Interoperability between Web Services for Geoinformation and Earth Sciences

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Interoperability between Web Services for Geoinformation and Earth Sciences

by

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Abstract

This research focuses on data sharing problems between Earth Science (ES) and Geoinformation (GI) Science communities, namely, the issue of interoperability of web services. The motivation for the research is the current data distribution status for interdisciplinary studies that require data scattered among both communities. While the interoperability in GI community has already matured, the interoperability between GeoInformation and Earth Sciences is still in its initial state. Based on the experiences of the OGC Interoperability Program (IP), web service interface is considered the mediation of the interoperability. Accordingly, two web services, OGC Web Coverage Service (WCS) and Catalog Service for the Web (CSW) and the Geo-interface for Atmosphere, Land, Earth and Ocean netCDF Interoperability Experiment (GALEN IE) Project are evaluated in the study. In addition, Unidata THREDDS Data Server is chosen as the representative web service in ES community due to its capability of gathering web resources from other commonly used servers such as OPeNDAP and ADDE. Current experiments with THREDDS WCS gateway reveal the possibility of the interoperability. At present, three required WCS operations are supported by the gateway; however, implementation issues including spatial reference, granularity, regularization, downsize and multidimensional query are identified. Therefore, the gateway is merely practical in the skeleton level. Compared to WCS, CSW interface is at the conceptual level of the interoperability. To demonstrate the feasibility, a case study of the interoperability between two heterogeneous Servers, GeoNetwork opensource and THREDDS Data Server, is conducted. In short, OGC CSW 2.0 is recommended as a mediation of interoperability at the conceptual level while OGC ebRIM profile of CSW is recommended at the implementation level. The profile provides solutions to implementation issues such as core metadata schema and harvest protocols while shelving the issue of inventory structure for data collection for future debate. In conclusion, both WCS and CSW interfaces can be mediations for interoperability between web services for GeoInformation and Earth Science Sciences. The choice between them depends on the users' requirement.

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Terms and definitions

1. Coordinate

One of a sequence of n numbers designating the position of a point in n-dimensional space[1]

2. Coordinate conversion

Change of **coordinates**, based on a one-to-one relationship, from one **coordinate reference system** to another based on the same **datum**[1]

3. Coordinate reference system

Coordinate system which is related to the real world by a **datum**[1]

4. Coordinate system

Set of mathematical rules for specifying how **coordinates** are to be assigned to points[1]

5. Data structure

A way of storing data in a computer so that it can be used efficiently [2]

6. Datum

Parameter or set of parameters that define the position of the origin, the scale, and the orientation of a **coordinate reference system**[1]

7. Earth Science

Sciences related to the Earth including Oceanography, Hydrology, Meteorology, and Climatology[1]

8. Ellipsoidal coordinate system

Coordinate system in which position is specified by geodetic latitude, geodetic longitude, and (in three dimensional case) ellipsoid height, associated with one or more geographic coordinate reference systems[1]

9. Feature

Abstraction of real world phenomena [3]

10. GeoInformation Science

A field of information science specializing on the fundamental issues arising from creation, handling, storage and use of geographic information [4]

11. Geographic coordinate reference system

Coordinate reference system using an **ellipsoidal coordinate system** and based on an ellipsoid that approximates the shape of the Earth[1]

12. Map projection

Coordinate conversion from an **ellipsoidal coordinate system** to a plane[1]

13. Projected coordinate reference system

Coordinate reference system derived from a two-dimensional **geographic reference system** by applying a **map projection** and using a Cartesian coordinate system[1]

14. Session

In computer science, in particular networking, a session is either a lasting connection using the session layer of a network protocol or a lasting connection between a user (or user agent) and a peer, typically a server, usually involving the exchange of many packets between the user's computer and the server[5]

15. Spatial reference

Description of position in the real world[1]

16. Web Services Description Language (WSDL)

An XML-based language that provides a model for describing Web Services[6]

Acronyms

CORBA Common Object Request Broker Architecture

CRS Coordinate Reference System

CSW Catalog Service for the Web

ECA European Climate Assessment

ES Earth Science

GFDL NOAA Geophysical Fluid Dynamics Laboratory

GSFC NASA Goddard Space Flight Center

GI Geoinformation

HDF Hierarchical Data Format

IAP Institute of Atmospheric Physics

ICTP International Centre for Theoretical Physics

IFREMER French Research Institute for Exploitation of the Sea

ISO International Organization for Standardization

JPL Jet Propulsion Laboratory

OGC Open Geospatial Consortium, also referred to as OpenGIS®

OpenDAP Open-source Project for a Network Data Access Protocol

NCDC NOAA National Climatic Data Center

NCEP National Centers for Environmental Prediction

NetCDF Network Common Data Form

NERC Natural Environment Research Council

SDI Spatial Data Infrastructure

TDS THREDDS Data Server

THREDDS Thematic Realtime Environmental Distribution Data Services

WCS Web Coverage Service

WFS Web Feature Service

WMS Web Map Service

XML Extensible Markup Language

Z39.50 Service definition for information search and retrieval, also known as ISO23950

1. Introduction

1.1. Background

The sustainability of biodiversity has been an important issue for human society because human beings are dependent on the diversity of living things for survival. Measurements as well as predictions of biodiversity are therefore crucial, not only for explaining and understanding the issue but also for better management of human activities that influence the balance of the ecosystem. To this end, the use of interdisciplinary data including geography, biology, climate and human factors are fundamental for biodiversity studies.

Among identified indicator groups that drive biodiversity change in Biofrag project, climate-based indices outperform remotely-sensed indices (e.g. NDVI-derived indices) for predicting the distribution of herpetological species. The result concurs with previous researches[7]. The importance of understanding and manipulating climate data is therefore addressed.

While geospatial data are two/three dimensional parameters, climate data such as temperature, humidity, pressure, and wind speed, are commonly considered as multidimensional variables. Conventionally, data that store relevant information were handled by two different communities: Earth and GeoInformation Sciences[1]. Each community has its own perspective of the Earth, hence deploying distinct data model representing same phenomena. To be more specific, ES dataset by the name of multidimensional scientific dataset primary designed to capture and represent complex observed phenomena and keep the Earth location as simple as possible (i.e. implicitly positioned over the Earth)[8]. Conversely, the phenomena and the Earth location are considered equally important in GI dataset with the name of geospatial dataset. Consequently, two systems with different data structure, data exchange mechanism, and data analysis methodologies have been developed over the years[2].

[1] See terms and definitions

[2] GeoInformation science was originated in 1964 while ES data grows since 1985.

The issue of interoperability emerged for the two mature systems to interact. That is, by the definition of ISO TC 204 Document N271, the ability of systems to provide services to and accept services from other systems and to use the services so exchanged to enable them to operate effectively together[9].

Several organizations such as JPL, ESRI, OGC, RSI, UniData/UCAR, and NERC have dedicated in developing technologies in their own realm. There was little cooperation among these organizations before the kick-off teleconference meeting held by OGC interoperability program (IP) took place in 2005. During the meeting, OGC standard interfaces were approved to be the mediation that bridges existing technologies and communities associated with GI and ES realms[10]. In other words, service-oriented solution is considered the right path towards the interoperability between two realms. Since then, UniData has leading the OGC IP.

OGC and UniData as primary participants of the IP, however, have different objectives hence targeting at different audiences in terms of data usage due to distinct missions. More concretely, OGC specifications are for software vendors and developers to implement and communicate via identical concept so that end users could benefit from a vast pool of interoperable web based tools for geospatial data access and related geoprocessing services. Conversely, UniData middleware are for data users to find, distribute and manipulate datasets while people interested in the techniques of software can contribute their effort since the middleware is open-source. Understanding the work of two organizations is therefore crucial for the study. The similarity and difference of the works devoted by two organizations are covered in chapter 2. The followings are brief introductions of the two.

1.1.1. OGC

The Open GIS Consortium (OGC), cooperating closely with ISO TC211, is the major organization in GI community that sets standards for spatial information and services. The mission of OGC is to serve as a global discussion for the collaboration of developers and users of spatial data products and services, and to advance the development of international standards for geospatial interoperability[11]. Currently , it has more than 336 worldwide members, including companies, universities, and government agencies, who are interested in developing publicly available interface specifications[12]. Interoperability has been considered essential task of the organization and an Interoperability Program (IP) is committed to the issue.

1.1.2. UniData

UniData, one of programs in the University Corporation for Atmospheric Research (UCAR) Office of Programs (UOP) in the United States, is considered as the primary organization in ES community that leads the development of relevant technologies. The mission of UniData is to provide data, tools and community leadership for enhanced Earth-system education and research[13]. The organization has been practicing its mission for over 20 years while over 160 institutions (e.g. NCEP, GFDL, GSFC, NCDC, IFREMER, ICTP,IAP, and ECA) has empowered it in the common goal of sharing data as well as tools for data access and visualization.

1.2. Research Problem

Web Portal, or simply a portal, is a web site or service that offers a broad amount of web resources and services. In other words, users search for information through portal that collects relevant online information and redirects users to the contents. With the success of portals such as Yahoo!, Youtube, etc., a portal appears to be a better solution for an organization (e.g. Department of Natural Resource in ITC) to provide information and/or data to its members than distributed web sites. To this end, a NRS Data Portal is recommended for members to focus on scientific researches rather than finding and gathering data for each of their projects.

The need of interoperability emerged from existing diverse data sharing approaches to interact (see Figure 1-1) including remote disk storage for geospatial data copyrighted to NRS, THREDDS Catalog widely used in ES communities and Spatial Data Infrastructure (SDI) using OGC standardised GeoNetwork technique. In a broad sense, the problem can be considered as interoperability between GI and ES communities from the aspect of data systems.

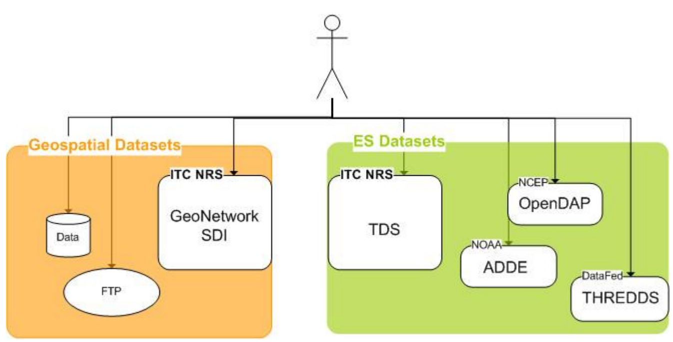

Figure 1-1 Current data exchange mechanism in ITC NRS department

Geo-interface for Atmosphere, Land, Earth and Ocean netCDF Interoperability Experiment (GALEON IE), an active OGC Initiative, leads the development of interoperating technologies since August 2005. The IE is considered as a step towards interoperability with data systems already in existence in the GeoInformation and Earth sciences. An interface to netCDF datasets via OpenGIS Web Coverage Server (WCS 1.0) protocol providing interoperability among OpeNDAP, ADDE, and THREDDS client/server and catalogue protocol was implemented in its Phase One stage[14].

While GALEON IE participants busy testing the feasibility of WCS geo-interface from client or server side, the study focuses on a hidden issue that should not be neglected: is multidimensional scientific dataset properly prepared for the interface to function when data models are fundamentally different? The argument based on the assumption that technical feasibility does not necessarily lead to practical usage.

The study aims for providing evaluations of the interoperability in existence between web services for GeoInformation and Earth Sciences from GI perspective. It is observed that previous work in terms of implementation, documentation and evaluation of the interoperability are mostly from ES perspective. Due to the fact that it takes two to cooperate, the conformance of work to GI standard is a practical issue in this research.

1.3. Research Objectives

The main objective of this research is to evaluate existing web services in GI and ES community from theoretical and practical perspectives. The study addresses the issue of interoperability between heterogeneous servers through proper web services. Accordingly, the research will propose a loose coupling architecture to tackle the issue at conceptual level.

1.4. Research Questions

In order to achieve the objectives, the following main questions should be answered:

1. What are prerequisites for the interoperability?
2. Is WCS interface practical for the interoperability?
3. Are there other options for the interoperability?
4. Case study: How could GeoNetwork SDI and TDS interoperate?

1.5. Research Scope

Network architecture consists of several levels and interfaces as shown in Figure 1-2. The study evaluates the theoretic aspects of the architecture and leave out the practical implementation detail. In addition, issues including internet capability for data exchange, performances of hardware and software, and non-standard solutions are not covered in this research. The following paragraphs describe the scope of each component of the architecture in a bottom-up order.

Data Level: The study reviews data characteristics of netCDF file as a common representative of multidimensional scientific data (e.g. HDF5, GRIB, NetCDF, etc.) while leaving out the structure of geospatial data based on the assumption that it is essential for GI community.

Data Model API: The study reviews OGC abstract specifications of geospatial data model as well as UniData Common Data Model of multidimensional scientific data. Brief descriptions are covered in section 2.1.

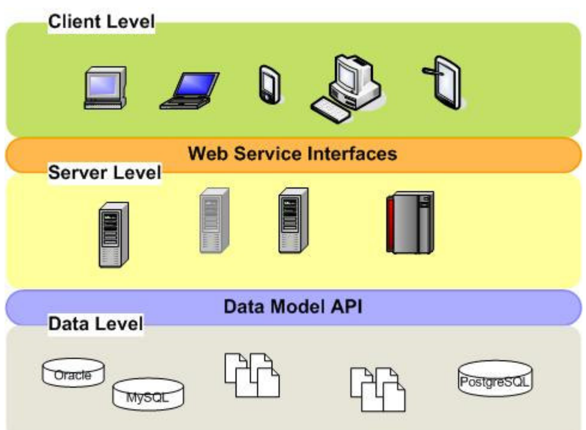

Figure 1-2 a generalized network architecture

Server Level: The study reviews the implementation aspect of two opensource server software, GeoNetwork and THREDDS, for case study. The choice is based on existing web services in ITC NRS Department.

Web Service Interface: The study reviews OGC web service interface specifications that are relevant to the issue of interoperability based on the agreement reached among GALEON IE participants. That is, interoperate via OGC web service interface.

Client Level: The study leaves out evaluations of client-side solutions based on the assumption that the interoperability should take place in a loosely-coupled architecture. That is, the interoperability through web services is a more cost-efficient approach than revolutions in both client and server side techniques.

1.6. Research Method

Illustrated in Figure 1-3, the study began with a literature review that covers standard specifications, technical notes, mail-lists and wikis that collect relevant discussions among developers. A survey of multidimensional scientific dataset usage in GI community (see Appendix B) was designed to demonstrate the current recognition and predict future attitude of members in GI community towards the use of multidimensional scientific dataset. Summary of survey results is presented in section 3.2.1 to support the discussion of user requirement for interoperability. The answer of the first research question shall be justified by this survey in addition to the difference of data characteristics.

The study identified proper web service interfaces for interoperability based on both technical and user aspect. The final result was at conceptual level. Instead of the proof of concept (i.e. validation), implementation constraints were identified in the case study.

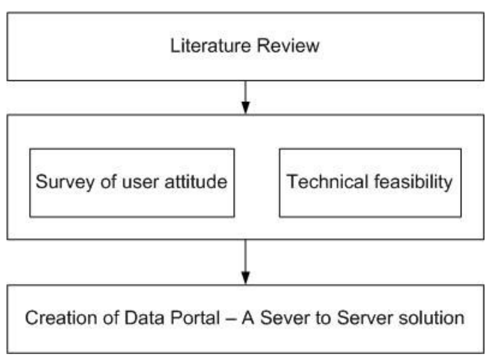

Figure 1-3 research approach of the study

1.7. Thesis Structure

Chapter 1: Introduction
Chapter 2: Overview of OGC and UniData Services
Chapter 3: Interoperability between Heterogeneous Servers
Chapter 4: Conclusion and Recommendation

2. Overview of OGC and UniData Services

2.1. Data Characteristics

Features representing in either vector or raster structure are fundamental concept in GeoInformation Science. The format stands not only for data model but also for analysis methodologies. Identifying the format becomes an initial step of data processing in GI community. On the contrary, data structure remains the same regardless of which data type (that defined in the data model, e.g. station observation, trajectory data, etc) the multidimensional scientific dataset referred to. To be more specific, the data is always stored in the form of arrays. This is the fundamental difference between geospatial and multidimensional scientific datasets.

Standards allow people to describe the same thing in the same manner. The uniformity is reached among the community in order to communicate with each other with the least risk of misunderstanding/misinterpretation. As mentioned in section 1.1, distinct data models have been developed in GI and ES communities to enhance cooperation among their own members. The study reviews these standardized data models and formats for a concrete understanding of conceptual differences between data models.

2.1.1. Geospatial Data

A generalised illustration of OGC data model for geospatial datasets is shown in Figure 2-1. Two geospatial technologies, Features with Geometry and Coverage, for modelling real world phenomena (i.e. features)[15]. In a nutshell, subtype Features with Geometry describes vector objects such as point, line, polygons, and composites while subtype Coverage inherits concept of raster data. Details are defined in *ISO 19107: Geographic information – Spatial schem*a[3], *OGC Abstract Specification Topic 5: Features*[15] and *OGC Abstract Specification Topic 6: The Coverage Type[16].*

One important component of the GeoInformation is spatial references that relate the features to position in the real world. The component is defined by coordinate reference systems as specified in ISO19111: *Geographic information – Spatial* *referencing by coordinates[1]*. The spatial location of feature is unambiguous only when with reference to a coordinate reference system.

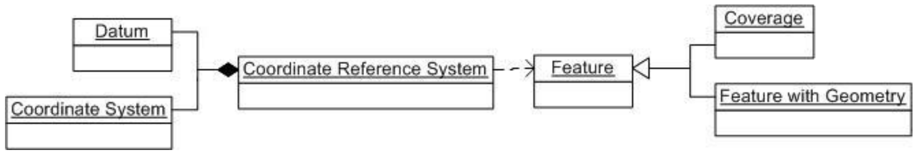

Figure 2-1 Generalised OGC data model

Two elements, datum and coordinate system, consisting of coordinate reference system are illustrated in Figure 2-1. To be more specific, a datum specifies the relationship of a coordinate system to the Earth, thus ensuring the spatial reference. Generally, coordinate reference systems are divided into seven subtypes[3]: 1) Geocentric, 2) Geographic, 3) Projected, 4) Engineering, 5) Image, 6) Vertical, and 7) Temporal. Conventionally, geospatial datasets are described by either Geographic or Projected coordinate reference system. The other subtypes are seemingly optional for most GIS users.

2.1.2. Multidimensional scientific data

ES data are stored in file formats including netCDF, HDF, GRIB and BUFR. In spite of slight differences between each format, multidimensional arrays is the main data structure of all the data format[17]. Accordingly, the study chose netCDF format as the representation of ES data.

A netCDF file is a binary file with header and data content. It contains three components: dimension, variable, and attribute. As a self-describing data format, header can be considered as metadata in GI terminology. It describes the number, naming and content of three components as well as relations among them. An ASCII CDL (network Common Data form Language, see an example in Appendix A) can be retrieved to show the metadata of a netCDF file.

In addition to three components, a unique case of component *Coordinate variable* is designed to associate a dimension with the very dimension of one or more data variables. It is a one-dimensional variable with the same name as its dimension.

[3] Principal sub-types of coordinate reference system defined in ISO19111.

Moreover, *Conventions* are formulated to provide definitive descriptions of what the data in each variable means as well as of the spatial and temporal properties of the data via a specification of standard naming. Sets of naming conventions including CF and NUMG Conventions are in use for reduction of inconsistency between different data sources.

A special design of the section *Grid mappings and projections* in CF-Conventions is considered the complement to geo-referencing capability of netCDF. A set of variables representing map projection approach, attribute grid_mapping_name, attribute standard_name (e.g. projection_x_coordinate, projection_y_coordinate, etc.) and a list of attributes for map projection parameters (e.g. false_easting, false_northign, etc.) are defined to facilitate direct calculation of latitude and longitude[18]. At the moment, the CF-Conventions 1.0 supports projection coordinate systems including Albers equal area, Azimuthal equidistant, Lambert azimuthal equal area, Lambert conformal, Polar stereographic, Rotated pole, Stereographic and Transverse Mercator.

For data itself, multidimensional arrays are designed to represent phenomena in the real world. Relations are defined not only by formulas (i.e. variable (dimension1, dimension2, dimension3…)) but also the position of array elements (i.e. index). Take Appendix A for example, variable *latitude* is a 480x640 matrix defined by dimension *line* and dimension *elems*. Same rule applied to variable *longitude*. The relation between latitude and longitude is based on the same index of two matrixes. A coordinate variable *bands* is stored as a one-dimensional array. It represents a physical coordinate corresponding to dimension *bands* indicating a five banded image. DN values of the image is stored in a three-dimensional array (i.e. variable *data*) defined by dimension *bands*, dimension *lines* and dimension *elems*.

Based on the data structure, a Common Data Model (CDM) that consists of four interactive layers[8] is designed to manipulate multidimensional scientific datasets:

1. **Data layer**: IO (i.e. Input/Output) is handled by this interface. Multidimensional array is the basic data type.
2. **Standard attribute layer:** The interface defines the metadata of the data content. For example, *units* as scientific data units of variables, *missing data values* as special values for absent data.

3. **Coordinate system layer:** The layer identifies the coordinates of the data arrays. Coordinate is a completely general concept for scientific data, it can make reference to any real physical dimension (i.e. not specifically referred to geographic coordinate).

4. **Scientific data type layer:** The layer identifies specific types of data, such as grids, images, and point data, and adds specialized methods for that kind of data.

2.1.3. Discussions of Data Characteristics

A comparison of basic facts between ES and GI data is summarised in Table 2-1. Apart from brief highlights, a detailed discussion is offered as follows:

Table 2-1 comparison of basic facts of two data types

	Earth Science data	***GeoInformation Science data***
File extension	nc, hdf, etc	shp, tab, img, etc
Dimension	multiple	two/three
Data structure	Array oriented	Object oriented
Temporal info	Dimension (time)	Attribute (timestamp)
Georeferencing	CF-Conventions	Coordinate reference system

1. **Terminology:**

   Terminology is the origin of confusion between two communities. For example, the term *attribute* represents the value a geospatial object possesses while it provides the metadata of variable and/or the whole multidimensional scientific dataset. A summary of different terminology based on three components of multidimensional scientific data is listed in Table 2-2.

Table 2-2 comparison of concept

Multidimensional scientific data	***Geospatial data***
Variable	Attribute
Attribute	Metadata
Dimension	—

Being able to interpret data content with accurate definitions is the first step towards correctly and efficiently manipulating datasets. Information in Table 2-2 should be able to lessen misinterpretation of data content.

2. **State of captured phenomena: static vs. dynamic**

   Accurate earth location is the foundation of geospatial data. Information related to locations is recorded as attribute. Consequently, time despite its nature of dimension is represented as attribute(s) in a geospatial data. In other words, the data captures static phenomena in the world. Spatial-temporal relation is difficult to be captured under such circumstances.

   The composition of multidimensional array is the foundation of ES data, as described in section 2.1.2. Theoretically, spatiotemporal relation could be better depicted using ES data due to time is a dimension of the structure. An illustration of the conceptual difference is depicted in Figure 2-2.

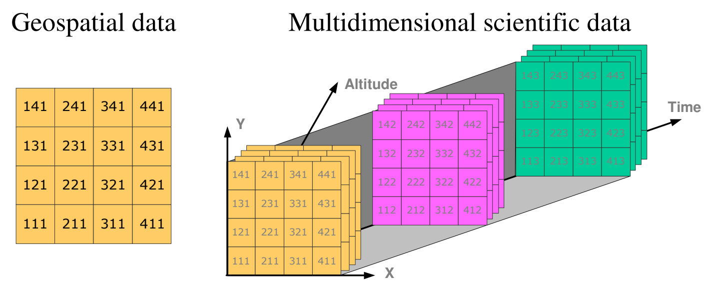

Figure 2-2 static vs. dynamic phenomena represented by datasets

3. **Spatial reference:**

   One noticeable incompatibility is the implicit spatial reference of the data. Put this in a concrete sense, the absent parameter – DATUM – due to different perceptions of the definition of the term. Initially locations are recorded merely by latitude-longitude coordinate. It is due to most models treat the Earth as a sphere hence no such information is in existence according to [19]. In general cases (Appendix A for example), spatial reference is determined by the *units* of the coordinate variables (e.g. degree_east and degree_north). Reference datum is considered optional therefore not standardised or specified in the data structure.

   Due to the lack of information however, the dataset is always assumed referencing to the WGS84 datum. The assumption is inadequate for data which references a particular sphere or ellipsoid other than WGS84 (e.g. Bessel-1841). The risk of inconsistency with other geospatial datasets is therefore aroused.

Discussions of the need of standardised DATUM attribute in CF-Conventions are ongoing in the UniData CF-metadata discussion list. A general agreement of the need is acknowledged at the moment. Nevertheless, final solution of the standard DATUM attribute (i.e. the semantics of the attribute) is not yet achieved.

4. Analogue of data models: OGC Coverage and netCDF CDM

Coverage is identified as the key concept for bridging the gap between ES and GI data models based on previous studies[8]. The conclusion was drawn by scientists in ES community and became the direction for interoperability. Following by the concept, analogue relations between scientific data types of ES common data model and OGC data models are identified as shown in Table 2-3. One–to–One mappings between each scientific data type of common data model and OGC coverage model are observed.

Table 2-3 ES scientific data types vs. GI data types

Scientific data	*Geospatial data*
Point Observation Data Trajectory Data Station Data	Feature with geometries: Point collection Coverage: Discrete Point Coverage
Radial Data* Grid Data	Coverage: Grid Coverage
Image/Swath* Data	

* (Possibly) irregular/non-rectangular grid

Despite the mapping is conceptually feasible, the concern of mapping ES data to OGC coverage is in existence. Three implementation issues are identified as follows.

a) **Granularity**: converting discrete points into regular grids

b) **Regularization**: rendering irregular grids such as radial datasets into regular grids

c) **Downsize**: rendering multidimensional data content into a set of two/three dimensional coverage

2.2. Web Services

While ES and GI communities make data widely available through web services, the concept of providing services is quite different from each other. OGC limits its scope for defining architecture of web services and leave the methodologies of server/client implementation to vendors and developers. On the contrary, UniData provides a set of services including client/server software and data management toolkits. Discussion on core technologies of web services is left out in order to focus on the issue: interoperability.

2.2.1. OGC Web Services (OWS)

A four-tier Web Services Architecture (see Figure 2-3) has been developed by the OGC. It focuses on 1) component definition on providing and/or consuming a defined service, and 2) interactions between components that implement the service in the form of service requests/ responses/exceptions. Consequently only service type (e.g. interfaces and abilities) and server data handling (e.g. content) need to be known for a defined service [20]. The study evaluates services in the Information Management Services tier which designed to store datasets and provide access to data as mediations of interoperability. A list of services included in the Information Management Services tier is summarised in Table 2-4.

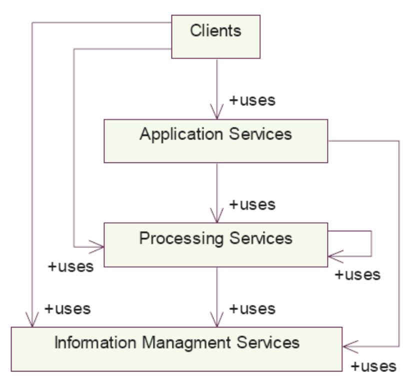

Figure 2-3 Service tier in OWS architecture[20]

In general, data can be served in two approaches: rendered into standard format or in its original format. Among increasingly deployed services specified in Table 2-4, Web Coverage Service (WCS, the former approach) and Catalog Service (the latter approach) are considered adequate candidates for interoperability.

Table 2-4 specific Information Management Services[20]

Service name [a]	Service description
Web Map Service (WMS) [b]	Dynamically produces spatially referenced map of client-specified ground rectangle from one or more client-selected geographic datasets, returning pre-defined pictorial renderings of maps in an image or graphics format
Web Feature Service (WFS)	Retrieves features and feature collections stored that meet client-specified selection criteria
Web Coverage Service (WCS)	Retrieves client-specified subset of client-specified coverage (or image) dataset
Catalog Service for the WEB (CSW) [c]	Retrieves object metadata stored that meets client-specified query criteria
Gazetteer Service	Retrieves location geometries for client-specified geographic names
Universal Description, Discovery and Integration (UDDI) Service	Allows a client to find a web-based service
Standing order services	Allows a user to request that data over a geographic area be disseminated when it becomes available, including reformat, compress, decompress, prioritize, and transmit information requested through standing queries or profiles
Order handling services	Allows clients to order products from a provider, including: selection of geographic processing options, obtaining quotes on orders, submission of order, statusing of orders, billing, and accounting

a Names ending in "Service" are currently specified specific services. Names ending in "services" are types of services that are not yet specified.

b Can store and access both feature and image (coverage) data.

c Many specific profiles of the CSW are expected to be specified and implemented, for metadata for many different types of datasets, and for also storing and accessing small whole datasets.

2.2.1.1. Web Coverage Service (WCS)

A summary of supported data type using different web services in OWS Information Management Service tier is listed in Table 2-5. Three services provide server's information based on client-requesting spatial constraints and other criteria in the similar manner. However, WFS and WCS provide available data with their detailed descriptions while WMS returns maps but not data. The choice of service to use for interoperability is based on datasets to be served. Supported by the viewpoint that multidimensional scientific data resembles coverage as mentioned in section 2.1.3, WCS is considered a possible mediation for interoperability.

Table 2-5 returned data type using different services

Service	*Return format*
Web Map Service	Static Map: PNG, GIF, JPG, SVG, webCGM, etc.
Web Feature Service	Discrete geospatial features in GML format
Web Coverage Service	Space-varying phenomena: satellite imagery, DEM, TINs

Three operations (aka. request), *GetCapabilities*, *DescribeCoverage* and *GetCoverage*, are mandatory in terms of implementations of WCS clients and servers. The request may be encoded as key-value pairs (KVP), or as an XML document using HTTP GET or HTTP POST method[21]. A simplified protocol diagram (see Figure 2-4) illustrates messages that might be passed back and forth between a client application and a WCS server via the specified interfaces in order to process a typical request. Definition of each interface is listed in the right hand side of the diagram.

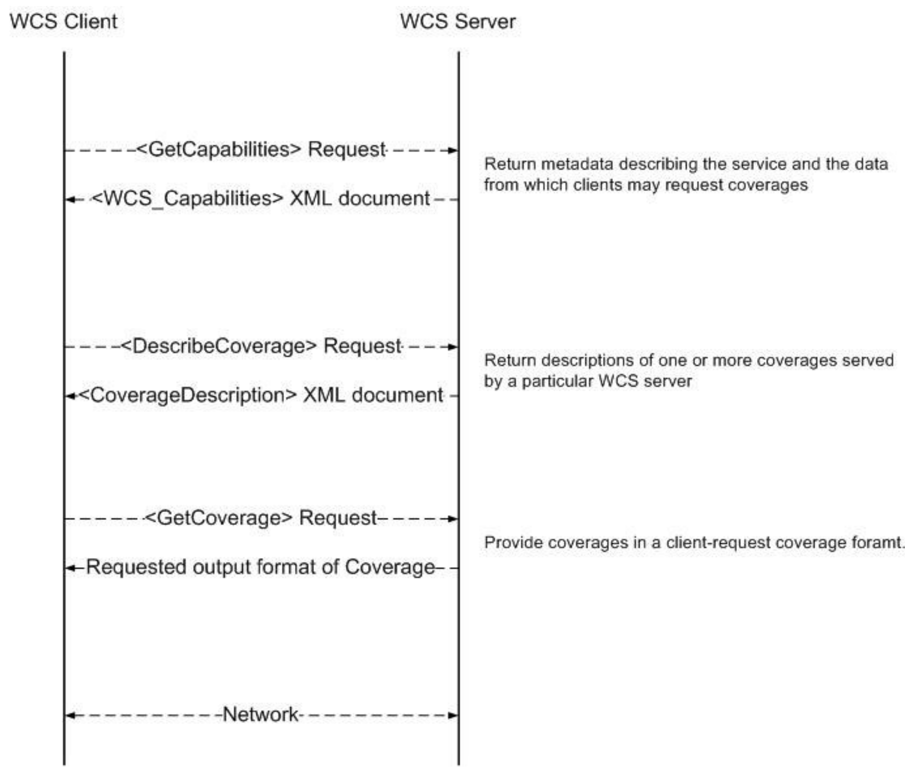

Figure 2-4 WCS protocol diagram

Criteria for assessing the feasibility of OGC WCS clients/servers is summarised in Table 2-6. It is not only crucial for software vendors/developers but also for users. For users, the criteria could be the guideline for retrieving dataset via HTTP method. Meanwhile, it could be the basic requirement for implementation of software.

Table 2-6 REQUIRED implementing components of operations

	GetCapabilites	DescribeCoverage	GetCoverage
URI request parameters	REQUEST=GetCapabilities SERVICE=WCS	http://server_url/path/script? REQUEST=DescribeCoverage SERVICE=WCS VERSION=1.0.0	http://server_url/path/script? SERVICE=WCS VERSION=1.0.0 REQUEST=GetCoverage COVERAGE=name CRS=crs_identifier BBOX=minx,miny,maxx,maxy,minz,maxz OR TIME=time1, time2… or min/max/res… WIDTH=w, HEIGHT=h DEPTH=d OR RESX=x, RESY=y, RESZ=z FORMAT
XML request components	service	service version	service version <sourceCovreage> <DomainSubset> <RangeSubset> <InterploationMethod> <output>
Response of service	<WCS_Capabilities> <Service> <Capability> <ContentMetadata>	<CoverageDescription> <CoverageOffering> <domainSet> <rangeSet> <supportedCRSs> <supportedFormats>	Coverage extracted from the request with specified spatial reference systems, bounding box, grid size/resolution and format

A WCS should be able to provide services as follows if the specified criteria are met.

1. Spatial query (via BBOX)
2. Temporal query (via TIME)
3. Range sub-settings (via WIDTH/HEIGHT/DEPTH)
4. Resampling (via InterpolationMethod and RESX/RESY/RESZ)
5. Multiple output format offerings (via output)
6. Reprojection (via CRS)

2.2.1.2. Catalog Service

Catalogue Service within a service-oriented architecture (illustrated in Figure 2-5) is a data serving approach essentially different from WMS, WFS and WCS interfaces. The design of the architecture is to publish (i.e. make data accessible), discover (i.e. search for published resources), and then bind (i.e. interacting with the resource provider to access the desired resources) queryable descriptive information (i.e. metadata) for prospective users. A catalogue service plays the role of matchmaker by providing publication and search functionality (as marked red in Figure 2-6), thus enabling a requester to dynamically discover and communicate with a suitable resource provider without requiring the Requester to have an advanced knowledge about the Provider[22].

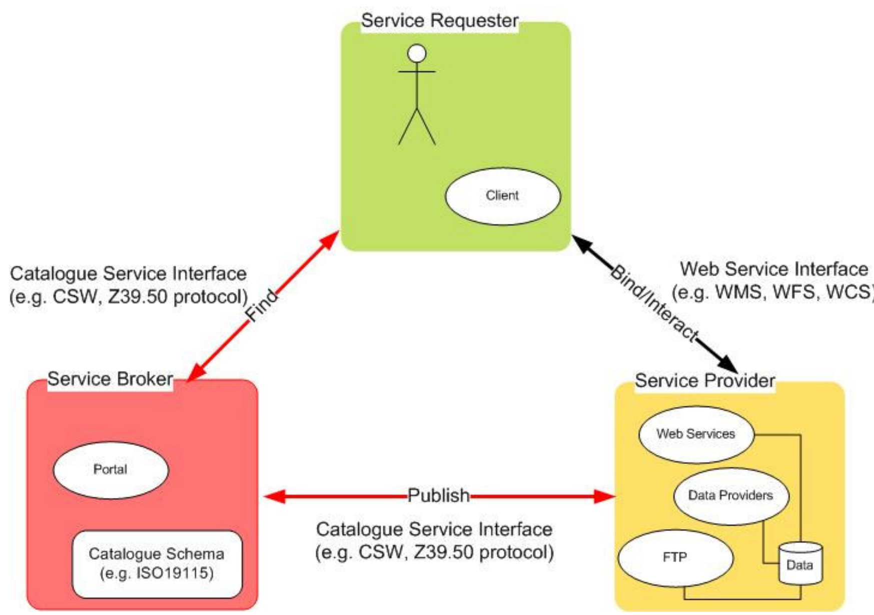

Figure 2-5 Service-Oriented Architecture

Due to the multitasking capability of Catalogue Services possess, two essential models that define abstract methodologies on server and web service interface levels are specified in OGC Catalogue Services Specification. The study summaries the 2.0 spec as follows.

1. **Catalogue abstract information model**

The model specifies two core components for sever implementation:

a) Query language

A BNF grammar for a minimal query language, a set of core queryable attributes (names, definitions, conceptual datatypes), and a common record format that defines the minimal set of elements that should be returned in the brief and summary element sets are specified in the model[23]. In other words, generalized descriptions of query content (i.e. query languages) instead of query using a specific format (e.g. SQL, CQL, Z39.50, etc.) are specified.

b) Catalogue schema

It is recommended but not compulsory to use a standard metadata schema such as ISO19119 in order to support search, retrieval, display and association the information in a consistent manner within distributed computing environment.

2. General catalogue interface model

Unlike other OGC web service interfaces that based on HTTP protocols in World Wide Web (WWW) environment, the OGC Catalogue Services specification provides a flexible framework for implementation design guidance that applied to multiple distributed computing environments. Four operation groupings along with one interface that support discovering, maintaining and organizing catalogues of geospatial resources is defined in the General Catalogue Interface Model [23](see Figure 2-6). Definitions of each component in the model are listed in Table 2-7.

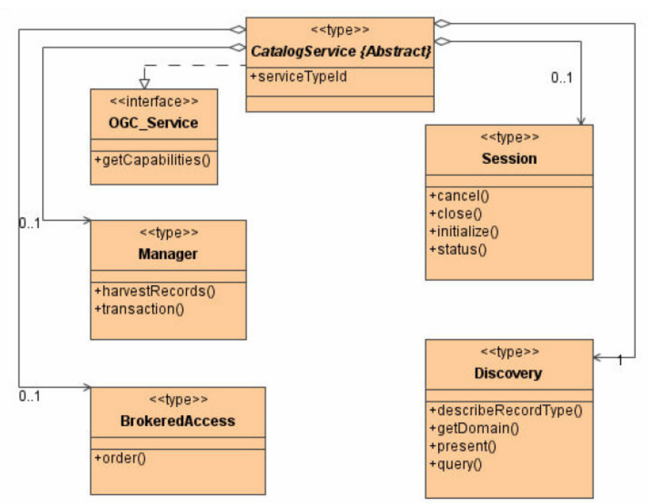

Figure 2-6 General OGC catalogue UML static model[23]

Table 2-7 definitions of operation groups

	Implementation	*Operations*	*Description*
OGC_Service	**Required**	GetCapabilities	Retrieve catalogue service metadata
Discovery	**Required**	query present describeRecordType getDomain	For client to discover resources registered in a catalogue
Session[4]	Optional	initialise close status cancel	Manipulating interactive session between a server and a client
Manager	Optional	transaction (push) harvestRecords (pull)	Maintaining (i.e. insert, update and delete) metadata by which resources are registered in a catalogue
BrokerAccess	Optional	order	Ordering an identified resource that is registered in a catalogue but is not directly accessible to the client

Among all specified operations, ***Harvest*** in the Manager grouping is a unique and crucial component of a Catalogue Service. Contrary to the *push* publication (i.e. insert, update, and delete on metadata stored by the Catalogue Service) that specified by the transaction operation, the harvestRecords operation performs a *pull* publication. That is, it enables the Catalogue Service to "harvest" information from specified remote locations within information-sharing community via the standard request and provides the collection as optional transactions on the local catalogue.

In order to provide the service regardless of the application environment, the model can be realized using the following protocols via different standards:

1. Z39.50 protocol binding in the ANSI/ISO standard.
2. CORBA protocol binding in the CORBA/IIOP standard.
3. HTTP protocol binding (Catalogue Services for the Web, CSW) in HTTP standard.

[4] See Terms and Definitions

Each protocol binding supports different combinations of operation groupings as illustrated in Figure 2-7. Due to different combinations of operation groups in each binding, each Catalogue Service could provide significantly different abilities.

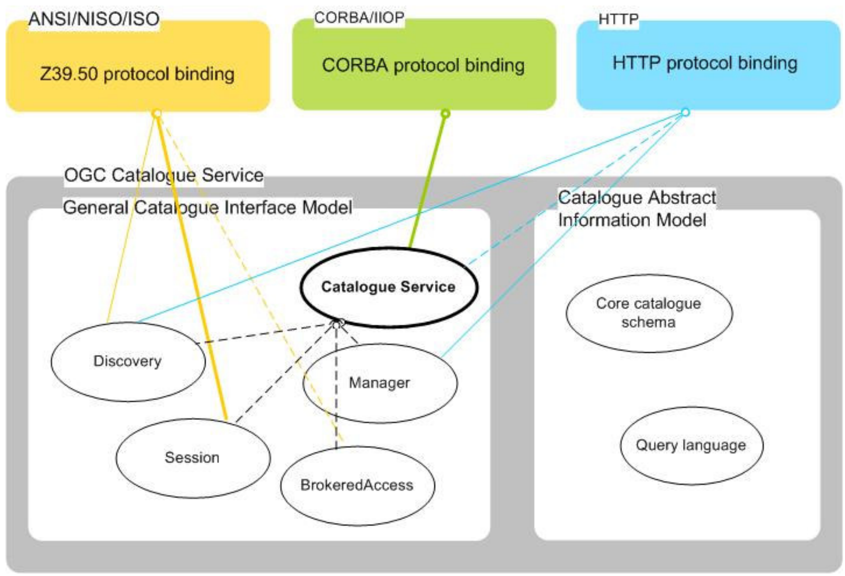

Figure 2-7 interactions of catalogue service using three standards[5]

Among three approaches, one significant difference is observed. That is, the implementation of harvestRecords operation is merely specified in HTTP protocol while not mentioned in the other two protocol binding specifications. Accordingly, it is recommended to construct a Portal that requires both push and pull publications through CSW interface.

2.2.2. UniData THREDDS Data Server (TDS)

Contrary to OGC that formulates specifications, UniData THREDDS (Thematic Realtime Environmental Distributed Data Services) project provides middleware to bridge the gap between data providers and data users. Students, educators and researchers use the middleware to publish, contribute, find, and interact with data

[5] Yellow dash line: implementation of the interface is optional.
Blue dash line: only "GetCapabilities" operation is specified in the implementation.

relating to the Earth system[24]. Under such circumstances, detail information of THREDDS in terms of practical implementation (e.g. interfaces, components of THREDDS Data Server, etc.) is not publicly available due to limited documentation.

The study reviews available user guides, technical notes, papers, meeting reports and semi-open source codes (i.e. available on demand for approved partners) for theoretical understanding of the TDS architecture (as illustrated in Figure 2-8). Implementation detail such as ncML-G data model and ncML-GML is preserved for future study.

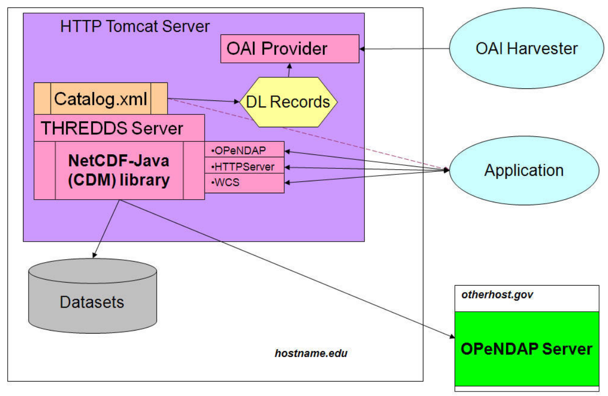

Figure 2-8 reference architecture of THREDDS Data Server[25]

NetCDF-Java CDM library and THREDDS server are core components of TDS system. To be more specifically, Web Coverage Service, Catalog Service and communications among THREDDS, ADDE and OpenDAP sever are developed using the library.

While THREDDS WCS implements the OGC WCS 1.0 specification, THREDDS Catalog applies its own specification. Detail explanations are available in the following sections.

2.2.2.1. THREDDS WCS gateway

The first prototype OGC WCS extension of TDS was published in June 2006. The service distributes only regular gridded data (i.e. radial data is not available since it is irregular) with identifiable geographic/projected coordinate systems in GeoTIFF and/or NetCDF format.

THREDDS WCS supports three compulsory operations specified in OGC WCS Specification 1.0 (as mentioned in section 2.2.1.1) in its unique manner. That is, the exact filepath string for each file in the server is required for constructing request URIs (e.g. http://motherlode.ucar.edu:8080/thredds/wcs**/galeon/testdata/RUC.nc**?request=GetCapabilities&version=1.0.0&service=WCS). In such way, operations provide file-based instead of integrated information. A summary of THREDDS WCS operations is listed in Table 2-8.

Table 2-8 THREDDS WCS implementing components of operations

	GetCapabilites	DescribeCoverage	GetCoverage
URI request parameters	REQUEST=GetCapabilities SERVICE=WCS	REQUEST=DescribeCoverage SERVICE=WCS VERSION=1.0.0	SERVICE=WCS VERSION=1.0.0 REQUEST=GetCoverage COVERAGE=name BBOX=minx,miny,maxx,maxy,minz,maxz AND/OR TIME=time1, time2… FORMAT=GeoTIFF or netCDF **VERTICAL=value**
Response of service	<WCS_Capabilities> <Service> <Capability> <ContentMetadata>	<CoverageDescription> <CoverageOffering> <domainSet> <rangeSet> <supportedCRSs> <supportedFormats>	Coverage extracted from the request with specified bounding box and format

To sum up, THREDDS WCS provides spatial dimension query (via BBOX constraint), temporal dimension query (via TIME constraint), vertical dimension query (via VERTICAL constraint) and multiple output format offering (via FORMAT constraint) while subsetting/resampling (via WIDTH/HEIGHT/DEPTH or RESX/RESY/RESZ, InterpolationMethod criteria) and reprojection (via CRS) are not supported. In addition, in order to maintain the special design of TDS (i.e. serving remote datasets), an additional request parameter *dataset* is provided. The syntax of extended URI is specified as the following.

http://motherlode.ucar.edu:8080/thredds/wcs?**dataset=http://las.pfeg.noaa.gov/cgi-bin/nph-dods/data/oceanwatch/nrt/gac/AG14day.nc**&request=GetCapabilites&version=1.0.0&service=WCS

2.2.2.2. THREDDS Catalog

OpenDAP, ADDE and THREDDS are commonly used client-server protocols that provide access to ES data. Among all, THREDDS is capable of gathering resources from the other two services and provides the collection as local entries. Therefore, the study chose THREDDS services as the representative of web service deployed in ES community.

THREDDS Catalog is the essential service in the TDS architecture. It provides available datasets in a nested manner. That is, datasets can be accessed via web browser as hierarchical folders in windows environment. In other words, individual dataset is presented as HTML that automatically generated when a service is startup. Discussions of THREDDS Catalog component of TDS system are as follows.

1. **Data Source**

To facilitate data exchange among its community, THREDDS Catalog serves two types of dataset: local dataset (i.e. on local machine) and/or virtual dataset on other THREDDS/OpenDAP/ADDE/IDD servers. To this end, metadata schema of the catalogue should conform to the specification as stated in the next paragraph.

2. **Metadata Schema**

Apart from auto-generated HTML, a top catalogue XML that organizes collections of datasets and accessing of each datasets in a THREDDS Catalog is crucial for TDS. The semantics of the catalogue is specified in Dataset Inventory Catalog Specification. A summary of basic catalogue elements is listed in Table 2-9.

Table 2-9 Descriptions and examples of basic catalogue elements

Element	*Aattributes: Descriptions and Example*
catalog	xmlns : declaration of the THREDDS catalogue namespace <catalog xmlns="http://www.unidata.ucar.edu/namespace/thredds/InvCatalog/v1.0">
service	name: unique within the catalog serviceType: DODS, ADDE, FTP, HTTP, etc base: base dataset URI <service name="test" serviceType="DODS" base=http://acd.ucar/edu/dodsC />
dataset	name: descriptive and unique in the catalogue serviceName: reference data service [optional] urlPath: appended to base for the dataset URI [optional] **harvest**: true for discovery services [optional] <dataset name="DC8 flight 1999-11-19, 1 min merge" serviceName="test" urlPath="SOLVE_DC8_19991119">

Element	*Aattributes: Descriptions and Example*
access	urlPath: appended to base for the dataset URI serviceName[optional] dataFormat: recommended when the serviceType is a bulk transport like FTP or HTTP[optional] <access serviceName=”ftp1” urlPath=”SOLVE_DC8_19991119.nc” dataFormat=”NetCDF”>
catalogRef	Xlink: refers to another valid THREDDS catalogue that becomes a dataset inside this catalog <catalogRef xlink title=””NCEP Model Data” xlink:href=”http://motherlode.ucar.edu:8080/catgen/uniModels.xml”/>
xLink	Href: URI of the resource Title: displayed resource title <documentation xlink:href=http://cloud1.arc.nasa.gov/solve xlink:title=”SOLVE”>

3. Functionality

A THREDDS Catalog provides services as follows using proper formulated catalogue to publish different types of datasets.

a) Direct dataset: a physical dataset on the local server or a virtual dataset from remote servers

b) Collection dataset
- Aggregation: a virtual dataset consists of datasets grouping by a collection type (e.g. TimeSeries, Station, etc…)
- Subsetting: a virtual dataset represents partial information of a physical dataset according to specified spatial and/or temporal constraints

2.2.3. Discussions of Web Services

In general, both Web Coverage Service and Catalog Service are available and functioning in GI and ES communities. These services perform similar functionality using different methodologies. Based on review of two systems (available in section 2.2.1 and 2.2.2.), several interesting issues are summarised as follows.

1. Experimental prototype WCS

THREDDS OGC WCS extension is still in the experimental process at the moment. Therefore, the methodology in terms of server implementation (e.g. methodology for conversion of netCDF into GeoTIFF) is not the concern of the study. The study focuses on theoretical conformance between two systems. In summary, four incompatibilities are identified:

a) **Coordinate Reference System(CRS) parameter**

The CRS parameter as required constraint of GetCoverage request is absent in the recent published THREDDS WCS while the coordinate system information is provided by DescribeCoverage. Accordingly, dataset can only be served in original coordinate system. More concretely, the reprojection function is not supported.

b) **Grid size (WIDTH/HEIGHT/DEPTH) or spatial resolution (RESX/RESY/RESX) criteria**

The two set of parameters for GetCoverage request are designed to support resampling coverage values according to the request constraint along the coordinate reference system specified in CRS. The fact these query constraints are not yet supported by THREDDS WCS implies incomplete geospatial descriptive conventions of the multidimensional dataset.

c) **Multidimensional query**

The singular query design (e.g. one BBOX, one TIME parameter) of WCS request may not be sufficient to make best use of multidimensional data. Take 5D dataset for example; it is difficult if not impossible to retrieve data containing two time dimensions(i.e. observation time and forecast time) using one TIME parameter.

d) **URI constructing**

Due to hierarchical inventory structure of THREDDS server, THREDDS WCS performs similar services. That is, each request (i.e. even if GetCapabilities) is practically querying a specified file in the service list and retrieve information of the very dataset. Such manner may cause difficulties for those who are not familiar with THREDDS WCS request syntax and trying to explore the service using OGC syntax request.

2. Design of catalogue

The concept of Catalog Service that make dataset accessible in its original format with metadata descriptions via unique URI on the internet is similar in two systems. In general, fundamental component of the services is the metadata of data sources. However, practical implementations are rather different from one another. Main differences between two systems are addressed in the following aspects:

a) **Metadata schema**

Core semantics metadata is not specified for OGC Catalog Service implementation while a THREDDSS Catalog applies the Dataset Inventory Catalog Specification. The difference hinders the communication between two systems.

b) **Harvest mechanism**

Apart from metadata schema, communication interface is also crucial for harvest operation to function. Harvesting from web resources are performed via HTTP protocol in both system. However, the implementation applies different standard: WCS protocol for OGC Catalog Service and OAI (Open Archives Initiative) protocol for THREDDS Catalog Service. Evaluation of both standards is beyond the scope of this study and reserved for future studies.

3. Interoperability between web services

Two types of web service, Web Coverage Service and Catalog Service, are evaluated for interoperability study. The former approach provides spatial coverage rendered from multidimensional scientific dataset while the later method offers the access of multidimensional dataset. Either approach could enhance the interoperability in terms of data sharing between two communities. However, to choose between one another is out of the scope in the research.

The study identifies pros and cons of two approaches in Table 3-2 for users' reference. Observations of WCS approach are concluded based on the THREDDS source code while comments of CSW approach are purely theoretical conclusions on the basis of OGC Catalogue Service specification. This is owing to unique implementation status of two approaches.

The Data aspect of two approaches is especially addressed based on the assumption that it is the core of web service for data sharing apart from communication mechanism and can not be overlooked. That is, wrong data can be served in the right way.

In general, implementation of CSW approach would be relatively less complex than WCS approach because the need of data rendering for services such as reprojection is not required. Nevertheless, implementation of both approaches remains challenges in the future.

Table 2-10 pros and cons of the approaches at current state

		Pros	*Cons*
WCS	Data	Geospatial data as output : no need for data conversion on client side	Data rendering issues: 1)granularity 2)regularization 3)downsize 4)spatial reference
	Service	Practical: available client/server software	Experimental: lack of 1) resampling function 2) reprojection function 3) multidimensional query
CSW	Data	No data rendering: full usage of multidimensional scientific data	1)Preprocess if required: for users who prefer spatial data format 2)Knowledge of netCDF format: in order to manipulate the datasets
	Service	Unlimited data pools: harvest from ES and GI communities	Conceptual: implementation difficulties 1)core metadata schema 2)harvest protocol

3. Interoperability between Heterogeneous Servers

3.1. GALEON IE

A considerable amount of researches have been conducted through the teamwork of Geo-interface to Atmosphere, Land, Environment, Ocean netCDF (GALEON) Interoperability Experiment (IE) project. The ultimate goal is to make the interoperability possible as illustrated in Figure 3-1. At the moment, the mission of primary Phase 1 is accomplished. Based on the experiences gained, a proposal of Phase 2 Plan was posed in January 2007 and the work shall be continued when the mission of this stage is verified.

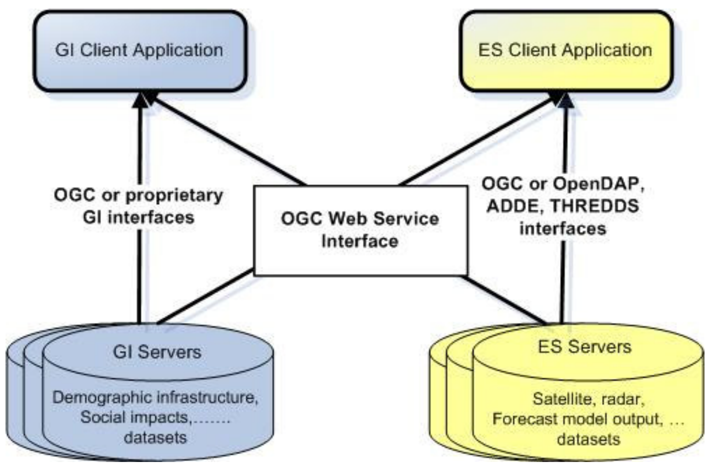

Figure 3-1 GI-ES Interoperability via Standard Interfaces

3.1.1. Achievement of Phase 1

As illustrated in Figure 3-2, the initial concept of GALEON IE for interoperability is to enable THREDDS Data server (TDS) for responding to WCS clients. That is, using WCS interface as a gateway between GI application (e.g. WCS client) and datasets available in existing servers that number in hundreds in ES community. These servers based on client-server technologies including NetCDF, OPeNDAP, ADDE and THREDDS along with a rudimentary WCS interface are integrated into the TDS system.

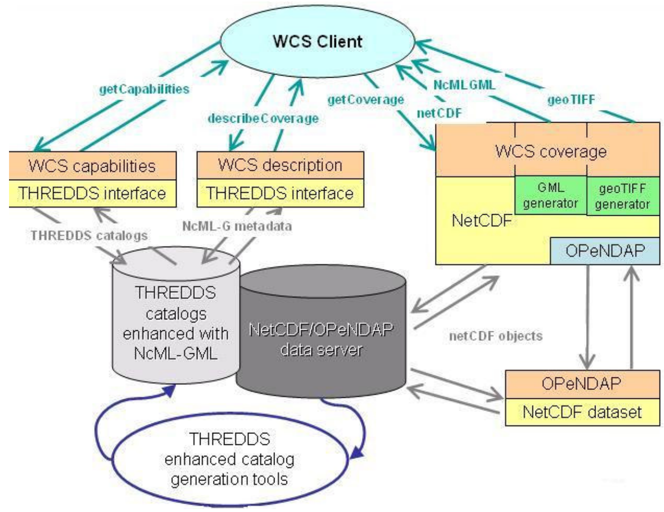

Figure 3-2 WCS-interface as a Gateway to Existing Services[26]

The mission of GALEON Phase 1 is to demonstrate the feasibility of conceptual interoperability by practical implementation. That is, to develop implementation methodologies and to test the performance of WCS geo-interface on existing THREDDS Catalog Service. Main tasks of experiments in this phase include:

1. Practical usage of ncML-G data model and ncML-GML encoding format
2. Techniques for converting netCDF to GeoTIFF
3. existing WCS clients to access and display the data
4. implementation using standard database technology

During the whole period, WCS clients and servers for netCDF datasets are developed to test the interface and modify client and server implementation accordingly; hence recommendation modification and augmentation of the OGC interface. A table with status information about tests of clients and servers developed by GALEON team is listed on the GALEON Wiki[27]. Moreover, a list of pointers to data available on GALEON WCS Servers is provided on the GALEON Network[28].

In order to demonstrate the outcome of GALEON team, accessibility and performance of servers on the list of pointers were tested via OGC WCS standard request stated in Table 2-6. The exact query strings are listed in Appendix C. The result is summarized in Table 3-1.

Table 3-1 Test result of dataset available on GALEON WCS Servers

<table>
<tr><th></th><th>GetCapabilities</th><th>DescribeCoverage</th><th>GetCoverage</th></tr>
<tr><td rowspan="2">UniData
THREDDS
server</td><td rowspan="2">○</td><td>○</td><td>○</td></tr>
<tr><td>Support format:
GeoTIFF and NetCDF</td><td>Absent parameters:
CRS, WIDTH/HEIGHT, RESX/RESY
Extension parameters:
vertical, dataset
Filepath prefix</td></tr>
<tr><td rowspan="2">GMU[6]
NWGISS
server</td><td rowspan="2">○</td><td>○</td><td>○</td></tr>
<tr><td>Support format:
GeoTIFF, HDF-EOS and NITF</td><td>Extension parameters:
measureName, axisname, axisvalue, store</td></tr>
<tr><td rowspan="2">DataFed
WCS
server</td><td rowspan="2">○</td><td>○</td><td rowspan="2">○</td></tr>
<tr><td>Support format:
CSV, GeoTIFF, GML, NetCDF</td></tr>
<tr><td rowspan="2">NERC
TPAC
OPeNDAP
server</td><td>○</td><td>○</td><td rowspan="2">○</td></tr>
<tr><td>Support
gml:timePosition</td><td>Support format:
netCDF</td></tr>
</table>

○: Functioning ×: Respond error

In general, three WCS operations on four servers based on different client-server technologies conform to OGC WCS standard. That is, the request and response format are provided in standard format. In this study, the tests aim at the communication between server and client using identical approach. Feasibility in terms of WCS services such as reprojection and resampling is preserved for further study.

In summary, the achievement GALEON IE Phase 1 includes:

1. Functioning WCS servers and clients providing multidimensional datasets
2. Recommendations for modification of WCS specification
3. A proposed complementation for interoperability with WCS approach: an OGC Catalog Service on the Web (CSW) geo-interface

6 Web Service Description Language (WSDL) is available at http://laits.gmu.edu/ServiceWSDL/gmu_wcs.wsdl

3.1.2. Phase 2 Plan

The tasks of GALEON Phase 2 include:

1. Define a CF-NetCDF profile of WCS
2. Expanding test environment: WCS client, server and datasets
3. Develop OGC CSW to complement the WCS interface

3.1.3. Discussion

GALEON Phase 1 has proved that WCS is a practical approach for interoperability with deficiency. The difficulties linger on interoperability of data level. That is a proper approach for mapping multidimensional data to geospatial data. The issue continues in GALEON Phase 2.

It is observed that a general agreement among stakeholders that both Web Coverage Service (WCS) and Catalog Service on the WEB (CSW) are recommended for interoperability. Feasibility of the concept shall be demonstrated by the work done in GALEON Phase 2.

3.2. Case Study: Data Portal

As mentioned in section 1.2 and illustrated by Figure 1-1, two services are in use for data sharing in ITC NRS department. A Data Portal is recommended to provide the data in the organization. The implementation is considered as a demonstration of the interoperability between web services.

As discussed in section 2.2 (especially section 2.2.3), two interfaces (i.e. WCS and CSW) are possible solutions for interoperability. However, despite how promising the approach might be in technical aspect, a system can not be successful without correctly specified requirements. Therefore a survey of user behaviour was conducted in order to identify the requirements.

3.2.1. System requirement

A small scale survey was taken place in GEM 2005 class in ITC NRS department. Three out of 27 (i.e. less than 12 %) students are aware of the existence of multidimensional scientific data. Regardless using a small sample for a big question *Multidimensional data usage in GI community*, the number (11.11%) indicates the lack of information in terms of data available (regardless sources and format) in the department hence the need of a Data Portal.

The attitude towards multidimensional scientific data usage could be observed in this survey. Only one student uses multidimensional data for his study (20% of research data) because of 1) open availability (i.e. free of charge), and 2) data content (i.e. oceanographic data). A considerable amount of data was downloaded and converted into raster images (pre-processing). The other two students tried to benefit from free sources but gave up because of difficulties in manipulating dataset. It appears that free source is the main reason for them to consider multidimensional scientific data as part of their studies.

None of them are familiar with data structure although one of them uses data for his research. Despite software such as IDV are designed to manipulate the dataset, none of them found it adequate for GIS analysis. Two of them will try to use the data if the data is readable using GIS software.

In summary, two contradict attitudes are observed by the survey:

1. Hesitation: difficulties of multidimensional data manipulation
2. Willingness: feasible GIS software and free access to datasets

The list of system requirement therefore includes:

1. Expose data access to users
2. Provide data in geospatial data format

As a result, one particular requirement stands out after ESRI ArcGIS 9.2 was released in December 2006. Now that GIS software capable to manipulate multidimensional scientific data is available, the second requirement can be withheld. The remaining requirement is then to expose data access to users. Technical issues of interoperability are discussed in the following section.

3.2.2. Web Services in existence

The interoperability in this case is a sever-to-server issue. The mission is to make an OGC standard SDI interoperate with a TDS so that a Data Portal can serve data from two big data pools. A review of SDI is provided in the remaining section to identify main issues of interoperability. The review of the TDS system is available at section 2.2.2 therefore is left out in this section.

GeoNetwork

Both the Portal component and the Catalog database of a Spatial Data Infrastructure (SDI) defined in the OGC Reference Architecture are implemented in GeoNetwork[29]. It provides services to manage and publish metadata on geospatial data as well as interactive map viewer. In addition, GeoNetwork servers are able to link with each other hence an enormous data pool.

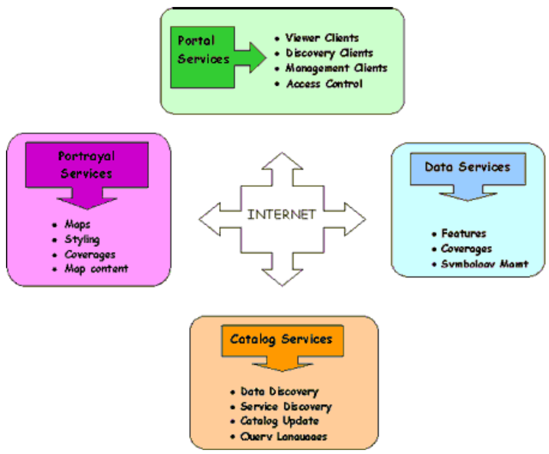

Figure 3-3 Geospatial Portal Reference Architecture[29]

In summary, four main services are available in GeoNetwork environment:

1. **Portal Service :**

   It provides the access to the geospatial information as well as the management and administration of the portal and users. The access to information is regulated according to users' privilege that set by authentication and access control rules.

   Metadata schema employed by GeoNetwork is based on ISO 19115. A tool, Advanced Metadata Editor Module, is available to create and edit required metadata for geographic data.

2. **Catalog Service**:

   GeoNetwork can access other data resources and vice versa. The descriptive information about the data (i.e. metadata) is stored in a database but not a physical XML file. GeoNetwork performs registration, collection and maintenance the information through database technology. OGC WCS Z39.50 protocol is applied in GeoNetwork for data publishing and finding while harvesting is implemented using non OGC standard GN2.0.

3. **Data Service** :

   The particular service provides access to spatial content in repositories and databases and allows data processing through defined common encodings and interfaces. It is a unique implementation by GeoNetwork.

4. **Map Portrayal :**

   Instead of developing its own map portrayal, GeoNetwork intergrates third party Map Portrayal component such as Degree, MapServer and GeoServer that implements OGC standards. It enables geospatial information visualization on the Internet via OGC web service interfaces such including WMS, WFS and WCS.

3.2.3. The interoperability solution: Data Portal

Taking the system requirement and implementation techniques into consideration, CSW is recommended to be the mediation of interoperability between web services for this case study.

3.2.3.1. A Server to Server Architecture at conceptual level

Comparing to a TDS system, GeoNetwork is more adequate to be the core of a Data Portal since it provides four services whilst a TDS provides only one of them. For cost-efficient concern, the interoperability in this case shall take place in web service level. More concretely, datasets regardless of the sources are provided using GeoNetwork Portal Service. To put it more concretely, different web resources are connected via GeoNetwork Catalog Service.

Why not WCS?

Firstly, in GeoNetwork architecture, WCS interface is employed for Map Portrayal Service only. That is, it is embedded in the Portal for data visualization but not providing data itself. In addition, WCS is a push service that server responds to request from client. Coverage on two servers is not exchangeable unless the server implements client functionality. However, such discussion is beyond the scope of the study.

Why CSW?

Secondly, Catalog Services performs both push and pull service that enables two servers interoperate (i.e. share data with each others). To be more specific, the harvest mechanism makes possible the interoperability between two web services. Therefore, an initial concept of interoperability is illustrated in Figure 3-4.

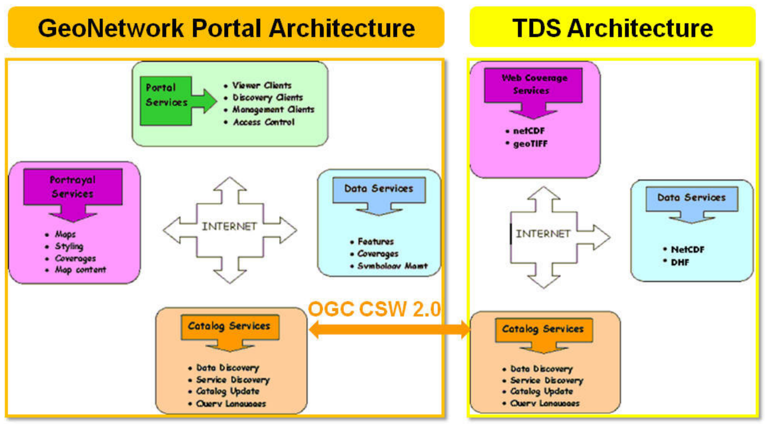

Figure 3-4 Data Portal Reference Architecture (interoperability in orange)

Provided the CSW protocol is feasible, users could benefit from an enormous data pool supported by SDI and TDS (see Figure 3-5) in the organization. It would save users' time from data hunting and allows users to spend more time for data analysis. Moreover, the vast datasets from Earth Science can be made to its best use for interdisciplinary studies such as biodiversity researches. Discussions on techniques are presented in the following section.

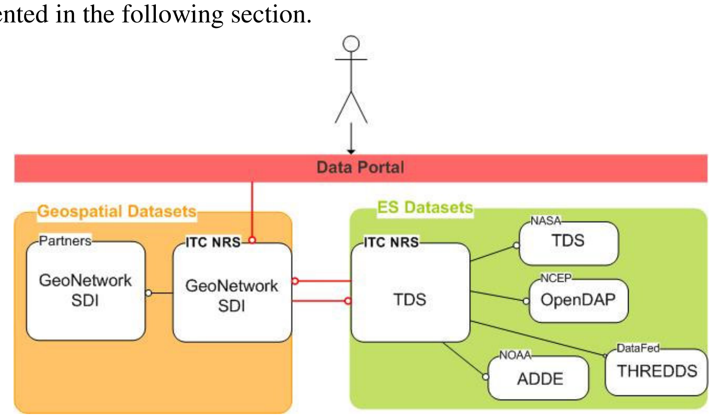

Figure 3-5 A simplified data sharing mechanism (recommended solution in red)

3.2.3.2. Issues of Implementation Constraints

At conceptual level, CSW is the proper solution for interoperability. However, there are difficulties at implementation level. Three main issues are addressed as follows.

1. Metadata on datasets

Metadata is in use not only for data publishing but also for harvesting. Therefore, it is crucial to use the same standard for two servers to interoperate. At the moment, GeoNetwork uses ISO19115 while TDS uses Dataset Inventory Catalog Specification as core metadata schema. Despite mapping relations between metadata elements in two schemas can still be identified, a standard would make the loosely-coupled system possible and save the hassles of remapping relations whenever a slight change is made in either system.

2. Harvest operations

The CSW harvest protocol is not implemented in GeoNetwork environment as expected at the moment. To be more specific, instead of using OGC standard specification, GeoNetwork developed its own mechanism (i.e. GN 2.0) to harvest from other GeoNetwork servers. On the other hands, THREDDS employs AOI protocol for harvesting operation. Under such circumstances, the modification is required in both systems.

3. Inventory structure

Hierarchical inventory structure is the core of THREDDS Catalog service. Accordingly, THREDDS WCS gateway was deployed using such structure but not plain inventory structure adopted by OGC or ISO specification. Such design affects not only the publication but also the discovery functionality between catalogue services. For interoperability, it is in fact the debate on which inventory structure would be proper for standard catalogue services. The issue has been addressed and discussed within data collection developer community for a long while. Regrettably, a consensus is not yet reached among stakeholders.

Due to time constraint, the proof of concept is not conducted. Instead, issues in terms of implementation constraints are identified in this section. In addition, a potential solution for implementation is proposed in the following section.

3.2.3.3. Discussions of future implementation

Despite constraints exist at the moment, consistent future plans are proposed in both GeoNetwork and THREDDS developer communities. That is, modifying existing services to conform OGC ebRIM profile of CSW. To put it briefly, metadata based on ISO19115 and HTTP protocol will be deployed in these two systems if the proposal is approved.

As promising as the similar architecture in the context of server and web interface levels using OGC ebRIM profile of CSW may be, the goal of modification is to improve the conformance of services towards OGC standard. The difference between hierarchical and plain inventory structure is still a challenging issue for data/metadata collections and services since current version of OGC ebRIM profile of CSW adopts the plain inventory structure. The interoperability would depend on how a TDS modify its Catalog service to conform the profile. No proper make do has been made or proposed over the issue at the moment.

4. Conclusion and Recommendation

4.1. Conclusion

The questions posed in section 1.4 are specifically outlined and critically discussed as follows.

Research Question 1: What are prerequisites for the interoperability?

The question has been addressed in section 2.1 and section 3.1. The prerequisites for the interoperability are as follows:

1. OGC Web Service Interface. Mediation via standard protocol is required for existing web services to interoperate. The concept is proved and supported by GALEON team and will continue to be realised by stakeholders.
2. Proper interpretation of multidimensional scientific dataset in geospatial aspect. Spatial reference is not completely compatible in multidimensional scientific dataset at the moment. This research addresses the issue in CF Conventions developer community in order to improve the conversion accuracy.

Research Question 2: Is WCS interface practical for the interoperability?

This question has been addressed and discussed in section 2.2.3 and section 3.1. It can be answered from the following aspects:

Firstly, practical in terms of data sharing mechanism, the WCS interface did make the interoperability possible. Clients using OGC WCS operations (i.e. GetCapabilites, DescribeCoverage, and GetCoverage) could access datasets in interest distributed by UniData TDS. However, this is only the make do with the skeleton of services.

Secondly, practical in terms of data querying capabilities, the WCS interface appears to be inadequate. Half of the functionality that an OGC WCS should equip with is not available using THREDDS WCS gateway. Services such as range subsetting, reprojection and resampling are not implemented at the moment. Moreover, considering the nature of multidimensional dataset, multidimensional query such as requests by constraints that consist of two time dimensions and multiple fields in coverage are not regulated in OGS WCS specification.

Thirdly, practical in terms of data content provided via the interface, it seems debating for the interoperability. Spatial reference, granularity, regularization (i.e. rendering irregular grids into regular ones), and downsizing (i.e. rendering a multidimensional dataset into a set of two/three dimensional datasets) are essential incompatibilities that can not be overlooked. The necessity of data rendering deserves further discussion.

In summary, WCS for interoperability is practical merely in skeleton level.

Research Question 3: Are there other options for the interoperability?

This question has been answered in section 2.2 and 3. CSW is considered to complement the interoperability.

Despite existing implementation constraints identified in section 2.2.3 at the moment, essential incompatibilities addressed in discussions for research question 1 are not in existence using CSW for interoperability. Data rendering is not required using OGC CSW interface, therefore the interoperability is simplified into technical cooperation. Choices of learning multidimensional data format or rendering the datasets into user preferable format are totally at users' will. In conclusion, interoperability via CSW interface is purely in data exchange level, multidimensional dataset is merely a fraction of supported data formats in that sense.

Research Question 4: How could GeoNetwork SDI and TDS interoperate?

This question has been discussed in section 3.2.3. To put it briefly, at a conceptual level, CSW protocol can make the interoperability possible. At implementation level, OGC ebRIM profile of CSW may be the approach to achieve the goal.

Inventory structure however remains an essential issue for the interoperability. The debate on plain and hierarchical structure deserves future discussion.

4.2. Recommendation and Future Research

In general, interoperability is an ambiguous term due to different perceptions and demands of individuals and communities. The best approach for interoperability is therefore users' requirement dependent. Based on the results of the study, the following recommendations are forwarded.

1. Spatial reference of multidimensional scientific dataset:

   The reference datum is observed an absent attribute in CF Conventions. However, the importance of the information can not be overlooked especially within distributed environment. A possible solution is the adoption of a geodetic_datum attribute that reference to EPSG geodetic parameters database for proper spatial referencing.

2. Make certain the definition of the interoperability:

   a) To serve ES datasets in GI data format: Concurrent WCS and WFS interface

      Although WFS interface is not yet proposed as the mediation for interpretation, it could be adopted in order to tackle the implementation issues in terms of granularity. Accordingly, multidimensional scientific dataset would be mapped into either vector or raster structure in GI aspect based on its nature content. As for the regularization issue, relevant modifications of OGC WCS specification are proposed by GALEON team and shall be solved in the next version.

   b) To provide ES datasets accessible by GI standard protocol: CSW interface

      Despite the mediation is still at conceptual level, it is the proper choice to publish ES data via OGC standard without rendering data content.

Interoperability between web services in GeoInformation and Earth Sciences is a challenging issue that requires intensive teamwork among stakeholders and constant experiments to validate the concepts. The study conducted an initial discussion on the issue. The following issues are identified for further research.

1. Evaluation of Hierarchical vs. Plain Inventory structure for data collections and services
2. OGC ebRIM profile of CSW

3. Implementation of mapping point, swath and radial data types of multidimensional data to OGC Coverage
4. Proof of concept experiments

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```
netcdf IMAGE0002 {
dimensions:
        lines = 480 ;
        elems = 640 ;
        bands = 5 ;
        auditCount = 1 ;
        auditSize = 80 ;
variables:
        int version ;
         version:long_name = "McIDAS area file version" ;
        int sensorID ;
         sensorID:long_name = "McIDAS sensor number" ;
        int imageDate ;
         imageDate:long_name = "image year and day of year" ;
         imageDate:units = "ccyyddd" ;
        int imageTime ;
         imageTime:long_name = "image time in UTC" ;
         imageTime:units = "hhmmss UTC" ;
        int startLine ;
         startLine:long_name = "starting image line" ;
         startLine:units = "satellite coordinates" ;
        int startElem ;
         startElem:long_name = "starting image element" ;
         startElem:units = "satellite coordinates" ;
        int numLines ;
         numLines:long_name = "number of lines" ;
        int numElems ;
         numElems:long_name = "number of elements" ;
        int dataWidth ;
         dataWidth:long_name = "number of bytes per source data point" ;
         dataWidth:units = "bytes/data point" ;
        int lineRes ;
         lineRes:long_name = "resolution of each pixel in line direction" ;
         lineRes:units = "km" ;
        int elemRes ;
         elemRes:long_name = "resolution of each pixel in element direction" ;
```

```
            elemRes:units = "km" ;
        int prefixSize ;
            prefixSize:long_name = "line prefix size" ;
            prefixSize:units = "bytes" ;
        int crDate ;
            crDate:long_name = "image creation year and day of year" ;
            crDate:units = "ccyyddd" ;
        int crTime ;
            crTime:long_name = "image creation time in UTC" ;
            crTime:units = "hhmmss UTC" ;
        int bands(bands) ;
            bands:long_name = "bands" ;
        char auditTrail(auditCount, auditSize) ;
            auditTrail:long_name = "audit trail" ;
        float data(bands, lines, elems) ;
            data:long_name = "data" ;
            data:type = "GVAR" ;
            data:units = "unitless" ;
        float latitude(lines, elems) ;
            latitude:long_name = "latitude" ;
            latitude:units = "degrees" ;
        float longitude(lines, elems) ;
            longitude:long_name = "longitude" ;
            longitude:units = "degrees" ;
data:

 bands = 1, 2, 3, 4, 6 ;
}
```

Appendix B Questionnaire: Multidimensional data usage in GI community

Name:
Organization:
Occupation:
Date:

- ○ How many staffs are there in your organization? ____________________
- ○ How many of them are aware of multidimensional data? ______________

I. Data content – netCDF as example of multidimensional data

1. How do you start to include netCDF as your research data?

   ____

2. What percentage of data usage for your research is netCDF? (If 0 please continue with Section IV)

   ____

   ____

3. Are you familiar with netCDF structure? (Yes/No)

   If Not, what makes it difficult for you?

   ____

   If Yes, are you aware of the datum and projection of netCDF dataset you use?

   ____

4. How would you evaluate the difficulty to manipulate netCDF data as a GIS user?

   ○ Easy ○ OK ○ Difficult

5. Do you generate data in netCDF format? (Yes/No)

   If Yes

   - How? Please give a brief description.

   ____

   - How do you evaluate the effort to generate the data?

     ○ Easy ○ OK ○ Difficult

6. What is the motivation for you to use netCDF?

   □ Free sources □ Temporal dimension □ Data content □ Other _____

7. What kind of software do you use for processing netCDF dataset?

   □ UniData solutions (please continue with section II)

   □ GIS software (please continue with section III)

II. UniData solutions – IDV as example

1. Do you find IDV easy to learn for a GIS user?

   ○ Easy ○ OK ○ Difficult

2. What is your main task using IDV?

   ○ Visualize Data ○ Analyze Data ○ Download Data

3. Which is your preference for data management?

   ○ Download to local disk

   ○ Load data from remote sources (not store data on your machine)

4. Which approach do you usually use for downloading data?

   ○ Web catalog

   ○ IDV

5. Do you find IDV GIS analysis functions fulfill needs of you research?

   ○ Not at all ○ Enough ○ More than enough

III. GIS software

1. What software do you use?

   ____

2. Do you have problems handling netCDF dataset? (Yes/No)

   If Yes, please give brief descriptions of the difficulties you are facing?

   ____

   ____

3. What do you think would be the most difficult part for a GIS user to use netCDF dataset?

   ○ Convert dataset into GIS readable format

   ○ GIS analysis of dataset

   ○ Access to dataset

○ None

○ Other____

4. Is there any reason to keep you from using netCDF?

____

____

5. How do you foresee the use of netCDF in GIS community?

____

IV. Behavior of usage

1. What makes you reluctant to use netCDF dataset for your research?

○ Data conversion

○ Unable to manipulate data

○ Finding free sources

○ Learning process

○ Others ____

2. Why did you try to use netCDF dataset for your research?

○ Free sources

○ Temporal richness

○ Compact data storage (i.e. abundant information within one file)

○ Others ____

3. Will you try to use netCDF dataset for your research if it is readable using ArcGIS? (Yes/No)

Appendix C WCS Test URI

Request URI : **UniData Galeon Test Data**	accessible
http://motherlode.ucar.edu:8080/thredds/wcs?request=GetCapabilities&version=1.0.0&service=WCS	×[1]
http://motherlode.ucar.edu:8080/thredds/wcs/galeon/testdata/RUC.nc?request=GetCapabilities&version=1.0.0&service=WCS	○
http://motherlode.ucar.edu:8080/thredds/wcs/galeon/testdata/RUC.nc?request=DescribeCoverage&version=1.0.0&service=WCS &coverage=Potential_temperature	○
http://motherlode.ucar.edu:8080/thredds/wcs/galeon/testdata/RUC.nc?request=GetCoverage&version=1.0.0&service=WCS &coverage= Potential_temperature&format=GeoTIFF&bbox=-134,11,-47,57	○
Request URI : **George Mason Galeon Test Data**	accessible
http://laits.gmu.edu/cgi-bin/NWGISS/NWGISS?request=GetCapabilities&service=WCS&version=1.0.0	○
http://laits.gmu.edu/cgi-bin/NWGISS/NWGISS?request=DescribeCoverage&service=WCS&version=1.0.0& coverage=/export/home0/GeoData/AIRDAS-CA-Fire-2003NOV/CEDAR_LINE2SCFM_UTM_3B.hdf:Grid:GeoTIFFGrid:B	○
http://laits.gmu.edu/cgi-bin/NWGISS/NWGISS?request=GetCoverage&service=WCS&version=1.0.0& coverage=/export/home0/GeoData/AIRDAS-CA-Fire-2003NOV/CEDAR_LINE2SCFM_UTM_3B.hdf:Grid:GeoTIFFGrid:B &bbox=480912.349000,3623638.140000,548064.349000,3655294.140000&format=GeoTIFF&crs=EPSG:32611	○
Request URI : **DataFed Test Data**	accessible
http://webapps.datafed.net/ogc_UniData.wsfl?SERVICE=WCS&REQUEST=GetCapabilities&VERSION=1.0.0	○
http://webapps.datafed.net/ogc_UniData.wsfl?SERVICE=WCS&REQUEST=DescribeCoverage&VERSION=1.0.0 &COVERAGE=THREDDS_CDM.Temperature_surface	○
http://webapps.datafed.net/ogc_UniData.wsfl?SERVICE=WCS&REQUEST=GetCoverage&VERSION=1.0.0&CRS=EPSG:432 6&COVERAGE=THREDDS_CDM.Temperature_surface&TIME=2007-01-27T06:00:00&BBOX=-180,-90,180,90,0,0 &WIDTH=720&HEIGHT=361&DEPTH=-1&FORMAT=GeoTIFF	○

Request URI : **NERC TPAC/NDG Test Data**	accessible
http://glue.badc.rl.ac.uk/cgi-bin/TPAC/WCS?SERVICE=WCS&REQUEST=GetCapabilities	○
http://glue.badc.rl.ac.uk/cgi-bin/TPAC/WCS?SERVICE=WCS&VERSION=1.0.0&REQUEST=DescribeCoverage&COVERAGE=salt	○
http://glue.badc.rl.ac.uk/cgi-bin/TPAC/WCS?SERVICE=WCS&VERSION=1.0.0&REQUEST=GetCoverage&COVERAGE=salt&CRS=EPSG:4979&BBOX=150,-70,150,-35,0,5000&TIME=0000-12/0001-02&FORMAT=CF-netCDF&RESY=0&RESZ=0	×[2]

Note
×[1] : standard OGC WCS request is not supported
×[2] : can't compare datetimes