Remote Sensing of Clouds and the Atmosphere XVII; and Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing VIII

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24–27 September 2012
Edinburgh, United Kingdom

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Published by
SPIE

Volume 8534

Proceedings of SPIE 0277-786X, V.8534

Remote Sensing of Clouds and the Atmosphere XVII; and Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing VIII, edited by E. I. Kassianov, A. Comeron, R. H. Picard, K. Schäfer, U. N. Singh, G. Pappalardo, Proc. of SPIE Vol. 8534, 853401 · © 2012 SPIE · CCC code: 0277-786/12/$18 · doi: 10.1117/12.2015425

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Please use the following format to cite material from this book:
Author(s), "Title of Paper," in *Remote Sensing of Clouds and the Atmosphere XVII; and Lidar Technologies, Techniques, and Measurements for Atmospheric Remote Sensing VIII*, edited by Evgueni I. Kassianov, Adolfo Comeron, Richard H. Picard, Klaus Schäfer, Upendra N. Singh, Gelsomina Pappalardo, Proceedings of SPIE Vol. 8534 (SPIE, Bellingham, WA, 2012) Article CID Number.

ISSN: 0277-786X
ISBN: 9780819492746

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

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Contents

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Session Chairs

5 Differential Absorption Lidar
Upendra N. Singh, NASA Langley Research Center (United States)
Gary W. Kamerman, FastMetrix, Inc. (United States)

6 Novel Laser Sources for Lidar Applications
Upendra N. Singh, NASA Langley Research Center (United States)
Gary W. Kamerman, FastMetrix, Inc. (United States)

7 Lidar Measurements
Brian M. Walsh, NASA Langley Research Center (United States)
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Maximizing the Use of EO Products: How to Leverage the Potential of Open Geospatial Service Architectures

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ABSTRACT

The demand for the rapid provision of EO products with well-defined characteristics in terms of temporal, spatial, image-specific and thematic criteria is increasing. Examples are products to support near real-time damage assessment after a natural disaster event, e.g. an earthquake. However, beyond the organizational and economic questions, there are technological and systemic barriers to enable a comfortable search, order, delivery or even combination of EO products. Most portals of space agencies and EO product providers require sophisticated satellite and product knowledge and, even worse, are all different and not interoperable.

This paper gives an overview about the use cases and the architectural solutions that aim at an open and flexible EO mission infrastructure with application-oriented user interfaces and well-defined service interfaces based upon open standards. It presents corresponding international initiatives such as INSPIRE (Infrastructure for Spatial Information in the European Community), GMES (Global Monitoring for Environment and Security), GEOSS (Global Earth Observation System of Systems) and HMA (Heterogeneous Missions Accessibility) and their associated infrastructure approaches. The paper presents a corresponding analysis and design methodology and two examples how such architectures are already successfully used in early warning systems for geo-hazards and toolsets for environmentally-induced health risks. Finally, the paper concludes with an outlook how these ideas relate to the vision of the Future Internet.

Keywords: Earth Observation, Heterogeneous Missions Accessibility, HMA, service-oriented architecture, Web services, Open Geospatial Consortium, service-oriented-analysis and design, SERVUS

1. INTRODUCTION

The demand for products that result from Earth Observation (EO) missions is continuously increasing. Over the last decade the demand and volume of EO data has increased more than 10 fold in line with the users' processing and analysing capabilities. In addition, more than 80% of users request and use data from more than one satellite [7]. Examples are the application of space technologies in the international humanitarian emergency response [1], e.g. products to support near real-time damage assessment after a natural disaster event such as earthquakes, tsunamis or hurricanes, or the hyperspectral remote sensing of vegetation [5] for land use or biodiversity monitoring.

However, despite of this increasing demand, it is still quite laborious to find a fitting EO product for an end-user problem. What is required is an infrastructure that enables the rapid provision of products with well-defined characteristics in terms of temporal, spatial, image-specific, thematic and economic criteria in order to exploit EO missions and to maximize the use of its products [4].

Whereby this is also true for Earth observations resulting from in-situ environmental monitoring stations, e.g. water or air quality information, this paper focuses on Earth observations resulting from remote sensing devices.

The problem starts with terminological issues as the terms used in EO applications are often mission-specific. In this paper, we are relying upon the terms used in the Heterogeneous Missions Accessibility (HMA) specifications [7].

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Earth Resources and Environmental Remote Sensing/GIS Applications III, edited by Daniel L. Civco, Manfred Ehlers, Shahid Habib, Antonino Maltese, David Messinger, Ulrich Michel, Konstantinos G. Nikolakopoulos, Karsten Schulz, Proc. of SPIE Vol. 8538, 853802 • © 2012 SPIE • CCC code: 0277-786/12/$18 • doi: 10.1117/12.2012149

HMA uses the term “EO product” as a synonym to an “EO dataset”, i.e. observations obtained by satellite instruments, whereby an “EO collection” corresponds to a series of EO products derived from data acquired

- either from an instrument in a dedicated mode onboard a single satellite platform or,
- by a series of instruments, possibly from different satellite platforms, but in this case working in the same instrument mode.

However, beyond the organizational and economic questions, there are technological and systemic barriers to enable a comfortable search, order, delivery or even combination of EO products. Most portals of space agencies and EO product providers require sophisticated satellite and product knowledge and, even worse, are all different and not interoperable.

This paper argues that widely established EO mission infrastructure, based upon open standards and agreed between users and software architects, may help in maximizing the use of EO products. In section 2, it starts with an overview about the use cases and the architectural solutions that aim at an open and flexible EO mission infrastructure with application-oriented user interfaces and well-defined service interfaces based upon open standards. Section 3 provides an insight into research frameworks for the design of information systems and mission infrastructures including both technical and organizational requirements and constraints. In section 4 major infrastructure initiatives are presented before a design methodology that is tailored to such environments is presented in section 5. Section 6 concludes with usage examples and an outlook to a possible future infrastructure – the Future Internet.

2. USE CASES FOR EARTH OBSERVATION MISSION INFRASTRUCTURES

The complexity of an EO mission infrastructure shall be hidden to the users as much as possible. Quite the contrary, the use shall be intuitive and straight forward, i.e., among others, it should behave similarly to other systems with comparable objectives that the user is accustomed to. Known usage patterns should lead to expected results. This is not just a challenge to the system architect when designing the user interface, which is just one façade of a system, but it is also a question of a good overall design based on rigorous design principles.

An EO system shall answer the following key questions in an easy-to-use way from the perspective of an end-user [7]:

- How can I participate in the system?

  This question leads to the management of user identities and authentication of users by means of login procedures.

- What is available in the system?

  This question leads to the functional package of searching for EO data products and collections on the one hand, but also searching for processing capabilities of such datasets on the other hand. In contrast to the search for documents in the World Wide Web such a search request is mostly targeted at structured data stored in databases and binary files whose meaning is contained in associated data and dataset descriptions or in descriptions of processing capabilities. However, users often do not have the knowledge about the entire interrelations between different satellites and missions producing the data, associated processing capabilities and responsible institutes providing the end product. Hence, there is a need for means to describe the products and the capabilities in a user-near way and to enable fuzzy queries.

- How to get EO datasets and data?

  Earth observation data may not be immediately available, e.g. when the time reference lays in the future or the data needs processing beforehand. Hence, there are the following two follow-on questions.

  - How to request and shape the EO data, or in general how to process EO data?

    This question is related to the feasibility of a request on the one hand, and influencing, if possible the data acquisition process (called programming or sensor tasking) on the other hand.

  - How to order the EO data?

This question refers to the specification of an order request, getting a confirmation and waiting for the delivery of the product. This requirement is similar to those of e-commerce systems.

- How to access EO datasets and data?

  This question leads to the functional package of accessing the actual data in electronic form, once discovered, selected, ordered, and available in the EO mission infrastructure. The data access may take place using simple file downloads using ftp or http or via a standardized service like OGC's Web Coverage Service [21] allowing for example spatial sub-setting and band selection.

- How to secure the access to EO data?

  This question leads to the functional package of specifying access control rights for EO data and ensuring that only those users who have the necessary rights may create, read, write or delete EO datasets. The handling of this question is closely related to the first one (identity management) and needs a consistent technical approach.

- How to view the EO data?

  This question refers to the rendering the data (viewing) in a form that is adequate to the end-user device. This may be a "simple" bitmap file in a standard format but also a layer to be added to a cartographic (Web) mapping system and visualized in the context of other geospatial data.

Typically, when designing information systems, such user expectations needs to be concretized and refined as user stories and user requirements, e.g. in terms of use cases on multiple levels.

3. RESEARCH FRAMEWORK FOR INFORMATION SYSTEM DESIGN

EO-related software applications fall into the category of information systems. Their design is a complex endeavor as technical requirements and constraints are intertwined with organizational requirements and constraints. The scientific discipline of Information Systems (IS) Research [19] is systematically handling this dualism. The realm of IS research is at the confluence of people, organizations, and technology [20]. Consequently, IS research distinguishes between the organizational design to create an effective organizational infrastructure that is derived from the business strategy, and the information system design to create an effective information system infrastructure derived from the information technology (IT) strategy. Hevner et al [3] state that on the one hand, "IT are seen as enablers of business strategy and organizational infrastructure", on the other hand "available and emerging IT capabilities are a significant factor in determining the strategies that guide an organization".

Figure 3-1 illustrates the impact of business strategies upon the strategies and infrastructures of the IT design activities:

- The Business Strategy for EO mission infrastructure approaches is mainly driven by international initiatives such as GMES and GEOSS (see below), national and cross-national (e.g. European) strategic interests and the resulting demand of the space agencies.
- The Information Technology Strategy for EO mission infrastructures is mainly determined by the rules of the business strategy, e.g. the request to realize a harmonized access to EO products.

These strategies determine the design activities of the organizational and the technical infrastructure which together comprise the EO mission infrastructure:

- The "design" of the Organizational Infrastructure shall support European environmental legislation. Space agencies, ministries, research institutes and private organizations are organized as nodes in networks or Public-Private Partnerships with defined levels of cooperation on managerial and technical level.
- An essential requirement for the Information System Infrastructure is an "open architecture" for a service platform which provides seamless access to information, services and applications across organizational, technical, cultural and political borders. "Open" hereby means that service specifications make use of existing standards where appropriate and possible, are published and made freely available to interested vendors and users with a view of widespread adoption.

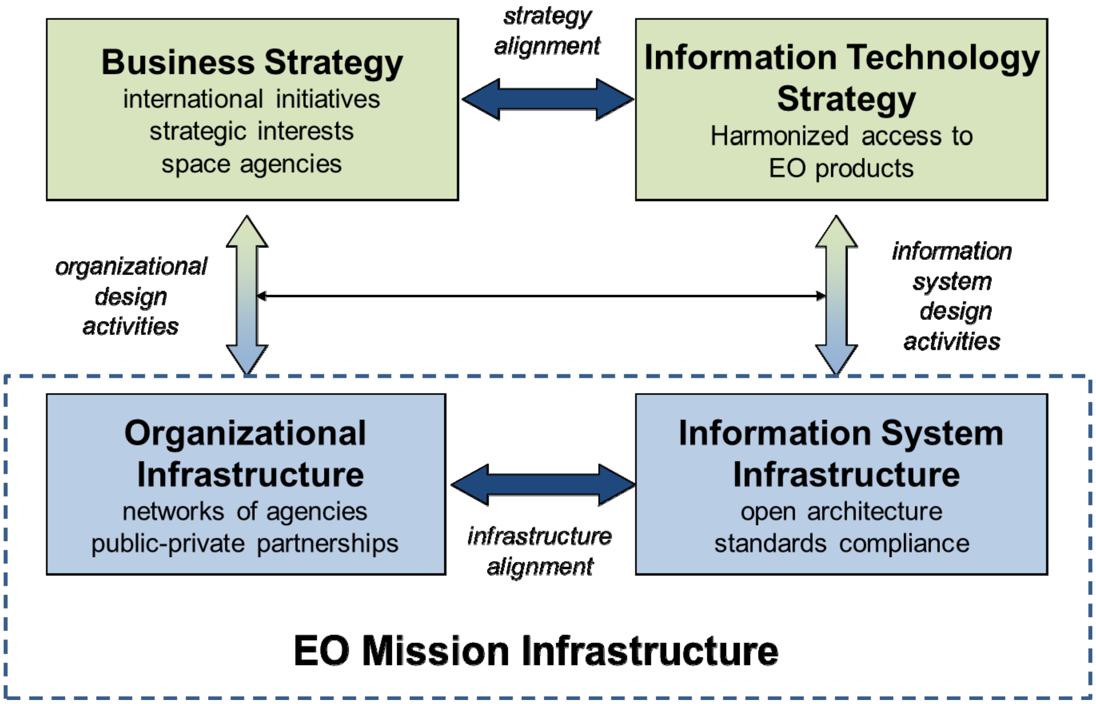

Figure 3-1: The Impact of the Business and IT Strategies upon the EO Mission Infrastructure (derived and adapted from [3])

In the following sections some important initiatives are presented that play a major role in the design and provision of EO mission infrastructures upon which EO software applications may be built in order to maximize the use of EO products.

4. INFRASTRUCTURE APPROACHES OF INTERNATIONAL INITIATIVES

4.1 Overview

There are several initiatives aiming at specifying and providing an open infrastructure for EO missions. Earth Observation hereby should be understood in its broader sense, encompassing not only observations resulting from remote sensing instruments carried by satellites or Unmanned Aircraft Vehicles (UAV), but also sensors of in-situ monitoring and measurement networks. Figure 4-1 presents these initiatives, mainly from a European perspective, but with a possible global impact. They are schematically organized in a diagram that is spanned by their functional scope, i.e. which elements of an EO Mission infrastructure are concerned by the initiative, and their regional scope, i.e. which geographic regions are mainly addressed by the initiative, namely federal states (i.e. sub-national), nations, Europe or the whole world. The functional scope addresses the definition and/or implementation of the initiatives and is categorized as follows:

- EO Sensors: The initiative comprises the design, specification and/or deployment of EO sensors.
- EO Data: The initiative comprises the specification of EO data and/or meta-data models.
- Web Services: The initiative comprises the specification of Web service interfaces.
- Services by systems: The initiative comprises the specification, implementation and/or deployment of complete systems including the services offered to the users according to a defined business model.
- EO System-of-systems: The initiative comprises the specification and/or implementation of an infrastructure that facilitates and organizes the coupling of autonomous systems into systems-of-systems.

The following initiatives are presented in more detail in the following sections relying upon résumés given in [7]:

- INSPIRE - Infrastructure for Spatial Information in the European Community

- GMES – Global Monitoring for Environment and Security
- GEOSS – Global Earth Observation System of Systems
- HMA – Heterogeneous Missions Accessibility.

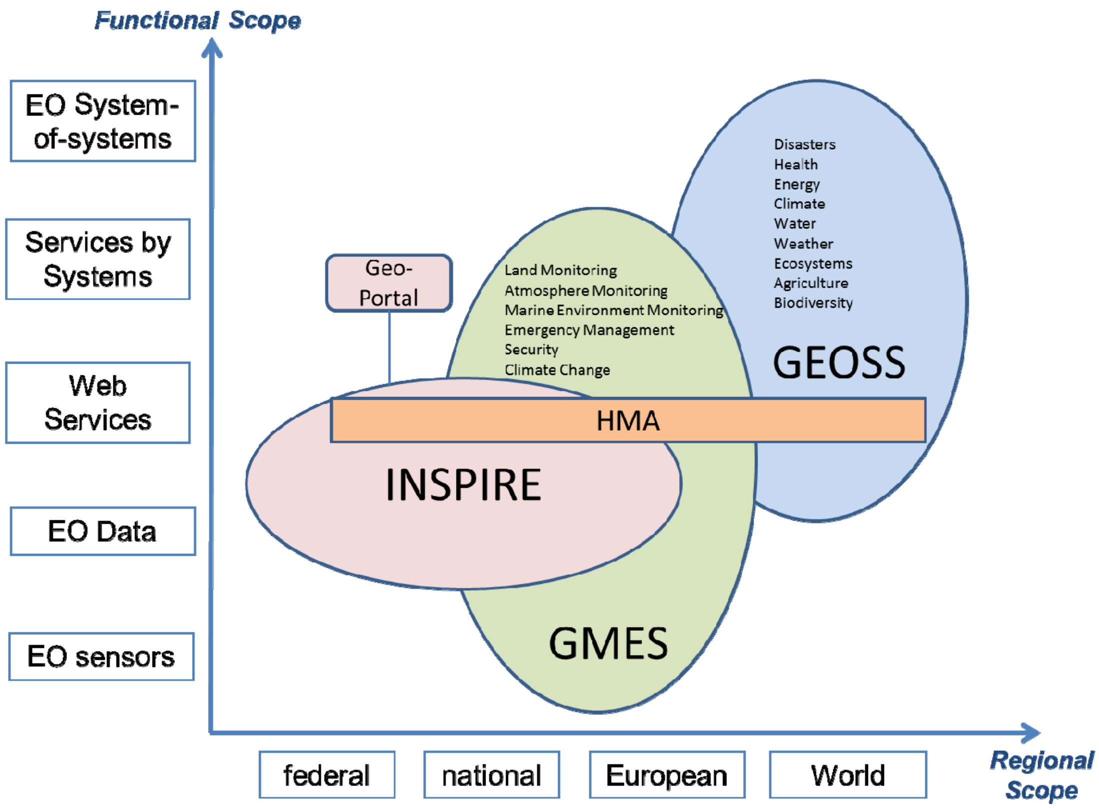

Figure 4-1: Initiatives for Earth Observation Mission Infrastructure

From the architectural and technological perspective there is a common denominator for all of these initiatives: they are all using and applying geospatial service and information model standards as defined by the Open Geospatial Consortium (OGC) [16]. However, full interoperability across these initiatives is not yet possible due to different profiles, versions and governance regimes of these initiatives. With the exception of HMA, it was the objective of the European GIGAS (GEOSS, INSPIRE and GMES an Action in Support) project (http://www.thegigasforum.eu) to promote the coherent and interoperable development of the GMES, INSPIRE and GEOSS initiatives through their concerted adoption of standards, protocols, and open architectures.

4.2 INSPIRE - Infrastructure for Spatial Information in the European Community

INSPIRE is a legal instrument of the European Community. It is driven by the Directive 2007/2/EC of the European Parliament and of the Council establishing an Infrastructure for Spatial Information in the European Community (EC, 2007). INSPIRE has been motivated by the fragmentation of datasets and sources, gaps in availability, lack of interoperability or harmonization between datasets at different geographical scales and duplication of information collection in Europe. These problems make it difficult to identify, access and use data that is available.

INSPIRE is complementary to related policy initiatives, such as the Commission proposal for a Directive on the re-use and commercial exploitation of Public Sector Information. The initiative intends to trigger the creation of a European spatial information infrastructure that delivers to the users integrated spatial information services. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an interoperable way for a variety of uses. The target users of INSPIRE include policy makers, planners and managers at European, national and local level and the citizens and their organizations. Possible services are the visualization of information layers, overlay of information from different sources, as well as spatial and temporal analysis.

The implementation of INSPIRE requires technical arrangements that are summarized in Implementing Rules (and associated guidelines) on metadata, network services, data specifications, data and service sharing, and monitoring and reporting. Referring to Figure 4-1, INSPIRE covers the functional scope of EO data and Web Services.

EU Member States shall create metadata and keep them up to date. The metadata shall include information about:

- conformity with the implementing rules on interoperability,
- conditions for access and use of data sets and services,
- quality and validity,
- the public authorities responsible, and
- limitations on public access.

EU Member States shall operate a network of the following services available to the public for data sets and services for which metadata has been created:

- Discovery services (at no charge): search for spatial data sets and services on the basis of the content of the corresponding metadata and to display the content of the metadata.
- View services (basically at no charge, however, there may be exceptions): to display, navigate, zoom in/out, pan or overlay viewable spatial data sets and to display legend information and any relevant metadata
- Download services: enabling copies of spatial data sets, or parts of such sets, to be downloaded and, where practicable, accessed directly.
- Transformation services: enabling spatial data sets to be transformed with a view to achieving interoperability.
- Services allowing spatial data services to be invoked.

Moreover, the member states shall ensure the technical possibility, for public authorities,

- to link their spatial data sets and services,
- that access to services may be restricted;
- that services shall be available on request to third-parties under conditions;
- that an INSPIRE Geo-portal shall be established.

Concerning data sharing, the EU Member States shall adopt measures for the sharing of data and services between public authorities for public tasks relating to the environment without restrictions at the point of use. Note, however, that public authorities may license and/or charge other public authorities and Community institutions provided that

- it is compatible with the objective to facilitate sharing between public authorities, and
- it is restricted to the minimum necessary to ensure sustained availability and quality of the data and services.

When spatial data or services are provided to Community institutions for reporting obligations under Community law relating to the environment, then this may not be subject to charging. Member States shall provide the institutions and bodies of the Community with access to spatial data sets and services in accordance with harmonized conditions.

Furthermore, an Implementing Rule shall be adopted for interoperability and where practical for the harmonization of spatial data sets and services. Examples for harmonization needs are the classification of spatial objects or a common system of unique identifiers for spatial objects.

Note that more and the latest information about INSPIRE is available at http://inspire.jrc.ec.europa.eu/ .

4.3 GMES – Global Monitoring for Environment and Security

The objective of GMES is to provide, on a sustained and operational basis, reliable and timely services related to environmental and security issues in support of public policy needs. GMES is an initiative led by the European Union, in which the European Space Agency (ESA) implements the space component and the European Commission (EC) manages actions for identifying and developing services. Referring to Figure 4-1, GMES covers the complete range from EO sensors, EO data, Web Services up to services by systems.

In 2005 the 3rd Space Council confirmed the EC proposal for a phased implementation of GMES, starting with three GMES Fast-Track Services which aim at establishing the following services:

- Land Monitoring Core Service,
- Emergency Response Core Service, and
- Marine Core Service

Products will be rolled out based on prototypes developed by the research projects mentioned above. The services shall be made operational in order to meet the demand in terms of data volumes to be processed for full pan-European or global coverage and steady-state operation on a 24/7 basis, with the shortest possible response times.

Today the GMES services address six main thematic areas:

- Land Monitoring
- Marine Environment Monitoring
- Atmosphere Monitoring
- Emergency Management
- Security
- Climate Change

The support of research on Climate Change will be provided by the three services about Land Monitoring, Marine and Atmosphere. All three will seek to provide added value on the essential climate variables. In addition, GMES will strive to support socio-economic analysis and the derivation of impacts.

The GMES Services will rely on three categories of input data:

- Space observation data will be provided by various satellite missions that are combined to form a GMES Space Component (GSC). The GMES Space Component is co-funded between ESA and the EC under a specific delegation agreement. The GMES Space Component also integrates data from other international or national contributing space missions and will provide these data through the so-called GSC Data Access component (GSCDA).
- In-situ observation data will be provided by a network of observation infrastructures organized in different themes on local, regional or national level. These networks are typically owned and governed by the EU member states. The homogeneous and sustainable provision of these data poses a considerable challenge, which is being tackled under the lead of the European Environment Agency (EAA). Beyond the firm expectation that INSPIRE Implementing Rules are going to be respected for data discovery and access, no details are so far documented about network service implementations for in-situ data.
- Reference data, which fulfil a specific and complementary role as compared to the observation data, will be provided as a geographic or positional framework. These data are – amongst other - topographic data (including road networks, hydrography, digital elevation models etc…) and other data such as geological maps.

Note that more and the latest information about GMES is available at http://www.gmes.info .

4.4 GEOSS – Global Earth Observation System of Systems

GEOSS (Global Earth Observation System of Systems) is an intergovernmental programme, coordinated by the Group on Earth Observations (GEO). GEOSS is a 10 year global programme that aims to provide to the broad environmental science and user community decision-support tools and support for the monitoring, analysis and modelling of various environmental phenomena through the integration of existing and future sources of Earth Observation information.

As of August 2012 88 countries, the European Commission and 64 organizations (e.g. European Environmental Agency, Global Spatial Data Infrastructure, International Society for Digital Earth, Open Geospatial Consortium, United Nations Framework Convention on Climate Change, World Meteorological Organization) participated in the GEOSS work plan. GEOSS aims to integrate Earth Observation systems into a global system that can be applied to various areas of environmental science and management. GEOSS is composed of a variety of systems (leading to a system-of-systems approach) including those for data collection, processing, discovery and dissemination. Hence, referring to Figure 4-1, GEOSS focuses on the EO System-of-systems functional scope, encompassing, however, the provision of services on a business and technical (Web services) level.

Currently, the GEOSS programme work plan focuses on the following nine so-called societal benefit areas (SBA:

- Reduction and Prevention of Disasters
- Human Health and Epidemiology
- Energy Management
- Climate Change
- Water Management
- Weather Forecasting
- Ecosystems
- Agriculture
- Biodiversity

Interoperability arrangements ensure that the heterogeneous systems within GEOSS can communicate and interoperate. Data, information and service providers within GEOSS are guided by technical specifications for collecting, processing, storing, and disseminating shared data, metadata, and products. Interoperability arrangements in GEOSS are based on open standards, with preference to formal international standards. Within the architecture, interoperability arrangements are registered in the GEOSS Standards and Interoperability Registry, after assessment by the Standards and Interoperability Forum.

Note that more and the latest information about GEOSS is available at http://www.earthobservations.org/geoss.shtml .

4.5 HMA – Heterogeneous Missions Accessibility

The European/Canadian Ground Segment Coordination Body (GSCB) coordinates the missions of the European Space Agency (ESA) and the national space agencies (such as CNES, ASI, DLR, CSA). After having started its work in 2005, Heterogeneous Missions Accessibility (HMA) was the main collaborative project identified by the GSCB. It was “related to interoperability from the point of view of inter-accessibility across heterogeneous missions”.

Further organizations that have a contractual relationship with ESA in the framework of HMA are the European Maritime Safety Agency (EMSA), the European Union Satellite Centre (EUSC), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) in order to ensure data access and interoperability with meteorological missions, the Joint Research Centre (JRC) of the European Commission in order to ensure alignment to the INSPIRE Implementing Rules, and the commercial data distributors Spot Image and Infoterra GmbH for specific missions [8].

The motivation for HMA was that EO missions pose the problem that each of them offers its own way and technology of how to search for and access to mission results in terms of software products, i.e. series of EO datasets, or images derived from these source products. As illustrated in Figure 4-2 these tasks are provided by ground segment services which may be called through corresponding interfaces by client applications, e.g. Web portal applications, or any other software components [7].

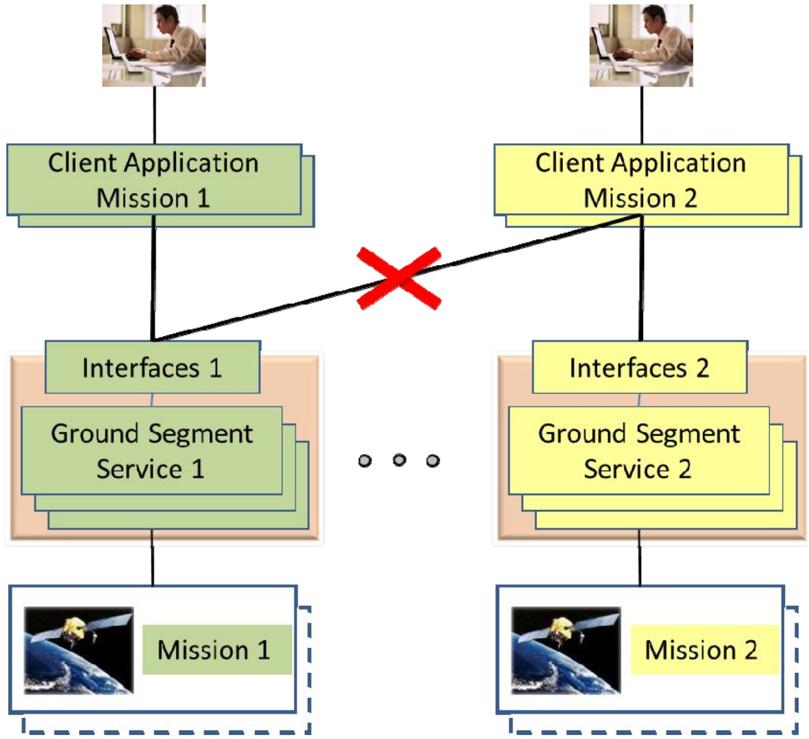

Figure 4-2: Access to EO Mission Products through Ground Segment Services

However, without a coordinated strategy and harmonised development, these ground segment services all will have different interfaces following the needs and the business requirements of the individual stakeholders. While this may not be a problem when accessing EO products just from one mission, it gets difficult and tedious when EO products are required from multiple missions, or even worse, when the EO products from multiple missions have to be combined or processed together in order to provide higher-level services. A client application of one mission cannot call ground segment services of another mission if their interfaces are not agreed upon.

Hence, there is a need to find and define a common technological foundation in order to harmonise the ground segment interfaces, or in the language of the software architects, to ensure interoperability between the ground segments. Furthermore, the initial step of HMA was "to define the discovery, catalogue, ordering, EO instrument programming and data access and data delivery standards". These standards should rely upon the experience gained from previous attempts and should follow to the maximum extent international standards.

The final objective of HMA, at least on but not limited to the technical level, is to leverage the idea of a service-oriented architectural style. This means, that the individual ground segment systems shall be loosely-coupled by means of an HMA Service Network, whereby each individual ground segment system offers its functionality of its ground segment services through a set of well-defined harmonised HMA interfaces as shown in Figure 4-3.

However, although the access through the HMA interfaces may be the preferred way according to the HMA objectives, each ground segment system still has the option to offer its services to mission-specific or provider-specific client applications by means of ground segment-specific interfaces. Therefore, for the "HMA system of ground segment systems" it is the interface design of the ground segment services that is of major importance. Hence, referring to Figure 4-1, its functional scope is focusing on the delivery of Web service interface specifications including data models for the parameters of the interface operations.

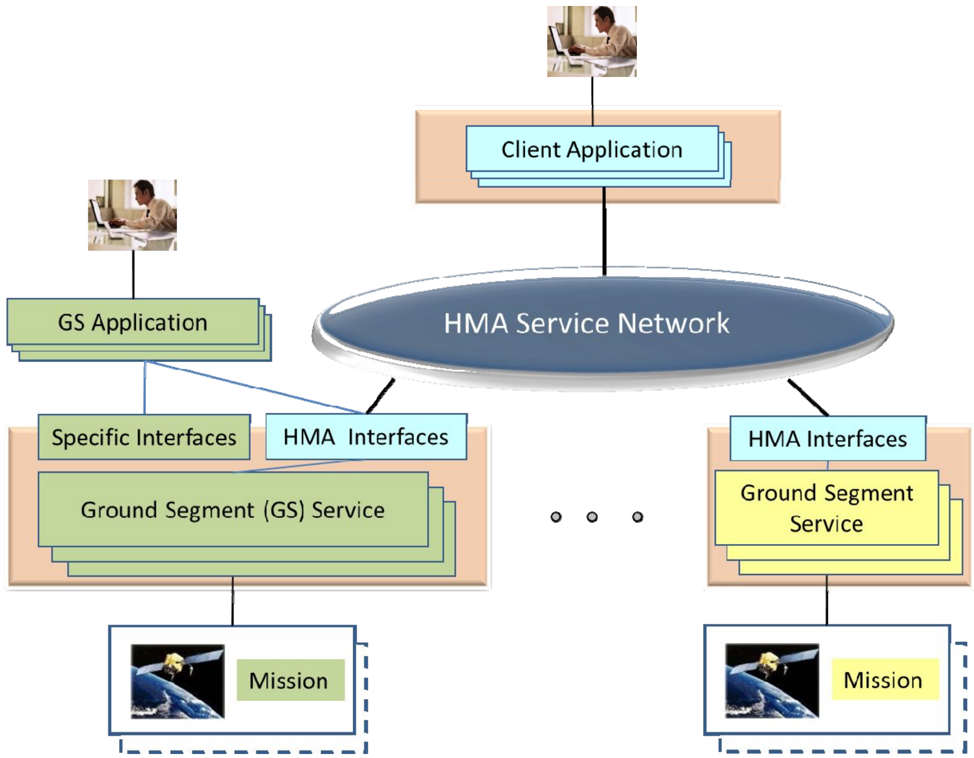

Figure 4-3: The overall picture of the HMA Service Network [7]

The set of the major interface specifications used in the HMA architecture are listed and referenced at the HMA Wiki site[1]. In order to give a comprehensive overview, a technical manual was edited [7] and made available for free download[2]. This manual, also called "HMA cookbook", explains the HMA architectural design following the viewpoint approach of the ISO Reference Model of Open Distributed Processing (RM-ODP) [10], also applied in the ISO 191xx series of geomatics standards [11][12] as well as for comparative analysis of information and data management systems [9].

5. CHALLENGES FOR THE DESIGN OF GEOSPATIAL SOFTWARE APPLICATIONS

Assuming a sound and agreed EO mission infrastructure, the kernel challenge for the design of geospatial (EO) software applications boils down to the question of how the requirements of the user can be assessed against the already existing capabilities of the EO mission infrastructure. Basically, functional, informational and qualitative requirements at one abstraction layer (A) have to be semantically matched to capabilities of another abstraction layer (B) taking side conditions into account (Figure 5-1) [6].

A pre-requisite to the matching is the discovery of possible capabilities which may fulfill the requirements. These are called candidate capabilities. The matching activity selects among the candidate capabilities those who fit best to the requirements, taking side conditions, such as the need to deliver standards-compliant services, explicitly into account. Discovery and matching need some associated semantic description of both requirements and capabilities in order to be effective. Such semantic descriptions give meanings to the terms used in the specifications, e.g. by means of semantic annotation to ontologies. Their representation forms range from text in combination with a glossary in which all important terms are defined for a given project up to specifications in description logics.

[1] http://wiki.services.eoportal.org/tiki-index.php?page=HMA+Configuration+Management+Table

[2] http://www.spacebooks-online.com/product_info.php?cPath=112&products_id=17510

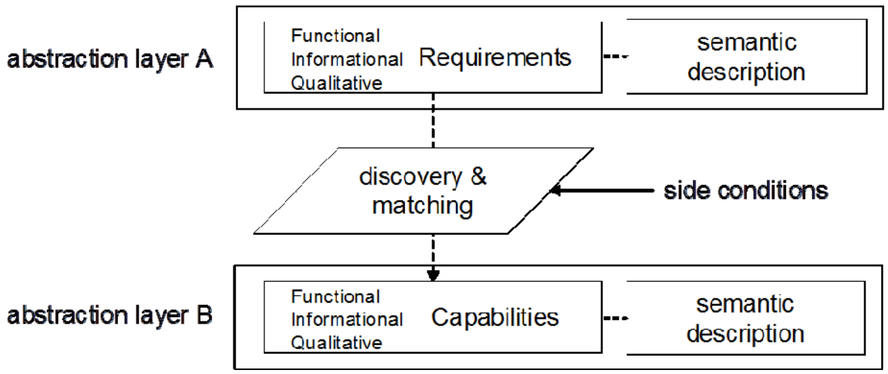

Figure 5-1: Mapping of Requirements to Capabilities

The discovery and matching problem repeatedly occurs when user requirements are broken down into multiple steps across several abstraction layers. In fact, capabilities turn into requirements for the next design step. Furthermore, there is a widely recognized need to package the development of requirement artifacts on a higher abstraction level and the development of architectural artifacts on a lower level into one single design step, leading to a so-called co-development of requirements (e.g. use cases, section 2) and architectural artifacts, e.g. service specifications or information models [15]. This requires a step-wise refinement of the design artifacts (Figure 5-2):

1. The Analysis step in which the user analyses the problem and expresses the outcome in the form of user requirements. Example: A use case that requests to "get a diagram containing the average nitrate concentration of the groundwater bodies in the Upper Rhine Valley of the last 10 years".
2. The Abstract Design step in which the user requirements are transformed by the system designer into system requirements which then have to be matched with the capabilities of an abstract service platform, i.e. a service platform that abstracts from the peculiarities of service platform technologies. Example: Provide a service that enables to "get observation values with a sampling time in the interval [2000-01-01, 2009-12-31] for the environmental parameter "nitrate" for all groundwater monitoring stations that are located in the Upper Rhine Valley".
3. The Concrete Design step in which the capabilities of the abstract service platform turn into requirements for the design of the concrete service platform and finally result in a specification of its capabilities. Example: The getObservation operation request of the OGC Sensor Observation Service as part of the OGC Sensor Web Enablement architecture [22].
4. The Engineering step in which the specified capabilities of the concrete service platform have to be implemented as service components and deployed in the context of a service network (here: EO mission infrastructure).

In the following a method for the analysis step is presented as a prelude of the SERVUS Design Methodology [18]. SERVUS focuses on the abstract design step and denotes a Design Methodology for Information Systems based upon Geospatial Service-oriented Architectures and the Modelling of Use Cases and Capabilities as Resources (SERVUS). SERVUS describes individual design activities that are interconnected by a common modelling environment interconnecting the Enterprise, Information and Service Viewpoint of geospatial architectures [6].

SERVUS relies upon a semantic resource model as a common modelling language to which both use cases and capabilities may be mapped. Hereby, a resource is an information object that is uniquely identified, may be represented in one or more representational forms (e.g. as a diagram, XML document or a map layer) and support resource methods that are taken from a limited set of operations whose semantics are well-known (uniform interface). A resource has own characteristics (attributes) and is linked to other resources forming a resource network. Furthermore, resource descriptions may refer to concepts of the domain model (design ontology) using the principle of semantic annotation, yielding so-called semantic resources. The basic idea of the SERVUS resource model is derived from the Representational State Transfer (REST) architectural style for distributed hypermedia systems as conceived by Fielding [14].

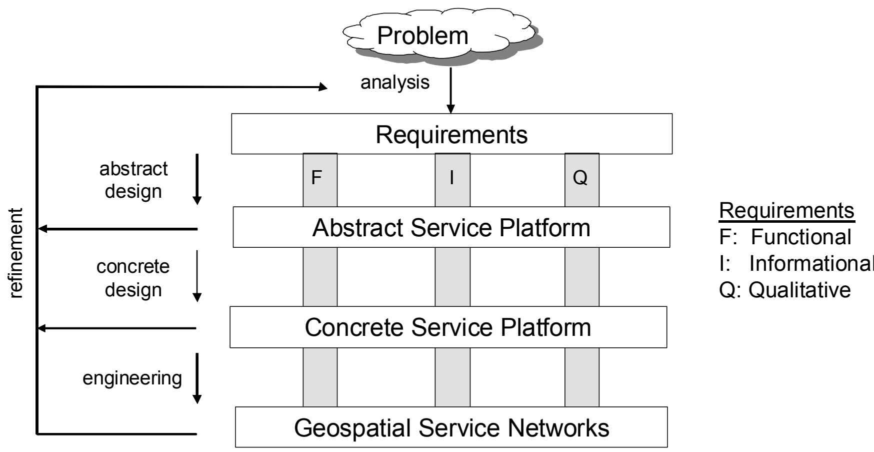

Figure 5-2: Analysis, Design and Engineering Steps

The abstract design step is then understood to be an iterative discovery and matching activity: requested resources derived from user requirements have to be mapped to fitting offered resources that represent the information objects being accessed and manipulated by geospatial services. Figure 5-3 illustrates the analysis phase as a prelude of the SERVUS Design Methodology. As part of the project planning there needs to be some agreement of how to document use cases. For this continuous activity a project space has to be created which preferably should be supported by a project management server that is accessible by all participants of the analysis process.

As a first step of an analysis iteration loop a set of preliminary use cases (UC) is identified, mostly be those thematic experts who drive the project. For each of them an entry in the project space has to be generated. The methodology proposes that use cases are initially described in structured natural language but already contain the list of requested resources. This small extension with respect to the approach of Cockburn [11] heavily facilitates the transition to the abstract design step (here: the specification of the information model in UML) but is still very easy to understand by thematic experts. Hence, this description is the language which is used in the UC discussion that takes place in workshops that are facilitated by the system analyst. Depending on the level of agreement that can be reached the iteration loop is entered again in order to refine or add new use cases.

In order to identify inconsistencies and check the completeness of the UC model, the system analyst may transform the semi-structural UC description into formal specifications in the Unified Modelling Language (UML). However, these UML diagrams should still be on a high abstraction level such that a discussion with the end-user is possible. However, in addition to the usual UML use cases they already comprise the links to the set of requested (information) resources, their representation forms and the requirements to create, read, write or delete them.

Once an agreement is reached about the set of use case descriptions and related UML specifications it is then up to the system analyst to specify the resulting information model taking the (semantic) resource model (see above) as a modeling framework.

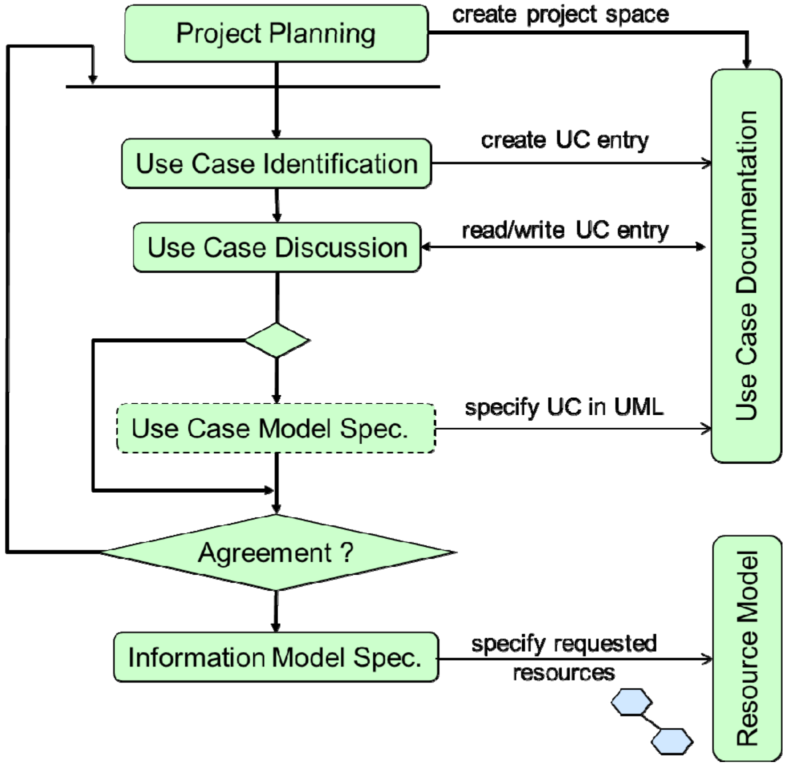

Figure 5-3: Analysis phase of the SERVUS Methodology

6. CONCLUSION

The international initiatives presented in this paper demonstrate the motivation and the potential of using open geospatial service architectures as an infrastructure basis for EO software applications. Beyond these architectural considerations, there are examples that prove the benefit of this approach. Two of them shall be mentioned here: tsunami warning systems and environmentally induced health early warning systems.

6.1 Tsunami warning systems

Tsunami warning systems are distributed software and hardware systems supporting the reliable detection of imminent tsunami hazards as a consequence of geological events, which are earthquakes in most of the cases. The typical component structure of a tsunami warning system comprises three major components: upstream from sensor systems, decide-and-act, associated by context information and models, and downstream to target groups. Although this basic high-level component structure basically remained unchanged, the software infrastructure that underpins tsunami warning systems has undergone several eras following the fast evolution of the information and communication technologies in the last 40 years [13]. Starting from the data processing era in the 1970s dominated by mainframes and minicomputers, following the Microcomputer era characterized by Personal Computers interconnected by local area networks in the 1980s, it has entered the Internet era in the 1990s in which the regional and global interconnection of a multitude of components and systems has become a major architectural design issue. Hence, interoperability of components and systems as well as the application of open standards became a major design criteria, however, having in mind the short time intervals in which decisions about tsunami warnings have to take place. This approach proved to be valid when designing, implementing and deploying the German Indonesian Tsunami Early Warning System (GITEWS) [23]. The GITEWS project addressed the specific challenges of early warning in a near-field environment with its limited reaction times. This project raised the opportunity to develop an overall generic architecture for tsunami warning systems based on best practices and the results of international standardisation activities in the geospatial software domain [13]. This approach included service-oriented architectural design principles but also open geospatial and Sensor Web service and data specifications from the OGC [16].

6.2 Health and environment-related early warning systems

The European research project EO2HEAVEN (Earth Observation and Environmental Modelling for the Mitigation of Health Risks, www.eo2heaven.org) is positioned in the GEOSS societal benefit area of "Health". It contributes to a better understanding of the complex relationships between environmental changes and their impact on human health. As the project name suggests, Earth Observation is a major element in this undertaking, but not only driven by the approach to include EO products into the toolsets, e.g. for air pollution mapping [24], but also by the software architectural approach. The EO2HEAVEN project defines a Spatial Information Infrastructure [26] that relies upon OGC standards and the work of former projects such as the Sensor Service Architecture [25]. As the same series of OGC standards are used in this a Spatial Information Infrastructure, EO2EHAVEN applications may easily benefit from EO products that are made available by other EO missions relying, for instance, upon the HMA services as presented in section 4.5 of this paper. Furthermore, workflow applications are facilitated based upon data from EO remote sensing and in-situ monitoring instruments [27].

6.3 Outlook

Global software infrastructure are getting more and more important for geospatial software applications, either being stand-alone systems that need EO data as input, or being software systems that offer their data to other systems in form of services. This tendency coincides with the evolution of the Internet as a whole into the so-called Future Internet: "As requirements are understood, applications lead to the discovery of reusable services, which become components in platforms, which lead to general purpose infrastructure" (pp. 9 in [2]). This paper highlighted the major EO mission infrastructure approaches, all relying upon standards of the Open Geospatial Consortium. Hence, there is a need to discuss these existing approaches with the proponents of the Future Internet. This endeavor is currently being carried out by the European research project ENVIROFI (http://www.envirofi.eu/) [28].

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