DEVELOPING AND CHAINING WEB PROCESSING SERVICES FOR HYDROLOGICAL MODELS

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ABSTRACT:

Available geospatial resources on the Web need to be accessed and easily exploited by scientists and decision makers. Organizations at multiple administrative levels are establishing interoperable infrastructures to improve accessibility, such as the Global Earth Observation System of Systems (GEOSS), and the Infrastructure for Spatial Information in Europe (INSPIRE). Also regarding hydrological resources management we encounter initiatives being carried out around the globe, to merge computer science with hydrology in order to improve the way experts work and make decisions.
The current trend in geospatial applications and the key unit in the mentioned initiatives are Spatial Data Infrastructures (SDI) based on access to data and processes via web services following OGC (Open Geospatial Consortium) standards. Traditional SDIs support the most common and basic requirements of geospatial data users: discovery, access, download and visualization of the data. Specialized users such as hydrological scientists, however, require more advanced services for processing data and observations using specialized models. There is a need to expose these models in SDI so scientific community can run and share them, as they do with data resources.
In this framework we deployed two hydrological models where functionality is offered by a set of reusable web processing services on top of an SDI. These web services, designed with the criteria of modularity, can be reused to orchestrate distributed hydrological applications where shared remote data sources can be processed together with local data.
In the framework of the GMES EC-funded project AWARE (A tool for monitoring and forecasting Available WAter REsource in mountain environments, www.aware-eu.info) we have built an application for predicting water discharge in the Alpine catchments based on a chain of these web geospatial services. The chain is provided to users within a Geoportal which is the entry point to an INSPIRE-based SDI where experts are guided to run one hydrological model.

1. INTRODUCTION:

Geographic Information System (GIS) applications are nowadays developing on a distributed architecture composed of independent and specialized geospatial web services, designed to offer distributed functionality over the Internet. The level of interoperability of Geospatial web services have greatly improved and it is now possible to offer modular and distributed GIS applications. Spatial Data Infrastructures (SDI) (Masser, 2005) and Web geoservices support effectively the most common requirements and needs of spatial information users, i.e. discovering, accessing and visualizing datasets. Connecting scientists to their data is an important task, which is beginning to facilitate access to distributed, heterogeneous geospatial data through the set of policies, common rules, and standards of SDIs that together help improve interoperability. However, a further challenge is under development, introducing a more service-based vision in which geospatial web services are used not only to access geospatial data, but also to transform them and process them, often in service chains (Lemmens et al., 2006).
In this context, scientists interested in geo-spatial information, as hydrologists, have specific and concrete requirements that involve not only discovering and access to geo-spatial data but also the possibility to analyze and process them by exploiting traditional or newly developed modelling applications. The traditional evolution of geospatial applications is aimed at including tailored geoprocessing functionalities within general purpose GISs, that become therefore closed applications customized to the purpose of a specific users' community, difficult to be adapted to either new or changing requirements. On the contrary, the perspective assumed following SDIs and Geospatial web services is to offer modular and reusable atomic components to be chained and orchestrated to meet users' requirements.
In the community of hydrological modelling, in particular, two main requirements should be addressed. The first one is to let the possibility to apply different models starting from the analysis of the available measurements of hydrological variables; the second one is the need to couple regional data with local measurements, fostering then the cooperation between model and data providers and users as proposed by the Global Monitoring for Environment and Security (GMES) initiative.
This paper illustrates the outcomes of the EC FP6 Project AWARE (A tool for monitoring and forecasting Available WAter REsource in mountain environments, www.aware-eu.info) that has designed and implemented a distributed, web-

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based application for running hydrological models in the realm of SDI compliant with the INSPIRE vision (INSPIRE EU Directive, 2007). AWARE application aims at providing users an entry point to run hydrological models through a set of loosely-coupled components such as user interfaces, web processing services, web access and download services, discovery services, wizards, and others. Moreover the application architecture is able to integrate in the model local data provided by the user with regional data coming from satellite remote sensing.

2. OVERVIEW AND RELATED WORKS

There are web-based hydrological applications publicly available on the Internet. Most of these are built around a web mapping service in which data sets are visualized by transparently applying hydrological model routines. However, it is important to highlight some general differences between these web solutions and our application. First, our solution allows expert users to interact directly with the underlying hydrological model. Second, in contrast to other applications that use static datasets, expert users should be able to load specific datasets of interest for their area of study, and to run a hydrological model using these ad hoc datasets. Finally, a key advantage is that our application is built on distributed geospatial processing services. This allows us to better approach so-called service-oriented science (Foster, 2005), which refers to scientific research structured as distributed networks of interoperating services.

StreamStats[1] is a USGS web-based tool that allows users to choose locations of interest and obtain stream flow information for these locations.

IJEDI WebCenter for Hydroinformatics (Soh et al., 2006) is an online application to identify drought-vulnerable regions. The authors propose a combination of data mining techniques to characterize the behaviour of water basins and classify them according to the drought index.

The Water Resource Management Information System (WRMIS) (Dzemydiene et al., 2008) has been developed according to the European Union Water Framework Directive and EIONET[2] ReporNet infrastructure requirements. It is realised as a Web portal where users can receive information on environmental water sectors, combining data and giving the opportunity to extract useful information by the available functions and tools.

Another related work for managing water resources is reported in (Mysiak et al, 2007) within the MULINO[3] project. It incorporates a decision support system (DSS) which contributes to improving decision-making in water management. This DSS, however, is implemented as a desktop application.

Our approach differs from these implementations in that it focuses on a library of distributed geospatial services deployed on top of an SDI to offer the capability to implement a distributed application for water resources management, with the added value of being reused in other scenarios.

Similar ideas and methods have been discussed by (Kiehle, 2006) in the sense of applying OGC Web Processing Services (WPS) (Schut, 2007) within SDIs. Here we demonstrate the suitability of the approach by means of a more elaborate use case to face hydrologists with their data sources and models via geoprocessing services. Also, (Shen et al., 2005) proposes a system for remotely sensed image processing with web services, highlighting the need of distributed processing for Earth Observation data, yet the authors do not contemplate the use of OGC specifications and thus interoperability is limited.

GMES-funded projects like AWARE or ORCHESTRA plead for the use of standard services deployed in SDI for effective geographic information process. In this line, (Friis-Christensen et al. 2007; Kiehle, 2006; Díaz et al., 2008; Granell et al., 2010) propose similar approaches to run geoprocessing in SDIs using OGC standards. (Brunner et al., 2009) propose as future work the implementation of relevant standards as WPS in their system to enable geospatial processing to support collaborative and rapid emergency response.

On the other hand, in work related to wrapping existing off-line algorithms in open source projects to expose them as web processing services, we must mention PyWPS (Cepický, 2007) which allows making native connections to GRASS4 routines, encapsulating them as contained processes in a given WPS service. GRASS is a GIS free software package for raster and vector data analysis that has been in use for more than 20 years.

The GeOnAS project (An Online Analysis System Based on Service Oriented Architecture) (Di et al, 2007) functions are data discovery, data analysis, and data visualization via the Web. It also provides many geospatial processing functions for manipulating and analyzing vector and raster geospatial data by using PyWPS. Our services take another perspective: combining other open source projects that we describe in the implementation section. Furthermore, in contrast, we focus on architectural aspects related with the integration and reuse of geoprocessing services within SDI contexts (Díaz et al., 2007; Friis-Christensen et al, 2007; Granell et al, 2010) rather than merely implementation aspects.

3. ARCHITECTURE OF THE APPLICATION

The architecture of the application developed in AWARE follows the INSPIRE philosophy pursuing the goals of maximizing service interoperability and service reuse. Service interoperability is partly accomplished by using international standards and specifications that permit self-described interfaces for services and components. In particular we used the OGC standard specifications for service interfaces. From the developer's perspective, the application exploits service reuse to accelerate the process of creating service compositions from existing services already registered in catalogues. Following INSPIRE recommendations, services are the cornerstone in the AWARE architecture in the sense that complex tasks are exposed as service chains by mainly reusing existing services.

Figure 1 illustrates an overview of the layered architecture of the application based on the INSPIRE (SDI) technical architecture (INSPIRE EU Directive, 2007). The Presentation layer involves user interface and interaction. In AWARE a Geoportal enables users to interact with the hydrological models and explore visually the model results. The Horizontal Service layer allows the description and implementation of concrete components, for the business logic, and includes service chaining control, as it is necessary for running the hydrological models, and then allows the instantiation and invocation of services instances.

[1] http://water.usgs.gov/osw/streamstats/ (accessed 1 June 2010)

[2] http://www.eionet.europa.eu/ (accessed 1 June 2010)

[3] http://www.feem.it/web/loc/mulino (accessed 1 June 2010)

[4] http://grass.itc.it/ (accessed 1 June 2010)

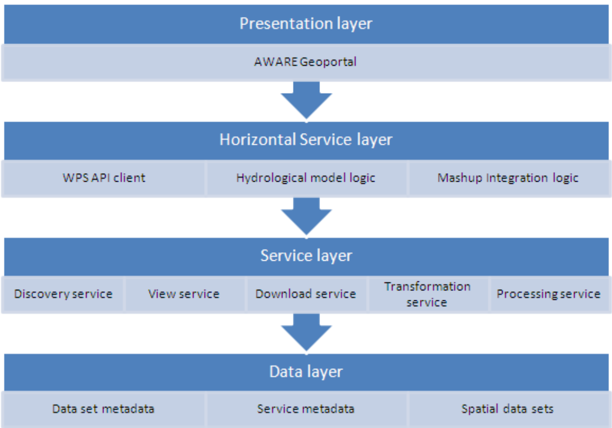


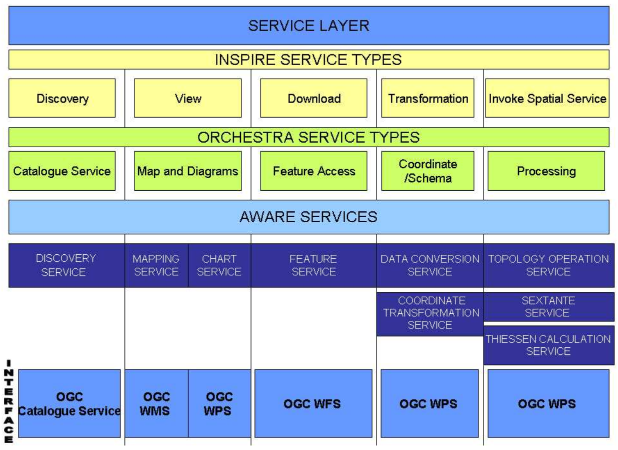
Figure 1 overview of the architecture of the AWARE application

The Service layer combines a set of service instances grouped in the INSPIRE service types needed to solve the concrete user requirements for hydrological models. Processing services are not a type defined in the INSPIRE Network Services: the INSPIRE technical architecture identifies 'invoke' services as the service type able to invoke and process services. However, in AWARE this type is identified as processing service, while the invocation service type is implemented as a concrete software component within the Horizontal Service layer. Finally, at the bottom, the Data layer contains spatial data sets and metadata of both data sets and services.
The core of the AWARE architecture is the Horizontal Service layer, responsible for the data processing logic and service integration, and the Service layer where the AWARE network services reside.
One way to separate concerns in software applications is to use the well-known Model View Controller (MVC) paradigm (Krasner & Pope, 1988). In short, the Model contains the code for business logic and represents the application status, the View contains the code of the user interface, and the Controller represents the navigational code or application flow. Our application implementation follows the MVC paradigm, where the Model and the Controller are represented in the Horizontal layer and the View rules the Presentation layer, in order to provide a clear separation of concerns with respect to the business model application and the user interface.
However, we extended the MVC paradigm by providing an extra Service layer where the service instances reside. In this way scalability and the reuse of service instances are improved, since it fosters the addition of new hydrological models (Model/Controller) that in turn can reuse the service instances already available in the Service layer. In this sense, the layered architecture presented here is also based on the Service-Oriented Architecture (SOA) paradigm (Newcomer & Lomow, 2004), which consists of loosely-coupled interacting software components that provide services. The basic principle of SOA is the process of fragmentation and simplification of large, complex pieces of code into more numerous but simpler software components. Furthermore, the Service layer is actually a cloud of interoperable services ready to be discovered, composed and executed by users and client applications like the one offered in AWARE (Baranksi et al, 2009).

4. SERVICE IMPLEMENTATION IN AWARE

This section focuses on technical details and software components used to implement the service layer of the application architecture.

At the core of the AWARE multi-tier architecture we have the Service layer, which comprises the AWARE Network Services to provide users with the capacity of finding, accessing and processing the required data and functionality for the application. The Service layer is all about services and has been implemented according to the SOA paradigm and deployed on top of a Spatial Data Infrastructure where, as far as possible, we implemented them according to standard OGC specifications. Following the INSPIRE Directive and the ORCHESTRA implementing rules (OGC Best Practices Paper) (cit) we have adopted a unique methodology for the design process: based on the service abstract definitions, we have then chosen specific interfaces and platforms to create the concrete service implementations of the different services types.



2 AWARE Application Service Layer

Figure 2 offers an overlook on the Network Services defined in INSPIRE, ORCHESTRA, and AWARE, respectively. In general AWARE service types correspond to those defined by INSPIRE, with some remarks. For example, AWARE processing services are included in the type processing, a service type identified by ORCHESTRA but lacking in INSPIRE (see Figure 2). Specific plot and diagram capabilities have been added to the view service since, as in ORCHESTRA, we consider lines plots and bar chart, common outputs for scientists, as an output similar to a map, in the sense that both are different ways of displaying geospatial data. The bottom of Figure 2 shows the concrete interfaces for defining the service instances. Note that the Chart service has been interfaced by using the Web Processing Service specification although it falls under the view service type. The rest of this section describes the AWARE service types and the concrete service instances implemented for each type.

4.1 AWARE Discovery Services

AWARE implemented the INSPIRE discovery service type by instantiating this service through the OGC Catalogue Service for Web (CSW) interface. AWARE Catalogue Service is an instance of the GeoNetwork Catalogue (http://geonetwork-opensource.org/), which is an open source implementation of the CSW specification. This catalogue offers the functionality to search and retrieve the metadata of data sets available for the study areas of the project.

4.2 AWARE View Services

AWARE three services of view service type for dealing with different visualization requirements.

- AWARE Web Mapping Service: This service implements the OGC WMS specification and provides the user with some graphical maps of datasets over the study areas. The instance is a deployment and configuration of Minnesota MapServer (http://mapserver.gis.umn.edu/), an open source implementation of the OGC WMS.
- AWARE Chart Service: Diagram services are not included in the first draft of the INSPIRE Service Network as an identified type, but it is an important requirement for AWARE users, who need to be able to represent some of the useful information not as maps, but as descriptive plots in a graphical way. Like in ORCHESTRA, AWARE includes services for plot creation as instances under the view service type. To implement this service type the service implementation has followed the OGC WPS interface, since this interface offers the possibility to integrate some processes such as plot creation.
- Google Server: the mapping service offered by Google in its Google server is also included in AWARE View services, since the presentation layer makes use of it to be able to present a background layer in the mash upof the Presentation layer.

4.3 AWARE Download Services

To meet requirements to download or feature access AWARE has instantiated a service implementing the OGC Web Feature Service (WFS) specification to provide users with vector data and their associated information over the study area. The data model provided by a WFS service follows the Geographic Markup Language (GML) profile according to the WFS specifications and makes use of an application schema defined for AWARE according to the Information Model defined in the project.

4.4 AWARE Transformation Services

The INSPIRE Directive identifies a transformation service as a reference system conversion, while the ORCHESTRA project includes also a schema mapping in this type. AWARE offers two different service instances of this service type, i.e.:

- AWARE Coordinate Transformation Service: It converts coordinates from a source reference system to a target one. This service is implemented following the OGC WPS interface.
- AWARE Data Conversion Service: AWARE users have the need of transforming data in different formats. To this purpose, this service converts from shapefile format to GML format. Again, it implements the OGC WPS specification.

4.5 AWARE Processing Services

It is important to note that INSPIRE assumes that all kind of data processing is performed using web services. According to the INSPIRE service types it is not clear which type matches the data processing, meaning for data processing any kind of spatial or non-spatial algorithm executed using existing data to create or extract any kind of useful information for the application. According to the technical specifications transformation services would only transform coordinates, while the Invoke Spatial Data Services should be able to invoke and chain services. AWARE follows ORCHESTRA philosophy and place its Processing Services under the type processing. The following subsections describe how AWARE WPSs have been designed and implemented.

4.5.1 Functional design of WPSs

In order to provide useful geospatial processing services that suit the concrete requirements of hydrological models, but, at the same time, foster modularity and reuse, a thorough analysis has been performed to identify basic functions shared among various tasks. The ultimate goal is to create a library of well-tested and domain-independent geospatial processing service modules on which more customized and elaborated functions rely. In this way, the process of creating new coarser-grained geospatial processing services is made possible by mainly reusing already available fine-grained services (Díaz et al., 2008; Granell et al, 2010).

Our design strategy begins by analysing and identifying simple functions required for the hydrological models. Then we assume a suitable basic geospatial processing service as one which performs a basic function, can be easily tested and is domain-independent enough to be applicable to other contexts (Granell et al, 2010). Some examples are geospatial processing services concerned with topological relations such as *intersect with*, *within*, *crosses*, *contains*, etc., as well as methods for calculating geospatial proximity or distances among geospatial objects and spatial operations like *buffer*, *area* and *volume*. In general, basic processes perform basic GIS operation in a wider sense, and could be part of more complex operations that would imply a chain of basic functions. They can be used in domains different than hydrology, since they are theme-neutral.

On the other hand, when these basic functions are invoked many times in the same order, their compositions identify coarser-grained geospatial processing services that reduce network traffic and increase efficiency. This kind of services normally performs a specific task, so they are less reusable; In this design methodology the service granularity often results from a trade-off between reusability and efficiency. In this sense, coarser-grained processing services are similar to the concept of opaque or aggregate service chaining defined by OGC as one approach for web service chaining (Alameh, 2003). Coarser-grained processes are by definition more domain dependent. In AWARE, that deal with models for snowmelt dynamic representation in mountainous regions, there are processes related to snow percentage estimation over different elevation zones (ranges of altitude).

This is the case of SnowPercentage process. It is basically a chain of other processes, thus it has been implemented as a controlled-chain WPS-integrated complex processes.

Figure 3 illustrates the SnowPercentage process workflow. It invokes first the *area* process in one elevation zone that belongs to the study water catchment. Secondly, it calls a WFS to get vector data representing the Snow Covered Area (SCA) of the basin at a certain date. After this, the *intersect with* process is called to obtain the regions which are intersection between SCA and the current elevation zone. Now the SnowPercentage process invokes again the *area* process, this time to calculate the surface of this intersected region. Finally SnowPercentage returns a snow percentage, i.e. the ratio between snow-covered area and the elevation zone area in the day of interest.

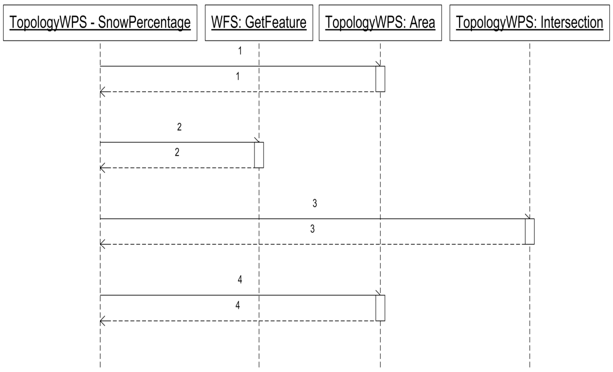


Figure 3 SnowPercentage process workflow

Once identified the services, they are grouped on the basis of similar functionality. For instance, Topology groups several processes related to GIS topological operations. Table 1 shows the Processing Service library with the available processes that have been created.

Web Processing Services	Service processes
Topology	Area, Intersection, Buffer, MaxExtent, SnowPercentage, GetFeatureByAttribute, Thiessen
Sextante	CoordinateElevation, StationsElevation, ElevationCurves, ElevationZones, HypsometricElevation, Reclassify, Vectorize
Chart	DepletionCurvesPlot, DischargePlot,HbvRunoffPlot, HbvSWEPlot, SensorDataChart
CoordinatesTransformation	TransCoordGMLPoint, TransCoordPoint, TransCoordPoint7P
Data Conversion	CoordTransformer, Shp2GML

Table 1 AWARE WPSs grouped by function similarity

4.5.2 Implementation of WPSs

AWARE Processing services have been implemented according to the OCG WPS implementation specification. For the implementation of the WPS services in AWARE we have chosen the OGC WPS specification implementation from 52North[5] that enables the deployment of processes on the web. It features a pluggable architecture for processes and data encodings. The implementation is based on the current OGC WPS specification, supporting at the moment versions 0.4.0 and 1.0.0. Using this framework, which provides us with the WPS interface we have implemented the algorithms required for the processes listed in Table 1, Processes implement these algorithms, either wrapping and adapting existing functionalities in open source libraries or implementing the algorithm from scratch. In the last step we deploy these processes in instances of WPS implemented with 52North framework.
As regards Topology WPS and Data Conversion WPS, we have used Geotools[6] and Java Topology Suite (JTS)[7] libraries to have an object model to work with spatial information; in order to read and generate GML we have used the parsers within 52North. To generate the Thiessen polygons in the Thiessen algorithm we have adapted the open source applet provided by P. Chew[8]
The plot functionality available in Chart WPS has been developed by using JFreeChart[9] within the implemented algorithms to create and return the required images. Regarding Sextante WPS, the processes offered by this WPS have been implemented using SEXTANTE application. SEXTANTE comprises a set of extensions, each of which represents a single analysis process. Each extension is based on a so-called Algorithm/Extension architecture, which formally separates the processing itself from other tasks such as creating the corresponding interface. This architecture is particularly suitable for exposing SEXTANTE algorithms through a WPS interface. Currently, Sextante WPS provides several SEXTANTE processes such as Reclassify and Vectorize. Besides these processes, we have added new ones that integrate multiple SEXTANTE algorithms, as the case of the complex process ElevationZones. All these processes are self-contained and loosely coupled with each other.

5. RESULTS AND DISCUSSION

The AWARE geoportal[10] is a web application by which hydrologists can discover, access and run the hydrological models proposed by the project through the web services described in the previous sections. Anyone accessing this geoportal can run the models independently on her/his hydrological background.
A first observation derived from the scenario experience is that the approach based on distributed geoprocessing services leads to a collection of reusable tools, available for other users in the case that they are well-documented and registered in open catalogues. This is possible in principle because WPS-based geoprocessing services do not work with pre-established datasets but rather they preserve a loosely-coupled relationship between ad hoc data and processing capabilities, making it possible to chain them in other geospatial web services. The OGC WPSs have been tested in different contexts illustrating that it is possible to combine several geospatial processing services for accessing, processing and visualizing data within an SDI. In our experience OGC standards seem to be mature enough to provide specifications to create interoperable web services with all the functionality needed to build a distributed application on top of an SDI.
To address some of the problems in implementing distributed geospatial processing services, we should mention the overall service chain performance, rather variable, when distributed data sources are involved. This is the case when large processing tasks are performed over the network, because data transportation and validation can dramatically increase the response time to users. In asynchronous messaging the WPS instance does not return immediately the process results but rather it responds some time later in a different communication session. These and other tests will form a part of our future work.

[5] http://52north.org/maven/project-sites/wps/52n-wps-webapp/ (accessed 1 June 2010)
[6] http://geotools.codehaus.org/ (accessed 1 June 2010)
[7] http://www.vividsolutions.com/jts/jtshome.htm (accessed 1 June 2010)
[8] http://www.cs.cornell.edu/home/chew/chew.html (accessed 1 June 2010)
[9] http://www.jfree.org/jfreechart/ (accessed 1 June 2010)
[10] http://geoportal.dlsi.uji.es/aware/ (accessed 1 June 2010)

6. CONCLUSIONS

In this work we have proposed and described an approach to provide expert users with remote tools by wrapping scientific processes as distributed standardized web services, so they can be shared and used in multiple scenarios.

The overall goal in this work has been to improve the availability of hydrological resources in SDI with special emphasis in processing resources to provide users with reusable tools to build applications in a distributed fashion. This alleviates the need to maintain multiple desktop software packages for the purpose of few occasional operations. The unstructured methodology of scientists, decision-makers and other SDI stakeholders using different scientific desktop tools, data and algorithms is migrated to a collection of standardized services accessible in an interoperable way (for instance, via a web-based entry point). The added value is that the scientific processes wrapped as standard web services can be reused in other scenarios. These applications can be dynamically configured and created by chaining geospatial services described using standard interfaces adopted by INSPIRE Directive. The final goal is to encourage the model web as a new paradigm for scientists working in a distributed and remote environment in order to reuse and share geospatial resources. The use case of AWARE has demonstrated that the proposed architecture and its components can improve the processing capabilities within SDI and that SDI can be a useful platform to fulfil advanced requirements like processing and modelling. Besides helping to access data in an interoperable way, SDI proved to allow running processes that access remote sources as well as local ones in a unique framework.

As the library of reusable web processing services has been implemented within a GMES project and following the INSPIRE technical architecture, it can have an added value by being reused in broader systems which aim to create and connect tools to monitor the environment, such as GEOSS.

7. AKNOWLEDGMENTS

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8. REFERENCES

Alameh, N.,2003. Chaining Geographic Information Web Services. *IEEE Internet Computing* 7(5), pp. 22-29

Baranksi B., Schäffer B., Redweik R, 2009. Geoprocessing in the Clouds, *GEOinformatics*, 8 (12), pp. 24-27

Brunner, D., Lemoine, G., Thoorens, T., Bruzzone, L., 2009. Distributed Geospatial Data Processing Functionality to Support Collaborative and Rapid Emergency Response. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 2,(1), pp 33-46

Caldeweyher, D., Zhang, J. & Pham, B., 2006. OpenCIS—Open Source GIS-based web community information system. *International Journal of Geographical Information Science*, 20 (8), pp. 885-898.

Cepický, J., Becchi, L. (2007) Geospatial Processing via Internet on Remote Servers - PyWPS. *OSGeo Journal*, vol 1. Available at http://www.osgeo.org/journal/volume1 (accessed 1 June 2010)

Di, L., Zhao, P., Han, W., Wei, Y., Li, X., 2007. GeoBrain Web Service-based Online Analysis System (GeOnAS). In *Proc. of NASA Earth Science Technology Conference*

Díaz, L., Costa, S., Granell, C. & Gould, M., 2007. Migrating geoprocessing routines to web services for water resource management applications. *Proceedings of the 10th AGILE Conference on Geographic Information Science*. Aalborg, Denmark, May, 2007: pp. 1-9.

Díaz, L., Granell, C., & Gould, M., 2008. Case Study: Geospatial processing services for web-based hydrological applications. In J.T. Sample, K. Shaw, S. Tu, M. Abdelguerfi (Eds.): *Geospatial Services and Applications for the Internet*. Springer. ISBN 978-0-387-74673-9.

Dzemydiene, D., Maskeliunas, S., Jacobsen, K. ,2008. Sustainable management of water resources based on web services and distributed data warehouses. *Baltic Journal on Sustainability*. 14(1), pp. 38-50

Foster, I., 2005. Service-Oriented Science. *Science* 308, pp. 814-017

Friis-Christensen, A., Lutz, M., Ostländer, N., Bernard, L. (2007) Designing Service Architectures for Distributed Geoprocessing:challenges and future directions. Transactions in GIS, 2007, 11(6) pag 799-818

Gamma, E., Helm, R., Johnson, R., and Vlissides, J. (1995) Design Patterns. Addison-Wesley

Granell, C., Díaz, L., Gould, M., 2010. Service-oriented applications for environmental models: Reusable geospatial services (in press). *Environmental Modelling and Software*, 25(2): 182-198, 2010. ISSN: 1364-8152

Hey, T., Trefethen, A. E., 2005. Cyberinfrastructure for e-Science. *Science* , 308, pp. 817-821.

INSPIRE EU Directive. 2007. Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Official Journal of the European Union, L 108/1, Volume 50, 25 April 2007.

Krasner, G., Pope, S., 1988. A cookbook for using the model-view controller user interface paradigm in Smalltalk-80. *Journal of Object-Oriented Programming*, 1(3), pp. 26-49.

Kiehle, C., 2006. Business logic for geoprocessing of distributed geodata. *Computers & Geosciences*, 32 (10), pp. 1746-1757.

Lemmens, R., Wytzisk, A., de By, R., Granell, C., Gould, M., van Oosterom, P., 2006. Integrating Semantic and Syntactic Descriptions to Chain Geographic Services. *IEEE Internet Computing*, 10(5), pp. 42-52.

Masser, I., 2005. *GIS Worlds: Creating Spatial Data Infrastructures*. Redlands: ESRI Press.

Martinec, J., Rango, A. & Roberts, R. 1994. *The Snowmelt Runoff Model (SRM) User's Manual*. Bern: University of Bern.

Mysiak, J., Giupponi, C., Rosato, P. (2005) Towards the develpment of a decision support system for water resource management, *Envorinmental Modelling & Software*, 20(2), pp. 203-214

Newcomer, E., Lomow, G., 2004. Understanding SOA with Web Services. Addison-Wesley Professional.

Rampini, A., de Michele, C:, Lehning, M., Blöschl, G., Brilly, M., Llados, A., Sapio, F., Gould, M. 2006. AWARE: A tool for monitoring and forecasting Available Water REsoruce in mountain environment. *Geophysical Research Abstracts*, 8 (10780).

Schut, P., (eds.), 2007. OGC Web Processing Service (WPS) version 1.0.0. *OGC Standard Document*, Open Geospatial Consortium

Shen, Z., Ming, D and Li, J., 2005. Remotely sensed image distributed procesing system design with Web Services technology, in *Proceedings of the IEEE IGARSS 2005* , pp. 4244-4247,.

Soh L-K, Zhang J, Samal A., 2006. A Task-Based Approach to User Interface Design for a Web-Based Hydrologic Information Systems. *Transactions in GIS*, 10 (3), pp. 417–449