment, version 0.9, OGC 07-063r, Online at http://portal.opengeospatial.org/files/?artifact_id=34833 (accessed 21 April 2010)

[WMST] OGC Web Map Tile Service Implementation Standard, draft version 1.0.0 (2009-12-06).

[WPS10] OGC Web Processing Service, version 1.0.0, OGC 05-007r7. Online at http://portal.opengeospatial.org/files/?artifact_id=24151 (accessed 26 April 2010)

[WPSWG] OGC Web Processing Service 2.0 Standards Working Group (SWG). Online at http://www.opengeospatial.org/projects/groups/wps2.0swg (accessed 26 April 2010)

Appendices

Appendix A. List of abbreviations

AGPL	Affero General Public License
AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BOSS4GMES	Building Operational Sustainable Services for GMES
BPD	Business Process Diagram
BPEL	Business Processing Execution Language
BPMN	Business Process Modeling Notation
CAS	Central Authentication Service
CDI	Common Data Index
CDS	Coordinated Data access System
CEN	Comité Européen de Normalisation
CF	Climate and Forecast
CMS	Content Management System
CQL	Common Query Language
CS	Context Service
CSDGM	Content Standard for Digital Geospatial Metadata
CSML	Climate Science Modelling Language
CSR	Cruise Summary Reports
CSW	Catalogue Service for the Web
DAIL	Data Access Integration Layer
DCPC	Data Collection or Production Centre
DiGIR	Distributed Generic Information Retrieval
DODS	Distributed Oceanographic Data System
DWG	Domain Working Group
E2E	End to End
ebRIM	ebXML Registry Information Model
ebXML	e-business XML
EC	European Commission
ECOOP	European COstal-shelf sea Operational observing and Forecasting system
EE	Enterprise Edition
EEA	European Environment Agency
EDIOS	European Directory of the initial Ocean-observing Systems
EDMED	European Directory of Marine Environmental Data sets
EDMERP	European Directory of Marine Environmental Research Projects
EDMO	European Directory of Marine Organisations
EIS	Environmental Information System

ENVISION	ENVIronmental Services Infrastructure with ONtologies
EO	Earth Observation
EO DAIL	Earth Observation Data Access Integration Layer
ESA	European Space Agency
EUMIS	European Marine Information System
EuroDeSS	European Decision Support System
EuroMISS	European Marine Information Systems of Systems
FE	Filter Encoding
FES	Filter Encoding Standard
FGDC	Federal Geographic Data Committee
FP	Framework Programme
FP6	Sixth Framework Programme
FP7	Seventh Framework Programme
FTP	File Transfer Protocol
G-MOSAIC	GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises
GCI	GEOSS Common Infrastructure
GDS	GrADS Data Server
GENESI-DR	Ground European Network for Earth Science Interoperations - Digital Repositories
GENESIS	GENeric European Sustainable Information Space for Environment
GEO	Group on Earth Observation
GeoDRM	Geospatial Digital Rights Management
GeoDRM RM	Geospatial Digital Rights Management Reference Model
GeoREL	Rights expression language for geographic information
GEOSS	Global Earth Observation System of Systems (GEOSS)
GeoTiff	Geo-referenced Tagged Image File Format
GIF	Graphics Interchange Format
GIGAS	GEOSS INSPIRE and GMES Action in Support
GIS	Geographic Information System
GISC	Global Information System Centre
GMES	Global Monitoring for Environment and Security
GML	Geography Markup Language
GNU	GNU's not Unix
GPL	General Public License
GPPF	Generic Portal & Portlets Framework
GrADS	Grid Analysis and Display System
GSCDA	GMES Space Component Data Access
GSP	GMES Service Project
GTS	Global Telecommunication System
GUI	Graphical User Interface
HDF	Hierarchical Data Format

HMA	Heterogeneous Missions Accessability
HTTP	Hypertext Transfer Protocol
I3	Integrated research Infrastructure Initiative
ICES	International Council for the Exploration of the Sea
IE	Interoperability Experiment
IETF	Internet Engineering Task Force
IGS	Information Grounding Service
INSPIRE	Infrastructure for Spatial Information in the European Community
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
IOOS	Integrated Ocean Observing System
IMOS	Integrated Marine Observing System
IR	Implementing Rules
ISO	International Organization for Standardization
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
JPEG	Joint Photographic Experts Group
JRC	Joint Research Centre (European Commission)
JSR	Java Specification Request
KML	Keyhole Markup Language
KVP	Key-Value Pair
LADM	Land Administration Domain Model
LAS	Live Access Server
LGPL	GNU Lesser General Public License
MACC	Monitoring Atmospheric Composition and Climate
MarCoast	Marine & Coastal Environmental Information Services
MarineXML	A pre-standardisation development for marine data interoperability using XML (project)
MCP	Marine Community Profile
MERSEA	Marine Environment and Security for the European Area
MFC	Monitoring and Forecasting Centre
MIME	Multipurpose Internet Mail Extensions
MiMS	Mineral resources Management System
MIS	MyOcean Information System
MIT	Massachusetts Institute of Technology
MR	Model Repository
MS	Mediator Service
NASA	National Aeronautics and Space Administration
NC	National Centre
netCDF	Network Common Data Form (format)
netCDF-CF	netCDF Climate and Forecast (CF) metadata conventions
NETMAR	Open service network for marine environmental data

NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Centre
O&M	Observations & Measurements
OASIS	Organization for the Advancement of Structured Information Standards
OBIS	Ocean Biogeographic Information System
OCO	Office of Climate Observation
ODE	Orchestration Director Engine
ODP	Ocean Data Portal
OGC	Open Geospatial Consortium, Inc.
OPeNDAP	Open-source Project for a Network Data Access Protocol
ORCHESTRA	Open Architecture and Spatial Data Infrastructure for Risk Management
OSGeo	The Open Source Geospatial Foundation
OSMC	Observing System Monitoring Center
OWL	Web Ontology language
PI	Place Identifier
PNG	Portable Network Graphics
PR	Permanent Representative
RDF	Resource Description Framework
RDF-S	RDF Vocabulary Description Language: RDF Schema
REST	Representational State Transfer
RFC	Request For Comments
RM-OA	Reference Model for the ORCHESTRA Architecture
RM-ODP	Reference Model of Open Distributed Processing
ROA	Resource-oriented architecture
ROOS	Regional Operational Oceanography System
RSS	Rich Site Summary / Really Simple Syndication / RDF Site Summary
SAFER	Services and Applications For Emergency Response
SAS	Sensor Alert Service
SDI	Spatial Data Infrastructure
SE	Symbology Encoding
SeaDataNet	Pan-European infrastructure for Ocean & Marine Data Management
SEIS	Shared Environmental Information System
SensorML	Sensor Model Language
SensorSA	SANY Sensor Service Architecture
SISE	Single Information Space in Europe for Environment
SKOS	Simple Knowledge Organization System
SLD	Styled Layer Descriptor
SME	Small and medium enterprise
SOA	Service-oriented architecture
SOAP	Simple Object Access Protocol
SOS	Sensor Observation Service

SPARQL	SPARQL Protocol and RDF Query Language.
SPS	Sensor Planning Service
SVG	Scalable Vector Graphics
SWE	Sensor Web Enablement
SWG	Standards Working Group
SWING	Semantic Web services Interoperability for Geospatial decision making
SWS	Semantic Web Service
TAC	Thematic Assembly Centre
TAP	Trans National Data Access Platforms
TC	Technical Committee
TDS	THREDDS Data Server
THREDDS	Thematic Realtime Environmental Distributed Data Services
TML	Transducer Markup Language
TransducerML	Transducer Markup Language
UDDI	Universal Description Discovery and Integration
UML	Unified Modeling Language
UnCertML	Uncertainty Markup Language
UNESCO	United Nations Educational, Scientific and Cultural Organization
URI	Uniform Resource Identifier
W3C	World Wide Web Consortium
WCPS	Web Coverage Processing Service
WCS	Web Coverage Service
WCS-T	Web Coverage Service Transactional
WDCS	Workflow Design and Construction Service
WebCGM	Web Computer Graphics Metafile
WFS	Web Feature Service
WIS	WMO Information System
WMC	Web Map Context
WMO	World Meteorological Organization
WMS	Web Map Service
WMTS	Web Map Tile Service
WNS	Web Notification Services
WPS	Web Processing Service
WS-BPEL	Web Services Business Process Execution Language
WSDL	Web Services Description Language
WSMX	Web Service Modelling eXecution environment
WSRP	Web Services for Remote Portlets
XDPL	XML Process Definition Language
XML	eXtensible Markup Language
XML-RPC	XML-Remote Procedure Call
XPath	XML Path Language

XPDL	XML Process Definition Language
XSD	XML Schema Definition
XSLT	XSL Transformation

