A Hybrid Approach to Disseminate Large Volume Sensor Data for Monitoring Global Change

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Abstract. Monitoring global change is one of the major challenges in the 21st century. It requires accessing large volumes of various data, collected by a multitude of remote and in-situ sensors. Various approaches (file-based, service-based and satellite-based) have demonstrated significant disadvantes, which can be concluded as inappropriate. In this article, we describe a hybrid approach using a satellite-based system for accessing sensor data on distributed nodes and then disseminating the data on the web through web services. The approach is demonstrated based on the satellite-dissemination system of GEONETCast using two use cases for raster-based (MSG2) and feature-based (MODIS) data.

Introduction

Monitoring global change requires various data, collected by a multitude of remote and in-situ sensors worldwide. This large volume of data cannot be disseminated over the web exclusively due to limited bandwidth. Also disseminating it only through satellite systems is not reasonable, due to proprietary standards of the received data (i.e. different file formats), missing concepts for attaching metadata and the costs to receive the data at each node. In this paper a hybrid approach is described, in which central nodes receive the sensor data through a satellite dissemination system and make the data available in a structured, standardized and customizable way through web service interfaces for specific use cases and for a limited number of client applications.

The hybrid approach is presented based on the GEONETCast satellite dissemination system (Wolf & Williams, 2008) as a representative of a satellite-based dissemination system and is using principles of Spatial Data Infrastructures (as a representative approach for organizing geodata in a network-based environment). The hybrid approach results in distributed archives of real-time and historical environmental data, which are accessible on the web.

At our department such a node for disseminating GEONETCast data is under development. The hybrid approach is exemplified by two different use cases focusing a) on publishing meteorological remote sensing data (Schmetz et al., 2002) and b) on publishing data about fire events extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) (Justice et al., 1998). The presented use cases are implemented based on Free and Open Source Software.

This article contributes to the efforts of publishing large volume of data on the web. As the documented research shows (Section 2.3), this has not been fully achieved yet. Therefore, we advocate the use of standards and propose a hybrid approach of satellite-based and web-based data dissemination. Additionally, it contributes to the Persistent Testbed initiative of the Association Geographic Information Laboratories Europe (AGILE), Open Geospatial Consortium (OGC) and the European Spatial Data Research (EuroSDR) for research and teaching (Hobona et al., 2009).

Section 2 provides an overview of state-of-the-art dissemination of large volume sensor data through GEONETCast and the web. Based on the analysis, the hybrid approach is presented (Section 3), which is then demonstrated by two use cases in Section 4. Finally, the article ends with a conclusion.

Related Work

This section summarizes basic concepts of GEONETCast and Web Services. The presented concepts are later on applied to realize the hybrid approach of disseminating large volume of sensor data.

GEONETCast

GEONETCast is a satellite-based dissemination system for environmental data created by remote and in-situ sensors. GEONETCast is a part of the Global Earth Observation System of Systems (GEOSS). In particular, GEONETCast is a task in the Group on Earth Observations (GEO) Work Plan and is led by EUMETSAT, the United States, China, and the World Meteorological Organization (WMO). Many GEO members and participating Organizations contribute to this task. The dissemination of GEONETCast products is managed by regional centers using regional satellite-based dissemination systems:

- FENYUNCast(Asia)
- EUMETCast (Africa & Europe)
- GEONETCast Americas (North and South America).

An overview of the different regional satellite-based dissemination systems and their coverage is depicted in Figure 1.

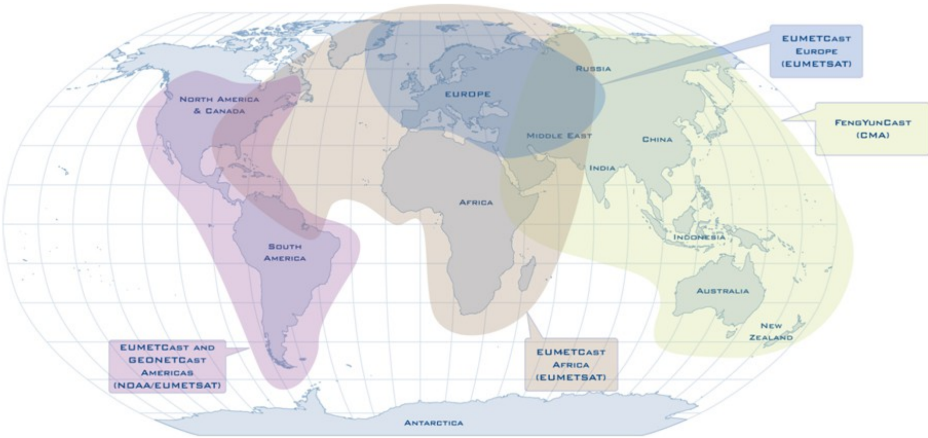

Figure 1: GEONETCast overview (GEO, 2012).

With its over 180 products GEONETCast offers a broad thematic range from spectral transmission and climate measures (i.e. surface temperature, precipitation) to disaster management (e.g. fire monitoring). The data is free for use in research and education. Additional data is available under specific license agreements.

One of the freely available products is MODIS data, which is part of Nasa's Earth Observation System. MODIS provides a set of land surface products, which are described in Justice et al. (1998). In particular, MODIS fire data (MOD14) has been selected for this study and also serves as a basis for other derived products of MODIS.

Another example of available GEONETCast data is Meteosat Second Generation (MSG-2), which consists of 12 channels of which 11 channels have a resolution of 3 kilometers (Schmetz et al., 2002). The 12 channels are collected from visible to infrared spectrum. The raw MSG-2 data received from GEONETCast is transformed into GeoTiff format and can thereby be directly served in state-of-the-art applications and Web Services.

Both data sets are used to examine vector and raster-based data dissemination of GEONETCast data (Section 4).

To receive such GEONETCast products, a common technical setup is available. The setup is depicted in Figure 2 and consists of three steps: receive, store and serve. The GEONETCast groundstation receives the data from the GEONETCast satellites through a standard TV dish (connected through TV-card) and decodes the received data stream. The GEONETCast Toolbox (Maathuis, Mannaerts, & Retsios, 2008) acts as a data manager to filter the desired products, which are then stored in a structured way on the data server. The data server is able to manage user access and serves the data through the file system. It is important to note, that in some setups the data server and the ground receiving station are hosted on the same computer. For the technical setup as used for this implementation these two components are separated on different machines for scalability and maintenance reasons (e.g. the data server has a periodic backup).

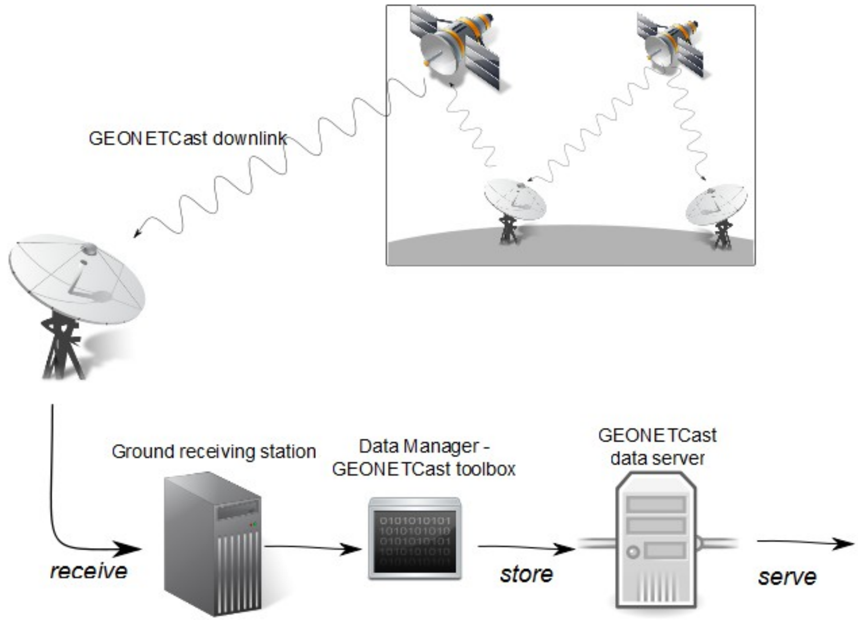

Figure 2: Technical setup to retrieve GEONETCast products.

Based on this technical setup each node can be configured and the required data can be published (Section 3).

Web Services and Spatial Data Infrastructures

Web Services are defined as self-describing components, providing functionality and data on the web through a common interface (Alonso, Casati, Kuno, & Machiraju, 2004). A major aspect is thereby the encoding of metadata for the functionality as well as for data. To share geodata between organizations of different countries, as for instance described by the INSPIRE directive (INSPIRE, 2007), Spatial Data Infrastructures (SDIs) are created. They aim at integrating different data and heavily depend on Web Services and sufficient metadata. Geospatial Web Services are specified by the Open Geospatial Consortium (OGC) (Kralidis, 2007). The three OGC web service interfaces for disseminating raster-based data (Web Coverage Service) and vector-based data (Web Feature Service) as well as the portrayal of the data (Web Map Service) are described.

Web Coverage Service

To serve coverage data on the web as for instance mostly provided by GEONETCast, the Web Coverage Service (WCS) has been specified (OGC, 2006). It allows users to query coverage data and especially grid data regarding multiple aspects (space, time and channel). To interact with a WCS instance, three operations are required. *GetCapabilities* provides the service metadata and describes the different data available at the specific instance. To retrieve further information about a specific dataset, *DescribeCoverage* can be called by the client. The returned metadata describes the coverage including the following parameters (with OGC parameter names):

- extent (spatial domain)
- temporal resolution (temporal domain)
- the geographic layout of the grid (GridCRS)
- available channels (Axis).

Based on this metadata *GetCoverage* can be called to retrieve the designated data. Such coverage data can for instance be encoded in GeoTiff format (Ritter & Ruth, 1997).

Web Feature Service

Web Feature Service (WFS) interface allows users to query and access feature data consisting of (multiple) points, lines or polygons (OGC, 2005). The communication with WFS is based on the Internet Protocol HTTP using an XML-based encoding the so-called WFS Filter encoding. To retrieve specific features from a WFS, the getFeature operation is used, which receives messages as WFS Filters. WFS returns feature data (as result of the WFS Filter query) in the Geography Markup Language (GML) or also for instance in KML. KML is the data encoding established and used by Google-based applications. To also create and store new features on a WFS over the Web, a transactional interface has been developed. The additional operations of the so-called WFS-T (T stands for transactional) are insert, update, delete.

Web Map Service

To portray the data through a Web Service the OGC specified the Web Map Service (WMS) (OGC, 2004). It delivers plain images depicting the selected aspect of the geodata. For the given study, WMS is used, as it allows users to portray the data without downloading it.

Web-based GEONETCast Products

Related work about enabling GEONETCast data for the web has been reported by Davies, Ilavajhala, Wong, & Justice (2009). They also used MODIS data for monitoring fires and served this data on the Web. However, their setup involved a lot of manual steps and the access to the data was limited to portrayal (no querying possible). Additionally, the Center for Weather Forecast and Climatic Studies (CPTEC) of the National Institute for Space Research in Brazil (INPE) provides a web portal to access data about fire events. This portal only provides limited querying capabilities and does not allow users to integrate the data available in the portal into other applications.

Some attempts about enabling MSG-2 for web-based access have been reported. For instance Carvalheiro, Bernardo, Orgaz, & Yamazaki (2010) describe a web-based dissemination system using a web page, displaying the data in a browser-based map viewer (Google Maps).

The presented review shows, that a hybrid approach for disseminating this kind of data is missing. Moreover, interoperability only plays a little role in the documented attempts. The presented architecture in this article is more comprehensive regarding both aspects, as it is based on live streaming of data through GEONETCast using Web Service interfaces. These Web Service interfaces allow users to query the data and also to integrate it into other applications such as Google Earth. Finally, the described implementation is based on Free and Open Source Software and can be re-built with low cost, if required.

Approach

The hybrid approach for dissiminating large volume of sensor data, consists of two tasks. One task is to receive the data at a designated node using the technical setup described in Section 2.2. This node is configured with a satellite dish and stores designated data received from for instance GEONETCast on the data server. The other task is to dissiminate this data on the web. The hybrid approach is depicted in Figure 3. Since GEONETCast data is provided in different file formats (e.g. plain text, GeoTiff) a format conversion may be necessary to enable standardized access. The dissemination of GEONETCast data on the web requires sufficient metadata and can be seen as the main advantage of the hybrid approach, as at the receiving nodes, metadata for the products is not directly available. Additionally, the web service allows users to access the data in a customized way. In particular, users are able to query the data using spatial and temporal filters. This is an additional advantage over the file-based access provided by the receiving station. A customized access can be based on standards as described by the OGC (Section 2.2). Based on these standards the data is directly accessible from existing applications. Using such existing applications and standards allows users to integrate this data with other sources for monitoring global change.

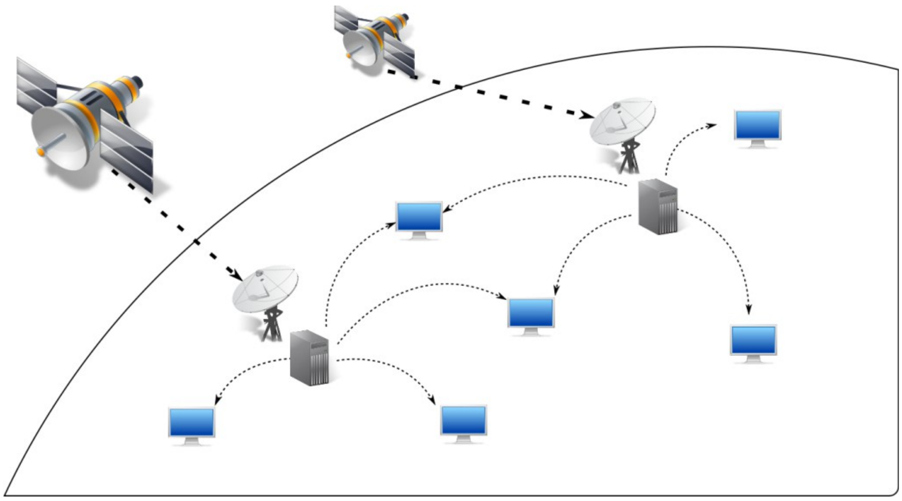

Figure 3. Overview of the hybrid approach.

Operating these nodes over the long term, allows users to access an archive of data, which has suitable metadata attached and which allows users to monitor global change on a spatio-temporal scale. The creation of metadata is initiated once and is updated constantly by the Web Service automatically.

The Web Service endpoints for the designated GEONETCast data, can also be used as input for existing Web Services, that for instance provide web-based geoprocess models. The Web Service endpoints for GEONETCast data as well as the available geoprocess models, can be made available through cloud computing (Foster, Zhao, Raicu, & Lu, 2008) to provide designated quality of service.

Different nodes can be configured to serve different data, thereby it is possible to set up a distributed network of web services for GEONETCast data. Serving only the required data through specific nodes also allows the providing organizations to scale their data services. Finally, client applications can retrieve different GEONETCast data from different nodes based on suitable metadata over the web and integrate such data with other sources to monitor global change.

In comparison to the existing approaches which are documented in Section 2.3, the presented approach has several advantages:

- Complete – The approach has been demonstrate for the two types of data, vector and raster-based. Thereby, it is complete in comparison to the other approaches, which either focus on one of the two, nor give full access to the data itself.
- Scalable & distributed – Due to the distributed nature of the nodes, the approach is scalable. Different applications will use different nodes, moreover the distribution supports novel techniques of distributed processing such as MapReduce (Cary, Sun, Hristidis, & Rishe, 2009).
- Standardized – As the distributed nodes are accessible through standardized web service interfaces serving data in standardized formats, the data and services can be integrated seamlessly in a wide range of applications.
- Extensible – Based on the distributed and standardized nature of the approach, the nodes can be extended with additional logic and capabilities (e.g. caching, cloud computing) to reduce performance bottlenecks, if applicable. Additionally, the nodes can be individually enhanced to support additional data formats.

Use Cases

The described approach is examined based on two use cases, which are implemented as part of the GEONETCast node at our faculty. In the first use case, meteorological remote sensing data is available through a browser-based application (Foerster, Trame, & Remke, 2010). In the second use case, MODIS data received from GEONETCast is processed to extract data about potential fire events (Foerster, Fechner, Fritze, Loock, & Remke, 2010).

1.1 Web-based Meteorological Data

Meteorological data supports many types of analysis. Often this data needs to be up-to-date to take appropriate decisions. Thus accessing up-to-date meteorological data on a global scale is a requirement of many users. In this use case, up-to-date MSG-2 data received from GEONETCast data stream is made web-accessible through WCS interface. The WCS instance serves only 11 of the 12 available channels, as GeoTiff format can only handle different channels with equal resolutions, thus the 12th band (high resolution visible light) cannot be included (resolution 1 kilometer).

The data server was connected directly to the WCS instance. We chose the Map Server software[1] as the Geospatial Web Service product. Map Server allows us to serve the data through WCS interface (data access) as well as WMS interface (data portrayal). Users are thereby able to inspect the data (using WMS interface) without downloading it. An example of a browser-based application accessing the data through WMS interface is given in Figure 4. The browser-based application allows the user to specify the data regarding time, geographic extent and specific channel. In the given example, data of hurricane Karl in the Gulf of Mexico in September 2010[2] is portrayed (based on channel 1 of MSG data collected at visible spectrum). The user can now select a geographic extent on the map, of which he wants to receive data. Based on this selection, the browser-based application generates a WCS-compliant URL, which can be used to download the designated coverage from the WCS instance. This URL can be used as input for web-based geoprocess models for performing geochange research.

This service can also be integrated into other applications based on the standardized WCS interface. For designated applications metadata is available through WCS DescribeCoverage operation. Based on this metadata the application can integrate the data accordingly through WCS GetCoverage operation.

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1 Map Server website: www.mapserver.org.

2 Timestamp: 17th September 2010, 12:00.

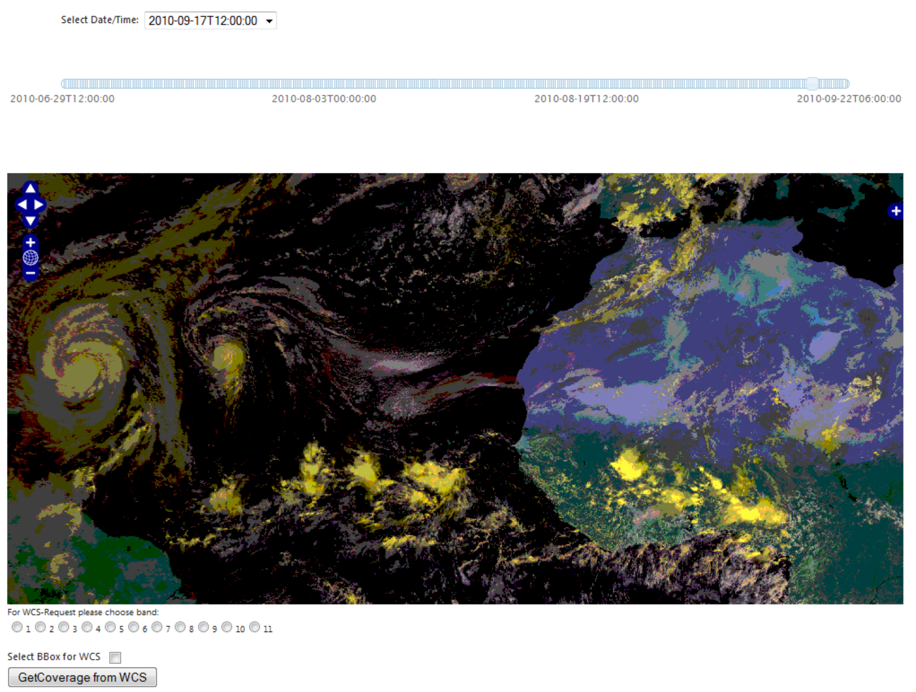

Figure 4: Screenshot of the browser-based client accessing meteorological data from GEONETCast depicting hurricane Karl in the Gulf of Mexico in September 2010.

Web-based Fire Web Service

Fire is a natural phenomenon and poses a threat especially when reaching built-up areas. Although it is a natural hazard a rigorous suppression leads to even more severe fires. Using fire for cultivating agricultural land has become an established element. However, an excessive application also leads to severe problems. Finally, monitoring such fires is required and different data is already available such as the MODIS fire products [Justice et al. 2002].

The fire events extracted from MODIS data are available as point-based data. For easy and customized access of this data, Web Service technology is used. To demonstrate the use case, an interoperable architecture (based on OGC standards) is applied to monitor fire events. In particular, a WFS-T is constantly updated with extracted point-based data from MODIS imagery served by GEONETCast. Users can access and query the data through a browser-based client and can use e.g. Google Earth to combine the data with other sources.

The browser-based application allows users to integrate the fire data with other third party sources such as Wikipedia or images from for instance Panoramio. Integrating the data with other third party sources is necessary to provide comprehensive information to the user and is possible due to established standards for data and Web Services. An example of the browser-based application is depicted in

Figure 5. The different parts of the interface are attached to the several tasks, which are described in the following:

Query data - The user is able to query the fire data available on the Fire Web Service based on its attributes (including time). By querying the temporal dimension, it is possible to not only receive up-to-date data about fire events, but also historic data. Another important attribute is the confidence value of a fire event, which indicates the possibility of a fire. The confidence value is a result of the applied fire detection algorithm performed on the MODIS data.

Map data - The result of the query can be inspected in the map view, in which the fire events are located on freely-available imagery such as from Blue Marble [Stockli et al. 2005]. Each fire event on the map can be clicked for further details.

Inspect attribute table - Based on the query, the data can also be inspected using a tabular view.

The fire data can also be integrated into Google Earth by KML format as supported by the WFS interface. The attributes of the fire can be inspected directly by the user. However, a query mechanism for the data such as provided by the browser-based application is not available.

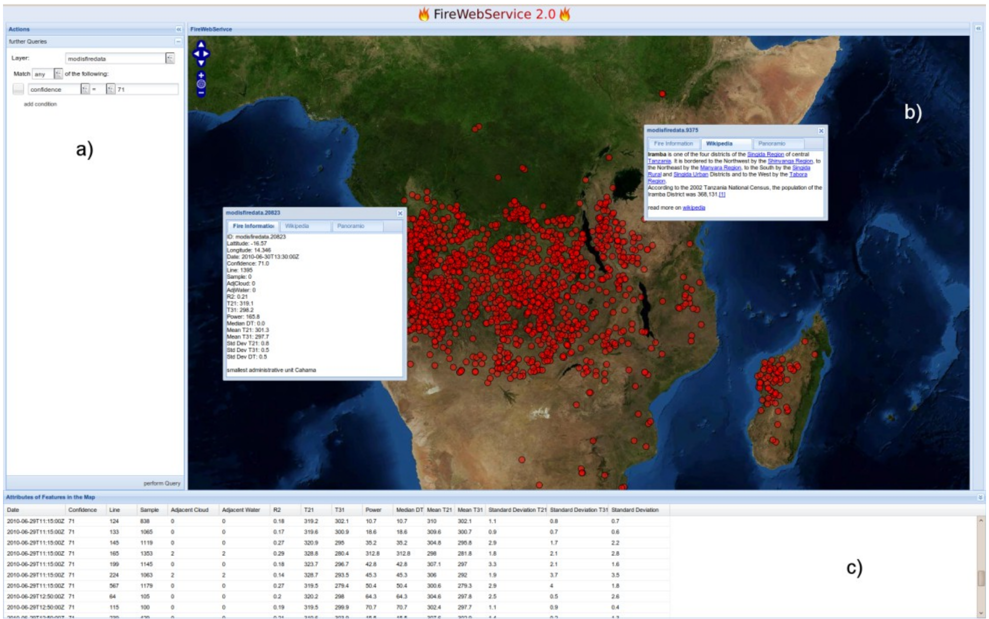

Figure 5: Screenshot of the browser-based application for the Fire Web Service with map of sub-Sahara region - different views: a) query view, b) map view, c) tabular view.

Conclusion

In this article we describe a hybrid approach for disseminating large volume of sensor data based on a satellite-based dissemination system such as GEONETCast and the web. The data is received from the satellite system at distributed nodes and disseminated on the web through web service interfaces. This allows to overcome the bottleneck of central services, which need to serve all data on the web, but also to operate cost-efficient, as the receiving node can share the data with other nodes at no costs. Additionally, the use of interoperable web service interfaces allows us to provide the data with appropriate metadata and allows users to directly integrate the data into existing applications for research on global change.

The hybrid approach has been demonstrated based on two use cases (Section 4) for disseminating raster- and vector-based data (Foerster, Fechner, et al., 2010; Foerster, Trame, et al., 2010). The use cases have been implemented using Free and Open Source Software.

Future research needs to evaluate the performance and scalability of the hybrid approach by implementing additional use cases with a broader user community as for instance the Persistent Testbed initiative. For extracting specific information products out of the web-enabled GEONETCast data, web-based processing needs to be integrated. In particular, processing the available data using web-based functionality available OGC Web Processing Service interface needs to be investigated (Foerster, Schaeffer, Baranski, & Brauner, 2011). To ensure performance of web-based processing of GEONETCast data, mechanisms such as caching and streaming of geodata need to be considered. Additionally, new methods for discovery and automated metadata creation are required for sharing of GEONETCast data across the web. Discovery has become more crucial considering the presented hybrid approach as specific content is only available at selected nodes.

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