Enabling Discovery of African Geospatial Resources

GIULIANI, Gregory, et al.

Abstract

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Enabling Discovery of African Geospatial Resources

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Abstract: In Africa, natural resources are degrading, while being at the same time essential for maintaining or improving people’s livelihood. The well-being of African communities is highly correlated to changes in local ecosystem services. Their vulnerability to degradation of natural resources is extremely high and resilience against natural changes (e.g. climate variability) and socio-economic changes (e.g. fluctuations in food markets) is low. Nowadays, it is widely accepted that reversing these trends and adapting to climate change require integrated responses tackling the underlying social, economic, political and institutional drivers of unsustainable use of natural resources. Integrated approaches intrinsically ask for cooperation, exchange of information and communication to better understand complex interactions and assess environmental issues. Understanding these interactions requires collecting and integrating various data describing physical, chemical, biological and socio-economic conditions. However, two common obstacles are currently preventing the implementation of such integrated approaches: (1) difficulties to find data, and (2) difficulties to integrate data.

In response to these issues, this paper presents the Africa Discovery Broker, a web-based tool that enables users working in different domains to search through and access 32 442 heterogeneous African geospatial resources (e.g. remote sensing, geospatial data, socio-economic data) coming from 17 international, regional, national and research projects repositories.

Keywords: Africa, Earth observation, geospatial, discovery, interoperability, metadata, brokering, GEOSS

1. Introduction:
Threats to the environment and natural resources, coupled with poor management, have serious implications for both poverty reduction and sustainable economic development (OECD, 2008). A proper management of natural resources actually requires safeguarding food production, preserving livelihoods and socio-economic development. Various global environmental assessments (Millennium Ecosystem Assessment, 2005, UNEP, 2006,
UNEP/UNDP, 2009) have shown a continuous decline of natural resources, increasing the vulnerability of the poor as a result of ecosystem stress, competition for space, soaring food and energy prices and climate change. Nowadays, it is widely accepted that reversing these trends and adapting to climate change require integrated responses tackling the underlying social, economic, political and institutional drivers of unsustainable land and water use. Many sectors and disciplines have developed integrated management frameworks such as Integrated Water Resources Management (IWRM), Integrated Natural Resources Management (INRM), Integrated Coastal Zone Management (ICZM), Community-based forest management (CBFM), or Integrated Soil Fertility Management (ISFM) (Rebelo, Johnston et al., Tripathi and Bhattacharya 2004, GEO 2014), to name but a few. Common elements in these frameworks are the integration of social and natural systems, the integration of different kinds of knowledge, the integration of different actors, stakeholders and institutions, and the integration across scales and sectors. Integrated responses require multiple instruments for their implementation and ask for fundamental shifts in governance institutions in terms of skills, knowledge capacity and organization (Millennium Ecosystem Assessment, 2005).

In Africa, natural resources are degrading, while being at the same time essential for maintaining or improving people’s livelihood. The well being of African communities is highly correlated to changes in local ecosystem services. Their vulnerability to degradation of natural resources is extremely high and resilience against natural changes (e.g. climate variability) and socio-economic changes (e.g. fluctuations in food markets) is low. Integrated approaches intrinsically ask for cooperation, exchange of information and communication to better understand complex interactions and assess environmental issues. Understanding these interactions requires collecting and integrating various data describing physical, chemical, biological and socio-economical conditions (e.g., population, ecosystems, biodiversity, vegetation, land cover, soils, water, wetlands, biomass) (Vicente-Serrano, Begueria et al. 2012). These data have in common the description of a geographical location through a set of attributes and can be considered geospatial data. Geospatial data and information have been recognized as essential for socio-economic planning and development (Tripathi and Bhattacharya 2004, Ayanlade, Orimoogunje et al. 2008). Data describing the environment demonstrate their full potential when combined with other data sets allowing one to monitor and assess environmental status at different scales (e.g., global, regional, local), discover complex relationships between them, and to model future changes. This combination allows transforming data into information that can be used by decision-makers.

To facilitate geospatial data production, management, analysis and dissemination, Spatial Data Infrastructures (SDI) have been widely adopted (Craglia, de Bie et al. 2012). African countries have also embraced the concept of SDI (Rajabifard and Williamson 2001, Lance 2003) but at a slower rate. Access to geospatial data of high quality is a pre-requisite for many stakeholders involved in various fields of activities. Therefore, it is a necessity to find, access, and integrate various types of data coming from different scientific or non-scientific sources. In other words, a multi-disciplinary geospatial framework is required to support efficiently and effectively integrated approaches like INRM or IWRM. However two common obstacles are currently preventing the implementation of such a framework: (1) difficulties to find data, and (2) difficulties to integrate data (Woldai 2002, Lance 2003, Cooper and
In scope of this paper, we only mention the technical and data obstacles while a whole SDI also encompasses other aspects (e.g., laws, people and institutions). The amount of geospatial data is quickly growing but these data are not necessarily easy to access as they are often « siloed » in different locations (Gore 1998). This leads to useless duplication of efforts because users tend to re-create data that already exist. When accessible, these data might be very heterogeneous and hardly interoperable as they come from different disciplines and are based on different technologies, arrangements, protocols and formats.

The primary function of any SDI is data discovery, enabling users to search and evaluate data before accessing them (Nebert 2005, Nogueras-Iso, Zarazaga-Soria et al. 2005). The fundamental requirement for an efficient and effective data discovery mechanism is that data is properly documented with metadata and stored in a catalog (Foresman 2008, Charvat, Vohnout et al. 2013). Otherwise without appropriate metadata an SDI will fail in its main objective of facilitating discovery and access to geospatial data (Masser 2005). Unfortunately, most of the data produced are poorly documented or even worst are simply lacking metadata (Woldai 2002, Cooper and Gavin 2005), Guigoz, Giuliani et al. submitted). Potentially, there are lots of useful data repositories both inside and outside Africa but unfortunately most of these data are hidden to users simply because they are difficult to discover. In order to support integrated frameworks and environmental assessments in Africa a solution for facilitating data discovery and access across various disciplines is fundamental. Based on these considerations the aim of this paper is to present a proof of concept for an Africa Discovery Broker, a web-based tool for facilitating the discovery of heterogeneous geospatial resources in Africa (e.g. remote sensing, geospatial data, socio-economical data).

2. Methodology, implementation and preliminary results

Discovering existing geospatial resources in Africa supposes that these resources are structured in a way that allows reaching them, ideally through recognized standards, hence the importance of a SDI. If several frameworks exist to assess the SDI status at national level (Eelderink, Crompvoets et al. 2008), such an assessment is not so obvious at continental level. Nevertheless, Europe is doing well with its INSPIRE State of Play (Vandenbroucke 2010). For Africa, an assessment methodology has also been proposed (Guigoz, Giuliani et al., submitted). The outcomes of this assessment show that Africa stands behind most other parts of the world in terms of the SDI, even though regional differences exist. The SDI effort in the African continent is led by the UN Economic Commission for Africa (UNECA), that plays a key role in Africa (Schwabe and Govender 2009) and has been trying for years to promote the SDI concept across the continent, in particular through the Committee on Development Information, Science and Technology (CODIST) that holds regular meetings and comprise SDI actors from African countries.

Despite this situation, some geospatial data repositories for Africa can be found on the Internet but are often linked to specific projects or themes. Some of these repositories contain metadata with links to the data custodians; others provide data for download while others are web services that allow for direct visualization of the data and metadata, which makes them more easily discoverable. One can mention the following data repositories focused on Africa: SERVIR-Africa (URL1), SERVIR Eastern & Southern Africa (URL2), ECOWREX
implementing the brokering approach; based on this approach, client applications bindings systems, an important requirement for the GCI was to be able to change dynamically t Craglia and Pearlman 2013). Due to the distributed and autonomous nature of GEOSS interconnecting GEOSS systems with GEOSS Societal Benefit Areas (SBAs) users (Nativi, own mandates. The GCI is a third providing access to GEOSS contributing systems Earth Observation systems. Through the GEOSS Common Infrastructure (GCI), GEOSS standards technology but to continue using their tools and publishing their resources according their "Users and Data Providers are not asked to implement any specific interoperability technology but to continue using their tools and publishing their resources according their standards -as much as possible". As a System of Systems, GEOSS is composed of contributed Earth Observation systems. Through the GEOSS Common Infrastructure (GCI), GEOSS provides access to GEOSS contributing systems - that operate independently within their own mandates. The GCI is a third-party layer that is in charge of transparently interconnecting GEOSS systems with GEOSS Societal Benefit Areas (SBAs) users (Nativi, Craglia and Pearlman 2013). Due to the distributed and autonomous nature of GEOSS systems, an important requirement for the GCI was to be able to change dynamically the bindings – i.e. interconnections – between data providers and users. This was achieved by implementing the brokering approach; based on this approach, client applications – i.e. data
users – and servers – i.e. data providers – are separated by a new intermediary component called Broker. When a client application needs a resource, it sends a query to the broker. The broker then forwards the query to connected servers, which process the request. Finally, the broker aggregates results and returns the result set back to the client application. The GCI builds on a broker for each main functionality: discovery (Nativi and Bigagli, 2009), access (Boldrini et al., 2013), and semantic interoperability (Santoro et al., 2012). All the GCI brokering components are part of the GEO Discovery and Access Broker (DAB) framework. Currently, the GEO DAB brokers about 40 systems, providing access to about 14 million complex resources (e.g. time series) and more than 80 million individual resources (e.g. single satellite scenes) (Nativi et al., 2015).

To facilitate the discovery of heterogeneous resources across Africa, the Africa Discovery Broker (ADB) has adopted a brokering approach using the caching and mediation capabilities proposed by GI-cat (URL13) to broker heterogeneous resources (data catalog and access services) (Nativi, Bigagli et al. 2009). GI-cat is an implementation of a broker catalog service developed by ESSI-Lab in the frame of the EU/FP7 EuroGEOSS project (URL14). It allows data providers to publish various catalog interfaces, enabling different clients to discover and evaluate geospatial resources over a set of heterogeneous data sources. A data provider can deploy his/her own GI-cat instance, grouping together disparate data sources, to accommodate his/her users' needs. GI-cat can access numerous catalog services, as well as inventory and access services to discover, and possibly access, heterogeneous resources. Specific components implement mediation services for interfacing heterogeneous service providers, which expose multiple standard specifications; they are called Accessors. These mediating components map the heterogeneous providers’ metadata models into a uniform data model that extends the ISO 19115 Core profile. The Accessors also implement the query protocol mapping; they translate the query requests expressed according to the interface protocols exposed by GI-cat, into the multiple query dialects spoken by the resource service providers. Currently, 45 discovery interfaces and 56 specifications are supported (Nativi, Mazzetti et al. 2015), including OGC WCS (Open Geospatial Consortium 2006), OGC WMS (Open Geospatial Consortium 2006), OGC WFS (Open Geospatial Consortium 2005), OGC WPS (Open Geospatial Consortium 2007), OGC SOS, OGC CSW (Open Geospatial Consortium 2007), THREDDS (URL 19), CDI, GBIF, GeoNetwork, Deegree, ESRI ArcGIS Geoportal, OpenSearch, OAI-PMH, NetCDF, NCML, ISO19115, GeoRSS, GDACS, DIF, File System, SITAD, INPE, HYDRO, and WaterML (Open Geospatial Consortium 2007). A complete list of supported sources and available catalog interfaces can be found atURL15.

A Discovery Broker can therefore transform query results to a uniform and consistent interface implementing metadata harmonization and protocol adaptation. Consequently, the Africa Discovery Broker enables users to search across various geospatial resources across Africa and to easily discover data that can fulfill their requirements (Fig.1).

Various heterogeneous resources have been registered (Tab.1) coming from various international (e.g., UNEP, FAO, UN WFP), regional (e.g., SERVIR-Africa, ECOWREX, Africa Soil Information Service), national (SAEON, ILWAC-Mali, Virtual Kenya) repositories and research projects (FP7 Afromaison, FP7 WetWin). The Africa Discovery Broker will take care of the harmonization process and will expose results in a consistent way.
Figure 1. The concept of brokering African geospatial resources: bottom: heterogeneous resources, middle: GI-cat, top: common interface.

Table 1. Africa Discovery Broker, registered resources and links (as of March 2015).

<table>
<thead>
<tr>
<th>Resource name</th>
<th>Endpoint</th>
<th>Type of service</th>
<th>Scale</th>
<th>Themes</th>
<th>Number of records</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN WFP</td>
<td><a href="http://geonode.wfp.org/catalogue/csw">http://geonode.wfp.org/catalogue/csw</a>?</td>
<td>CSW</td>
<td>International</td>
<td>Various</td>
<td>2204</td>
</tr>
<tr>
<td>Information</td>
<td>URL</td>
<td>Category</td>
<td>Type</td>
<td>Code</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>-----</td>
<td>----------</td>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>South African Environmental Observation Network (SAEON)</td>
<td><a href="http://app01.saeon.ac.za/PLATFORM_TEST/MAP/csw.asp">http://app01.saeon.ac.za/PLATFORM_TEST/MAP/csw.asp</a>?</td>
<td>CSW</td>
<td>National</td>
<td>Oceanography</td>
<td>14818</td>
</tr>
<tr>
<td>Open Data for the Horn</td>
<td><a href="http://horn.rcmrd.org/catalogue/csw">http://horn.rcmrd.org/catalogue/csw</a>?</td>
<td>CSW</td>
<td>Regional</td>
<td>Various</td>
<td>123</td>
</tr>
<tr>
<td>ECOWREX</td>
<td><a href="http://www.ecowrex.org/geoserver/ows">http://www.ecowrex.org/geoserver/ows</a>?</td>
<td>WMS</td>
<td>Regional</td>
<td>Energy</td>
<td>24</td>
</tr>
</tbody>
</table>

To ensure that data discovery is restricted to the African continent and enables search for data in repositories registered into the ADB, a tailored web-based application has been customized and is available at URL16. It is centred on Africa by default, has customized colours close to the Afromaison project look and feel as this application was originally built.
during this project. Finally, it has specific logos making reference to the supporting projects (Fig.2).

![Figure 2. The Africa Discovery Broker customized portal.](image)

Queries can be formulated by composing the desired constraints corresponding to simple user needs (e.g. Where, What, When, Who). The results will be displayed on the map and listed at the bottom part of the screen.

- The *Where* constraint can be selected by using the mouse, by a selection directly on the map. The corresponding fields under selected area (W-N-S-E) will be updated. Alternatively the values can be entered directly from the keyboard.
- The *What* constraint can be inserted using the Keyword field at the top right part of the screen.
- The *When* constraint can be selected using the calendars inputs under the "Time" section at the right.
- The *Who* constraint can be selected from the left frame (hidden by default).

Once the desired constraints are selected (all are optional), the search/query can be run and results will be displayed in tabular list of matching resources (if any). Each row contains information on specific matching resources and buttons to perform further actions on it (e.g., view on map, view metadata).

Currently 17 repositories have been registered in the *Africa Discovery Broker* giving access to more than 32442 resources. This allows to link resources published by data providers working in various disciplines and at different scales, adapting them to the tools commonly used by data users. The *Africa Discovery Broker* (ADB) exposes several interfaces, including the OGC CSW/ISO, GI-cat, REST, OpenSearch, OAI-PMH, CKAN, and ESRI-Geoportal. This enables various clients (e.g., QGIS: see Fig.3) to query directly the ADB without the need to use customized web applications.
3. Discussion

First tests/results show that the proposed proof-of-concept allows interconnecting heterogeneous data sources coming from various areas and at various geographical scales in a common, coherent and harmonized way. From both data providers and users perspectives, the proposed solution provides several benefits:

- it keeps their existing capacities autonomous, meaning that they are not requested to implement or comply to a dedicated standard but can continue working with their own tools,
- it supplements but not supersedes their system mandates: they first answer the needs/requirements of their own scientific community but at the same time contribute to a multi-disciplinary framework,
- this brokering approach lowers the barriers for both resource providers and users,
- it is flexible enough to integrate new systems/standards and consequently allows to build incrementally a system of systems by interconnecting additional resources, and finally
- it provides other non-technical benefits such as identifying – and further mapping - gaps (e.g., data, participation), offers a platform to coordinate information from various contributors/stakeholders, and can potentially foster a positive competition/emulation to make data discoverable.

Even if geospatial information can bring major benefits for the economy and development of African countries, most of them are still lacking timely access to proper geospatial data (Ayanlade, Orimoogunje et al. 2008). Several authors have identified the major barriers that are hindering efficient discovery and access to the vast amount of data existing across the African continent: (1) inadequate funding of geo-information services, (2) lack of people, skills, education in the field of geo-information, (3) lack of coordination at the continent scale, (4) lack of computing and communication infrastructure (e.g., poor Internet connectivity), (5) amount of data still in analog format (e.g., paper), (6) political priorities & support, (7) lack of standardization, (8) social and cultural issues, and (9) lack of institutional policies, regulations, and guidelines (Woldai 2002, Cooper and Gavin 2005, Ayanlade,
Orimoogunje et al. 2008). These authors also emphasized the necessity of having tools to facilitate the management of digital metadata (e.g., production and maintenance) and the publication of this metadata on the Internet. The search of African geospatial resources to include into the ADB also showed that several geospatial data repositories or metadata catalog still exist but do not work (e.g., dead links), probably because the related infrastructure is not supported and/or maintained anymore.

To address these issues the capacity building (at human, institutional, and infrastructure levels) appears a fundamental activity to be undertaken across the continent in order to develop skills about interoperability, standardization, metadata and data publication, data management, governance, fostering collaboration and cooperation (Giuliani, Ray et al. 2013, Giuliani, Lacroix et al. 2014, Donert 2015).

Another key enabler to succeed in leveraging geospatial resources in Africa is to build an efficient network of stakeholders across the continent and to develop an effective coordination mechanism and a robust governance structure. The African Earth Observations (EO) community is continuously growing and is establishing its presence in the region and in the global arena. This is supported by the development of the African Space Policy and Strategy led by the African Union Commission. This growing network takes also advantage of the national and regional programs and of the on-going cooperation initiatives with a great number of external partners. More specifically, the recently created AfriGEOSS initiative framework (URL17), developed within the GEO, will strengthen the African EO network through establishing links between GEO activities and the existing capabilities and initiatives in Africa. AfriGEOSS provides the necessary framework for countries and organizations to access and leverage on-going bilateral and multilateral EO-based initiatives across Africa, thereby creating synergies and minimizing duplication for the benefit of the continent (GEO secretariat 2012). This coordination initiative has been recognized essential to enhance Africa's capacity for producing, managing and using Earth observations, thus also enabling the Region's participation in the implementation of the Global Earth Observation System of Systems (GEOSS).

The ADB provides a discovery and access to the GEOSS Data Core and is brokered by GEOSS. The Africa Discovery Broker has been implemented with the vision of being hosted, managed, and promoted in Africa so that African stakeholders can be empowered to manage African resources. The UNECA a major actor in GIS/SDI/EO in Africa through its important network of partners/stakeholders represents a key enabler to support the adoption of interoperable solutions to share geospatial data and products, raise awareness about the benefits of increased access on geospatial data, and create commitments and active contributions in enabling and facilitating the discovery and access to geospatial data (EIS-AFRICA 2002, UNECA 2007). In this regards, UNECA has established the African caucus of the United Nations Global Geospatial Information Management (UN-GGIM:Africa -URL18) initiative, providing an overarching mechanism to coordinate geoinformation activities involving member States as the key players and putting in place a continental framework for common regional standards, standardization and compliance in line with international policy. Consequently, strengthening, extending and supporting the UNECA with the proposed Africa Discovery Broker might (1) benefit the UNECA’s network of stakeholders, (2) bring new and relevant/significant African geospatial resources in the ADB, increasing their visibility and dissemination, and (3) be a major contribution to the AfriGEOSS and the UN-
Finally, the Africa Discovery Broker is aiming at building bridges among various African geoinformation communities and allows searching and discovering resources available from various heterogeneous repositories. In particular, on top of the AFB different catalogue interfaces have been published to support the development of tailored applications (e.g., desktop, web-based, mobile). This has the potential of valorising African geospatial resources, helping African stakeholder empowerment, supporting integrated approaches and environmental assessments, and ultimately sustaining informed decision-making processes and supporting meaningful social and economic development. Ultimately, this can be seen as an implementation of a regional GEOSS portal supporting regional stakeholders to participate in the global mandate of the GEO (Gorgan, Giuliani et al. 2013).

4. Conclusions and perspectives:
Data discovery is a fundamental mechanism, enabling users to search and access data. In particular, for integrated approaches such as INRM, IWRM, ICZM, CBFM, ISFM or for environmental assessments, finding and accessing relevant data is a key requirement.

The Africa Discovery Broker facilitates the discovery of African Earth Observation resources by allowing searching across various heterogeneous repositories. It offers the possibility for users working in different domains to search through and access various metadata catalogues and data services in a common and customized frontend application. It includes 17 data sources giving access to 32'442 resources from international (e.g., UNEP, FAO, UN WFP), regional (e.g., SERVIR-Africa, ECOWREX, Africa Soil Information Service), national (SAEON, ILWAC-Mali, Virtual Kenya) repositories and research projects (FP7 Afromaison, FP7 WetWin). It is further connected to the GEOSS Data Core providing discovery and access to a growing number of data for Africa from the global community. Its flexibility enables users to register additional resources simply by entering new endpoints.

The proposed solution appears promising for creating synergies between various environmental related projects in Africa as well as fostering multidisciplinary collaboration/cooperation with environmental institutions (e.g., research, academic) in bringing various African stakeholders (e.g., decision-makers, scientists, local communities) relevant data on the environment.

However, this approach relies on the assumption that data repositories are well documented and may be accessible through the Internet. In order to improve data discoverability, accessibility, and integration, capacity building (at human, institutional, and infrastructure levels) is an essential prerequisite. This can be achieved for example through research collaborations coupled with workshops and trainings and this will help to raise awareness, gain commitments, convince and support African data holders to make their data and metadata available to a larger audience and to unlock the power of data, information, and services for the benefits of the African environment. The AfriGEOSS initiative and the UN-GGIM:Africa are viewed as critical vehicles in raising awareness on the benefits of a solution such as the Africa Discovery Broker.

Acknowledgments
The authors would like to acknowledge the European Commission “Seventh Framework Program” that funded EOPOWER (Grant Agreement no. 603500) and Afromaison (Grant...
Agreement no. 266379) projects. We are grateful to ESSI-Lab of the Institute of Atmospheric Pollution Research (IIA) of the National Research Council of Italy (CNR) who develops the GI-cat software.

A special thank to all data providers whose resources have been registered in the Africa Discovery Broker.

The views expressed in the paper are those of the authors and do not necessarily reflect the views of the institutions they belong to.

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Useful links (accessed March 2015):
URL 1: https://www.servirglobal.net/Africa.aspx
URL 2: http://servirportal.rcmrd.org/
URL 3: http://www.ecowrex.org/mapView/
URL 4: http://africasoils.net/services/data/
URL 5: http://horn.rcmrd.org/
URL 6: http://ags.servirlabs.net/crestviewer/
URL 7: http://www.sasdi.net/
URL 8: http://rcmrd.org/?page_id=4970
URL 10: http://www.masdap.mw
URL 11: http://data.saeon.ac.za/
URL 12: http://servir.rcmrd.org/metacatalog/
URL 13: http://essi-lab.eu/cgi-bin/twiki/view/GIcat/
URL 14: http://www.eurogeoss.eu
URL 15: http://essi-lab.eu/do/view/GIcat/GIcatDocumentation
URL 16: http://afromaison.grid.unep.ch/gi-cat/gi-portal
URL 17: http://www.earthobservations.org/afrigeoss.php
URL 19:
http://www.unidata.ucar.edu/projects/THREDDS/OGC/GatewayToNetCDF.htm