Open Geospatial Consortium

Publication Date: 2014-10-14

Approval Date: 2014-08-17

Posted Date: 2014-06-26

Reference number of this document: OGC 14-028r1

Reference URL for this document: http://www.opengis.net/doc/ER/testbed10/cloud-performance

Category: Engineering Report

Editors: Edric Keighan, Benjamin Pross, Hervé Caumont

Testbed 10 Performance of OGC® Services in the Cloud: The WMS, WMTS, and WPS cases.

Document type:	OGC® Engineering Report
Document subtype:	NA
Document stage:	Approved for public release
Document language:	English

License Agreement

Permission is hereby granted by the Open Geospatial Consortium, ("Licensor"), free of charge and subject to the terms set forth below, to any person obtaining a copy of this Intellectual Property and any associated documentation, to deal in the Intellectual Property without restriction (except as set forth below), including without limitation the rights to implement, use, copy, modify, merge, publish, distribute, and/or sublicense copies of the Intellectual Property, and to permit persons to whom the Intellectual Property is furnished to do so, provided that all copyright notices on the intellectual property are retained intact and that each person to whom the Intellectual Property is furnished agrees to the terms of this Agreement.

If you modify the Intellectual Property, all copies of the modified Intellectual Property must include, in addition to the above copyright notice, a notice that the Intellectual Property includes modifications that have not been approved or adopted by LICENSOR.

THIS LICENSE IS A COPYRIGHT LICENSE ONLY, AND DOES NOT CONVEY ANY RIGHTS UNDER ANY PATENTS THAT MAY BE IN FORCE ANYWHERE IN THE WORLD.

THE INTELLECTUAL PROPERTY IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NONINFRINGEMENT OF THIRD PARTY RIGHTS. THE COPYRIGHT HOLDER OR HOLDERS INCLUDED IN THIS NOTICE DO NOT WARRANT THAT THE FUNCTIONS CONTAINED IN THE INTELLECTUAL PROPERTY WILL MEET YOUR REQUIREMENTS OR THAT THE OPERATION OF THE INTELLECTUAL PROPERTY WILL BE UNINTERRUPTED OR ERROR FREE. ANY USE OF THE INTELLECTUAL PROPERTY SHALL BE MADE ENTIRELY AT THE USER'S OWN RISK. IN NO EVENT SHALL THE COPYRIGHT HOLDER OR ANY CONTRIBUTOR OF INTELLECTUAL PROPERTY RIGHTS TO THE INTELLECTUAL PROPERTY BE LIABLE FOR ANY CLAIM, OR ANY DIRECT, SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES, OR ANY DAMAGES WHATSOEVER RESULTING FROM ANY ALLEGED INFRINGEMENT OR ANY LOSS OF USE, DATA OR PROFITS, WHETHER IN AN ACTION OF CONTRACT, NEGLIGENCE OR UNDER ANY OTHER LEGAL THEORY, ARISING OUT OF OR IN CONNECTION WITH THE IMPLEMENTATION, USE, COMMERCIALIZATION OR PERFORMANCE OF THIS INTELLECTUAL PROPERTY.

This license is effective until terminated. You may terminate it at any time by destroying the Intellectual Property together with all copies in any form. The license will also terminate if you fail to comply with any term or condition of this Agreement. Except as provided in the following sentence, no such termination of this license shall require the termination of any third party end-user sublicense to the Intellectual Property which is in force as of the date of notice of such termination. In addition, should the Intellectual Property, or the operation of the Intellectual Property, infringe, or in LICENSOR's sole opinion be likely to infringe, any patent, copyright, trademark or other right of a third party, you agree that LICENSOR, in its sole discretion, may terminate this license without any compensation or liability to you, your licensees or any other party. You agree upon termination of any kind to destroy or cause to be destroyed the Intellectual Property together with all copies in any form, whether held by you or by any third party.

Except as contained in this notice, the name of LICENSOR or of any other holder of a copyright in all or part of the Intellectual Property shall not be used in advertising or otherwise to promote the sale, use or other dealings in this Intellectual Property without prior written authorization of LICENSOR or such copyright holder. LICENSOR is and shall at all times be the sole entity that may authorize you or any third party to use certification marks, trademarks or other special designations to indicate compliance with any LICENSOR standards or specifications.

This Agreement is governed by the laws of the Commonwealth of Massachusetts. The application to this Agreement of the United Nations Convention on Contracts for the International Sale of Goods is hereby expressly excluded. In the event any provision of this Agreement shall be deemed unenforceable, void or invalid, such provision shall be modified so as to make it valid and enforceable, and as so modified the entire Agreement shall remain in full force and effect. No decision, action or inaction by LICENSOR shall be construed to be a waiver of any rights or remedies available to it.

None of the Intellectual Property or underlying information or technology may be downloaded or otherwise exported or reexported in violation of U.S. export laws and regulations. In addition, you are responsible for complying with any local laws in your jurisdiction which may impact your right to import, export or use the Intellectual Property, and you represent that you have complied with any regulations or registration procedures required by applicable law to make this license enforceable

Preface

For many years the OGC has been developing a suite of web service standards for geospatial processing. The suite includes a web map service (WMS), a web map tiling service (WMTS), a web feature service (WFS), a web coverage service (WCS), a web processing service (WPS), a web catalogue service (CS-W), and others. These service standards have been widely adopted and deployed across the world but little information has filtered out regarding the performance and scalability of products based on OGC standards. Easy access to large IT computing resources such as the Amazon EC2 Cloud infrastructure provides an opportunity to use a flexible and low cost IT resource environment to investigate the performance and scalability of products based on OGC standards. This document presents the web mapping and other geo-processing use cases as a way to characterize the performance of OGC data services deployed in Cloud infrastructures.

A key use case investigates the performance characteristics of web mapping using OGC WMS and WMTS services from imagery deployed in an Amazon environment. It covers access to maps only and meets the needs of most geospatial data providers wishing to publish their geospatial data to the largest possible number of map users through OGC web map services.

Contents

Figures

Tables

OGC® Performance of OGC Services in the Cloud

1 Introduction

1.1 Scope

This document characterizes the performance and scalability of OGC data services in the Cloud. Three use cases highlighting different geo-processing aspects of OGC data services have been developed, implemented, and benchmarked. Each use case is presented in a separate section of this document with performance results and discussions.

This document contains useful information for any organization anticipating the deployment of OGC data publishing services in an operational environment supported by a Cloud infrastructure. It is important to note that Cloud service costs and business models applied to the use of Cloud infrastructures are out-of-scope for this project.

1.2 Document contributor contact points

All questions regarding this document should be directed to the editor or the contributors:

Name	Organization	Email Address
Edric Keighan	CubeWerx Inc.	ekeighan [at] cubewerx.com
Benjamin Pross	52North	b.pross [at] 52north.org
Hervé Caumont	Terradue	herve.caumont [at] terradue.com

1.3 Revision history

Date	Release	Editor	Primary clauses modified	Description
21/02/2014	Rev1	E. Keighan		Creation of the document & section 1
21/02/2014	Rev1	B. Pross		Creation of section 2
14/04/2014	Rev1	H. Caumont		Creation of section 3
14/04/2014	Rev2	E.Keighan		Completion & revision of section 1
22/04/2014	Rev2	B. Pross		Completion & revision of section 2
29/04/2014	Final	H. Caumont		Completion & revision of section 3
30/04/2014	Final	E. Keighan		Final revision of the document
6/24/2014	Rev5	R. Singh	Multiple	Staff edit based on PC guidance

1.4 Future work

1.4.1 Performance of OGC WMS and WMTS in the Cloud (Section 1)

Cloud infrastructures offer geospatial data providers a unique opportunity to reduce their technology risks, reduce operational costs, promote the use of open and interoperable interfaces and deploy enterprise-wide geospatial services and very large geospatial solutions in a collaborative and distributed environment.

Section 1 of this document identified future improvements on additional testbed activities in the following Cloud infrastructure areas:

- Explore deployment of collaborative geo-processing services such as collaborative WMTS services. Of interest are the anticipated potential benefits from:
    - ✓ Deploying large distributed geospatial services.
    - ✓ Collaborative maintenance of geospatial services.
    - ✓ Incremental updates to imagery services.
- Explore and demonstrate an optimal business costing model to reduce computer costs by a group of partner organizations interested in exchanging geospatial data and sharing geospatial services.

1.4.2 Performance enhancements of Geodata processing using a Hybrid Cloud (Section 2)

Section 2 of this document identified future improvements on conducting additional Hybrid Cloud tests. The benchmarks conducted with the Hybrid Cloud were initial basic tests. The test results could be diversified using different test set-ups. Another public cloud provider could be used and the performance of the Hybrid Cloud could be tested between the different cloud providers. Also we envision the use of raster datasets for the tests. In general, the processes used in the Hybrid Cloud could be examined for their fitness to be parallelized, so that single requests could be split up in sub-tasks that each could be send to a dedicated WPS instance in the Cloud. This could further boost performance.

Major issues in Cloud Computing are security and trust aspects. Data needs to be stored in a secure way and also the execution of a process needs to be constrained if it uses sensible data. Suitable methods to enable secure and trusted processing of data in the Cloud need to be investigated.

1.4.3 Performance enhancements of DinSAR processing using a Hybrid Cloud (Section 3)

Section 3 of this document identified future improvements by investigating the use and benefits of a Cloud infrastructure in support of multi-tenant geospatial services deployments. This encompasses use of Service Level Agreements and Cloud Marketplaces for selection and on-demand deployment of Cloud Services.

1.5 Forward

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

Amazon S3 (http://aws.amazon.com/s3/)

Baranski, B., Foerster, T., Schäffer, B. and Lange, K. (2011), Matching INSPIRE Quality of Service Requirements with Hybrid Clouds. Transactions in GIS, 15: 125–142. doi: 10.1111/j.1467-9671.2011.01265.x

Differential Interferometry Synthetic Aperture Radar (http://www.irea.cnr.it/en/index.php?option=com_k2&view=item&id=77:differential-interferometry-synthetic-aperture-radar&Itemid=139)

INSPIRE Network Services Drafting Team (2009). Draft Technical Guidance for INSPIRE Coordinate Transformation Services. Available online: http://inspire.jrc.ec.europa.eu/documents/Network_Services/INSPIRE_Draft_Technical_Guidance_Coordinate_Transformation_(Version_2.0).pdf (accessed 2014-01-28)

OGC Blog "Accessing the Cloud with OGC Services" (http://www.opengeospatial.org/blog/1866)

OGC Web Map Service (WMS) Interface Standard (http://www.opengeospatial.org/standards/wms)

OGC Web Map Tile Service (WMTS) Interface Standard (http://www.opengeospatial.org/standards/wmts)

OGC Web Processing Service (WPS) Interface Standard (http://www.opengeospatial.org/standards/wps)

OGC® Web Services Common Standard (http://www.opengeospatial.org/standards/common)

OGC® OpenSearch Geo and Time Extensions (http://www.opengeospatial.org/standards/opensearchgeo)

Schäffer, B. (2011). Cloud Computing as a means to reach Inspire Performance Requirements. Presentation at the AGILE 2011. Available online: http://sdi-testbed.eu/index.php?option=com_docman&task=doc_download&gid=55&Itemid=8 (accessed 2014-01-28)

3 Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard [OGC 06-121r3] shall apply. In addition, the following terms and definitions apply.

3.1
attribute
<XML>
name-value pair contained in an element
[ISO 19136:2007]
Note: In this document an attribute is an XML attribute unless otherwise specified.

3.2
association
named or typed connection between two web resources

3.3
client
software component that can invoke an operation from a server
[ISO 19128:2005]

3.4
coordinate
one of a sequence on n numbers designating the position of a point in n-dimensional space
[ISO 19111:2007]

3.5
coordinate reference system
coordinate system that is related to an object by a datum
[ISO 19111:2007]

3.6
coordinate system
set of mathematical rules for specifying how coordinate are to be assigned to points
[ISO 19111:2007]

3.7

element

<XML>

basic information item of an XML document containing child elements, attributes and character data

[ISO 19136:2007]

3.8

feature

abstraction of real world phenomena

[ISO 19010:2002]

NOTE: A feature can occur as a type or an instance. The term “feature type” or “feature instance” should be used when only one is meant.

3.9

feature identifier

identifier that uniquely designates a feature instance

3.10

filter expression

predicate expression encoded using XML

[ISO 19143]

3.11

Harvest operation

an operation defined by the CSW standard that may be used to automatically register resources (e.g. services) with the catalogue

3.12

interface

named set of operations that characterize the behavior of an entity

3.13

link

synonym for association

3.14

link relation

identifies the semantics of a link

NOTE: Typically specified using the “rel” attribute of a link or association

3.15

namespace

<XML>

collection of names, identifier by a URI reference which are used in XML documents as element names and attribute names

[W3C XML Namespaces]

3.16

operation

specification of a transformation or query that an object may be called to execute
[ISO 19119:2005]

3.17

property

face or attribute of an object, referenced by name
[ISO 19143]

3.18

response

result of an operation returned from a server to a client
[ISO 19128:2005]

3.19

server

particular instance of a service
[ISO 19128:2005]

3.20

service

distinct part of the functionality that is provided by an entity through interfaces
[ISO 19119:2005]

3.21

service metadata

metadata describing the operations and geographic information available at a server
[ISO 19128:2005]

3.22

Uniform Resource Identifier

unique identifier for a resource, structured in conformance with IETF RFC 3986
[ISO 19136:2007]
NOTE: The generate syntax is <scheme>::<scheme-specified-part>. The hierarchical syntax with a namespace is <scheme>://<authority><path>?<query>

3.23

web resource

referent of any uniform resource identifier (see RFC 3986), or internationalized resource identifier (see RFC 3987).

4 Conventions

4.1 Abbreviated terms

API	Application Program Interface

AWS	Amazon Web Services
CSW	Catalogue Service Web
EBS	Elastic Block Storage
EC2	Elastic Cloud Compute
EC	European Commission
ESA	European Space Agency
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
DInSAR	Differential Synthetic Aperture Radar Interferometry
GSS	GeoSynchronization Service
IaaS	Infrastructure as a Service
INSPIRE	Infrastructure for Spatial Information in Europe
ONe	OpenNebula
PaaS	Platform as a Service
SaaS	Software as a Service
SSEP	SuperSites Exploitation Platform
URL	Uniform Resource Location
URI	Uniform Resource Identifier
VM	Virtual Machine
WMS	Web Map Service
WMTS	Web Map Tiling Service
WFS	Web Feature Service
WCS	Web Coverage Service
WPS	Web Processing Service

5 Performance of OGC Services in the Cloud

This document is composed of three (3) sections. Each one presenting a particular geo-processing use case with its own methodology, assumptions, deployment configurations, and the use of independent Cloud software and hardware resources.

The topics covered in the three sections are:

- Section 1 - Performance of OGC WMS and WMTS data services in the Cloud.

- Section 2 - Performance enhancements of Geodata processing using a Hybrid Cloud in the context of INSPIRE
- Section 3 - Performance enhancements of DinSAR processing using a Hybrid Cloud in the context of GEOSS

5.1 Performance of OGC WMS and WMTS data services in the Cloud (Section 1)

In recent years we have observed a significant shift in the use of spatial data. Needs for spatial data today are multi-disciplinary in scope, travel far from surveyors and GIS professionals alone, and often include business IT systems and link a myriad of users from truck drivers to mayors to scientists in their paths. Many of the ‘new’ geospatial firms consider themselves to be part of the information technology industry, rather than GIS.

As data provider organizations are being pressured to publish more geospatial data over the web to larger audiences, there is a need to investigate the performance and scalability of OGC data services in support of more robust and operational geospatial services.

This use case explores the performance behavior of accessing OGC WMS and WMTS services in a Cloud environment. After many years of effort and large investments from many OGC sponsors across the world, it is still unclear how the performance of products based on OGC data service standards match up with other mapping services in the market such as those from Google or Microsoft. How would an interoperable and decentralized business model using OGC data services compare with a centrally managed and proprietary infrastructure? Considering that organizations across the world have invested large sums of money into deploying OGC data services over the last 10 years, it is surprising to note the lack of leadership in deploying large scale operational systems using OGC data services in a distributed computing environment. This Engineering Report sheds some light on the performance and scalability issues encountered when deploying OGC Web mapping services in a Cloud infrastructure.

For OGC Testbed 10, Amazon, Inc. donated the resources of their Amazon Web Services (AWS) cloud offering for these purposes.

5.1.1 Introduction

One objective of the OGC Testbed 10 is to explore the state of the art in geospatial Cloud computing. One aspect of the requirements is the use of OGC data services through Cloud infrastructures like AWS, and the need to investigate the performance and scalability of OGC-compliant Geospatial services.

CubeWerx deployed a set of OGC core data services in the AWS infrastructure and measured the performance and scalability of those services using a stress-tester tool developed for this project. OGC WMS and WMTS data services were deployed in AWS and a number of performance statistics were gathered that are particularly useful to data provider organizations and particularly revealing of the capacity of the Cloud.

This Engineering Report describes the project plan, methodology, assumptions, benchmarking activities, and performance results. The intent of this project is to shed some light on the performance of well-known OGC web map services when deployed in the Cloud. Cost benefits are also inherent in the use of such a Cloud infrastructure, but no efforts have been made in this project to quantify such benefits or investigate an optimal business model for exchanging geospatial data in the Cloud.

5.1.2 Project plan

The project plan was as follows:

a) deploy OGC-compliant WMS and WMTS data services in AWS using two different but well known system configurations

b) evaluate and compare the performance and scalability of the data services for each configuration, and

c) discuss the results and trade-offs that should be considered when deploying OGC data services in the Cloud..

The use of two system configurations is possible because AWS allows for multiple data storage solutions. One solution is designed to support traditional file systems with direct disk-attached storage and the other is based on network storage available as a web service (network attached storage). Each system configuration relies on the use of different Cloud resources delivering different performance and scalability characteristics.

The first system configuration, the one that supports traditional file system usage uses an Amazon Elastic Compute Cloud (EC2) with storage provided by the Elastic Block Storage (EBS) service. This configuration mimics the use of traditional computing resources deployed at existing geospatial provider sites. With this configuration, disk storage resources are directly attached to a virtual machine. In an AWS infrastructure, this corresponds to the usage of EBS disk storage mounted directly to a specific EC2 instance such as the c3.8xlarge EC2 instance type.

The second system configuration uses Amazon EC2 with Simple Storage Service (S3) resources, Amazon S3. With this configuration, AWS is offering network attached storage for accessing geospatial data. With this configuration, developers can benefit from the large bandwidth and caching infrastructure deployed by Amazon to support access to very large volumes of data. But contrary to the EBS, where access to the data is performed using a standard file I/O system, the second system configuration uses a cloud object store called Simple Storage Service (S3). This storage infrastructure uses a web API to interface with the data (not a standard file I/O system). Amazon S3 provides a simple web-services interface that can be used to store and retrieve any amount of data, at any time, from anywhere on the web. It provides developers with access to the same highly scalable and durable infrastructure that Amazon uses to run its own global network of web sites. S3 can be used simply as storage, or as a replacement for traditional file systems, but best practice for S3 is to support both read and write operations directly from a client application.

The use of a web interface for accessing data may cause performance latencies for any intensive read and write operations. The slowness of read and write operations may also cause data inconsistencies for large volume transactions and synchronized update operations. In practice, the use of a large network-based storage system optimized for user proximity offers the potential to scale OGC data services, meet performance and scalability requirements of large and small data providers and support large numbers of concurrent users at much lower costs than a typical direct disk-attached storage system. Because most OGC standards are web services, they are well adapted to perform in the web services environment of the Cloud. It is also important to note that the slowness of I/O operations and performance latencies can be mitigated by the use of parallel asynchronous operations.

The S3 system configuration also offers the possibility of deploying a large network of caching nodes that can deliver data and achieve performance that is on par with that of high-volume offerings such as Google Maps and Bing Maps. The S3 system can also be optimized based on the proximity of the user to the network node hosting the data. Compared with the typical direct disk-attached storage system, the S3 configuration is more scalable for access but will require software service oriented architecture design changes and a re-design of geo-processing operations that deal with changes to the data. Static data services with no changes to the data are not affected by an S3 configuration. In practice an S3-based system should scale up and serve a much larger user-base when compared to a direct disk-mounted system configuration.

5.1.3 Performance and Scalability Use Case - Access to OGC map services

This use case investigates the performance characteristics of web mapping using OGC WMS and WMTS services from imagery deployed in an Amazon environment. It covers access to maps only and meets the needs of most geospatial data providers wishing to publish their geospatial data to the largest possible number of map users through OGC web map services. Performance testing based on incremental updates to images (data currency use case) was considered out-of-scope for this project.

While there is a certain subjectivity and variability in how people may use a map service, we made some assumptions and developed a methodology to support all our performance tests. Our focus was on determining the capacity of a single AWS virtual machine to support a very large number of concurrent users without relying on additional artifice or scalability methods such as load balancers, sharing the data, Amazon Content Distribution Network (CloudFront), data caching by software applications or by the Amazon network storage system. Our focus was on identifying limitations of a single virtual computer, and comparing the two system configurations for their ability to support scalable solutions and serve a large number of concurrent map users. Our overall objective is to support data publishing requirements by keeping the deployment of OGC services in the Cloud simple, reduce publishing costs by using simple out-of-the-box Cloud infrastructure capabilities and promote the use of open and interoperable geospatial services solutions through the use of OGC standards.

5.1.4 Assumptions and methodology

To respond to the “access to OGC map services” use case, assumptions were made regarding how end-users access OGC map services with client software applications. More specifically, a model for accessing maps was developed and a method for simulating large numbers of concurrent users was implemented. The objective was to stress the map server by emulating continuous access from a large number of concurrent users, gather statistics, and report our findings. The following assumptions were made regarding the methodology used for the tests:

- The duration of the test – A period of 10 minutes was selected for the duration of any test. This time period was considered sufficient for the virtual machine to achieve stable conditions allowing us to monitor the behavior characteristics of the VM.

- Numbers of concurrent users – A number of tests were conducted using an incremental number of users in order to understand the physical limits of a single Virtual Machine and determine the ability of the VM to deliver maps to concurrent users within acceptable time limits. Tests were performed using 10, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1,000, 1,200, 1,400, 1,600, 1,800, 2,000, 2,200, 2,400, 2,600, 2,800, 3,000, 3,500, 4,000, 4,500, 5,000, 5,500, 6,000, 8,000, 10,000 and 20,000 concurrent users. A test with 81,000 concurrent users was also performed with the S3 system configuration. For each test performance statistics were recorded.

- Acceptable response time from the map server – The acceptable response time from the server was established at 2 seconds or less.

- Statistics captured during the test – For each test, the following statistical information was captured:

    - Number of concurrent users
    - Total number of map requests sent to the map server
    - % of acceptable requests (less than 2 min.) satisfied by the map server
    - Number of map requests satisfied per sec.
    - Avg. map response time in sec.
    - Avg. number of bytes received per map request
    - Avg. first byte received in sec.

    - Max first byte received in sec.
    - Highest observed request load average
    - Server bandwidth usage (MB/sec.)

- Concurrent users for the test – For each test, users were added incrementally to the test. This was done to avoid an initial overloading condition on the VM. Each user was added to the VM within a period that corresponds to 10% of the duration of the test. (i.e. for the 1,000 concurrent users test, one user was added to the test every 0.06 sec.).

- Generation of map requests – For all tests, each map request was generated randomly by a custom stress-tester tool within a window covering 95% of the image data set. Each request was randomly generated from each user every 4 seconds. Each map request was issued within a large geographic region at one of the selected multiple resolutions. No caching mechanisms were used and all cache images that were temporarily generated during the test by the client application and the web server were cleared after each test.

- Distribution of map requests – For all tests, each map was generated following a known distribution of map requests based on image resolution. The map request distribution was selected to match a typical map request pattern from someone using a GIS or a web browser application for accessing maps from an OGC-compliant map server:
    - 30% of map requests were selected between 0.5m and 4m (per pixel),
    - 40% of map requests were selected between 4m and 50m, and
    - 30% of map requests were selected between 50m and 850m.

5.1.5 Use of Cloud computing resources

Assumptions were made regarding the use of resources required for the project.

For the “EBS configuration”, we used the following resources:

- A “c3.8xlarge” EC2 instance (64 bit) with 18TB of standard direct disk-attached EBS storage. Because the maximum size of an EBS volume is 1TB we recreated a RAID 0 set of 18 EBS volumes. The c3.8xlarge is described by AWS as a compute optimized VM with 32 hardware hyperthreads running on 2.8 GHz Intel Xeon E5-2680 v2 (Ivy Bridge) processors with 60GB of available memory on a 10 Gigabit ethernet network.

- WMS and WMTS data servers.

- Stress tester software was deployed on “m3.2xlarge” instances. Of the many EC2 types available, the m3.2xlarge is categorized by AWS as a general purpose VM type. The stress tester tool was used to generate random map requests as per the methodology described above.

For the “S3 configuration”, we used the same resources as above except for the data storage:

- A “c3.8xlarge” EC2 instance (64 bit) with S3 network attached storage. The c3.8xlarge is described by AWS as a compute optimized VM with 32 hardware hyperthreads running on 2.8 GHz Intel Xeon E5-2680 v2 (Ivy Bridge) processors with 60GB of available memory on a 10 Gigabit ethernet network.

- WMS and WMTS data servers.

- Stress tester software was deployed on Amazon “m3.2xlarge” instances. Of the many EC2 types available, the m3.2xlarge is categorized by AWS as a general purpose VM type. The stress tester tool was used to generate random map requests as per the methodology described above.

5.1.6 Architecture diagram

5.1.6.1 Amazon EC2 with Elastic Block Storage (EBS)

The architecture diagram presented below illustrates resources used at typical data provider sites for deploying OGC map services. Whether the data provider uses a virtual or standard computer, the approach is the same. In the diagram below, we simulate access to map services by using a “stress tester” tool, deployed on a number of “m3.2xlarge” computer instances. These computers were used as client computers to generate continuous map requests to a single “c3.8xlarge” map server instance. The “stress tester” tool deployed on different instances was used to simulating access to map services from a large number of concurrent users.

This use case aims to measure the performance and scalability of a single Virtual computer and its ability to support the largest possible number of concurrent users requesting maps from both OGC-compliant WMS and WMTS servers. Since the objective is to measure the capacity of the data service to serve maps to users, data latency between the client environment and the map server environment was kept to the minimum. To that end, the “stress tester” tool was deployed in the same AWS availability zone as the map server. This was done to avoid masking the performance and scalability results with client side latency issues.

The diagram in Figure 1 below illustrates the Amazon EC2 with an EBS configuration. Each m3.2xlarge computer resource is used to simulate end-users requesting maps from the map server on a continuous basis. Each m3.2xlarge computer could support 1,600 open connections to the c3.8xlarge instance hosting the map server.

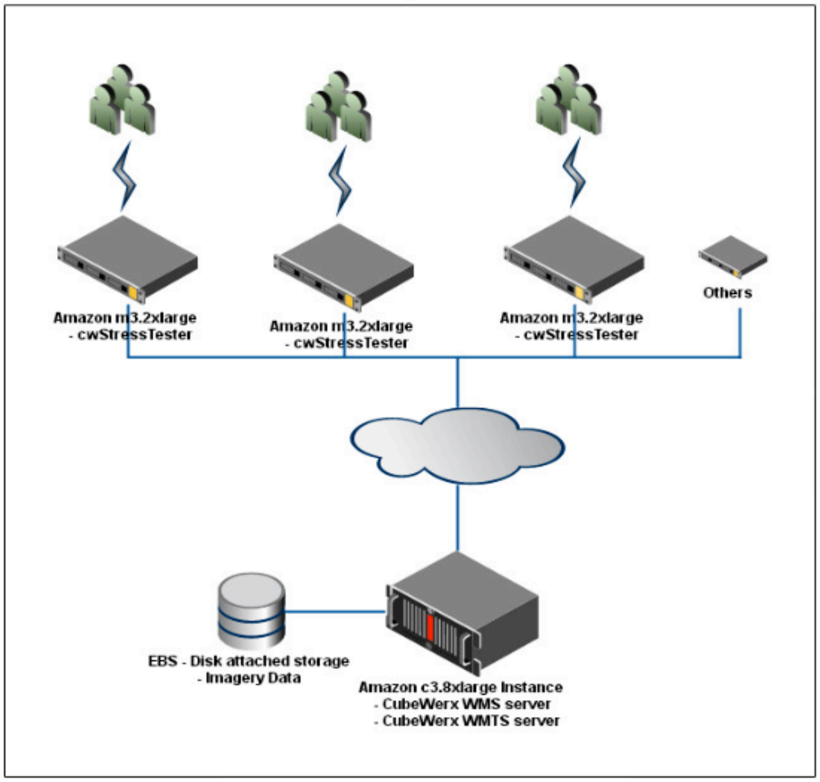


Figure 1 – Diagram illustrating concurrent user access to OGC-compliant map servers using an Amazon EC2 with an EBS direct disk-attached storage configuration

5.1.6.2 Amazon EC2 with Simple Storage Service (S3)

The diagram in Figure 2 below illustrates the Amazon EC2 with an S3 configuration. Each m3.2xlarge computer resource is used to simulate end-users requesting maps from the map server on a continuous basis. In this environment, the imagery data is hosted in an S3 network attached storage system. Each m3.2xlarge computer could support 1,600 open connections to the c3.8xlarge instance hosting the map server.

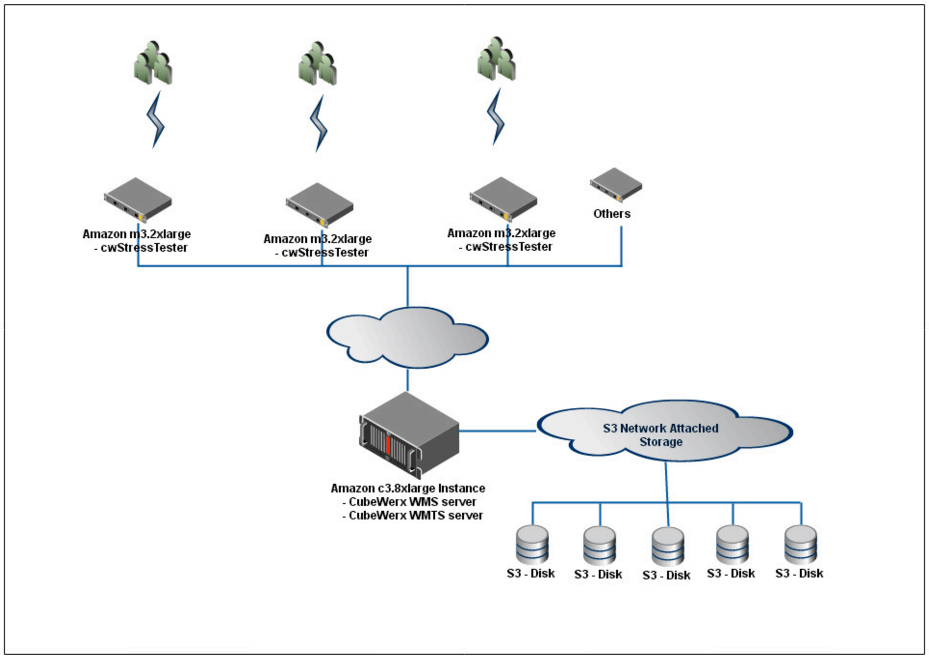


Figure 2 - Diagram illustrating concurrent user access to OGC-compliant map servers using an Amazon EC2 with an S3 network attached storage configuration

5.1.7 Performance results

The section below presents results from performance and scalability tests using the following two system configurations: a) Amazon EC2 with ABS, and b) Amazon EC2 with S3. All tests were conducted using a single Amazon computer instance (c3.8xlarge) for serving maps and all map requests were generated by the stress tester tool deployed on multiple computer instances (m3.2xlarge). Each map request was randomly generated and no map results were cached.

<u>Amazon EC2 with EBS</u>

The performance tests conducted with this configuration are listed below:

- Comparative average response time for serving maps from WMS and WMTS using a single "c3.8xlarge" computer instance.
- Number of maps per seconds satisfied by the WMS and WMTS servers.
- Average response time for delivering maps from a WMTS service to a large number of concurrent users.

<u>Amazon EC2 with S3</u>

The performance tests conducted with this configuration are listed below:

- Average response time for serving maps from a WMTS server using an EBS direct attached storage VS an S3 network attached storage service.

- Number of satisfied requests per second from a WMTS server using an EBS direct attached storage VS an S3 network attached storage service.

- Results from the largest test we performed using EC2 and S3.

5.1.7.1 Results from Amazon EC2 with Elastic Block Storage (EBS)

The first observation that can be made from the results in Figure 3 is that the WMTS service scales a lot better than the WMS does, as was expected.

If we establish an acceptable response time for returning a map at 2 seconds, results in Figure 3 below indicate that a single “c3.8xlarge” virtual computer can easily serve 450 concurrent users with a good response time while a WMTS service can serve maps to 1,700 concurrent users. This makes the WMTS service almost 4 times more efficient at returning maps from imagery than the WMS.

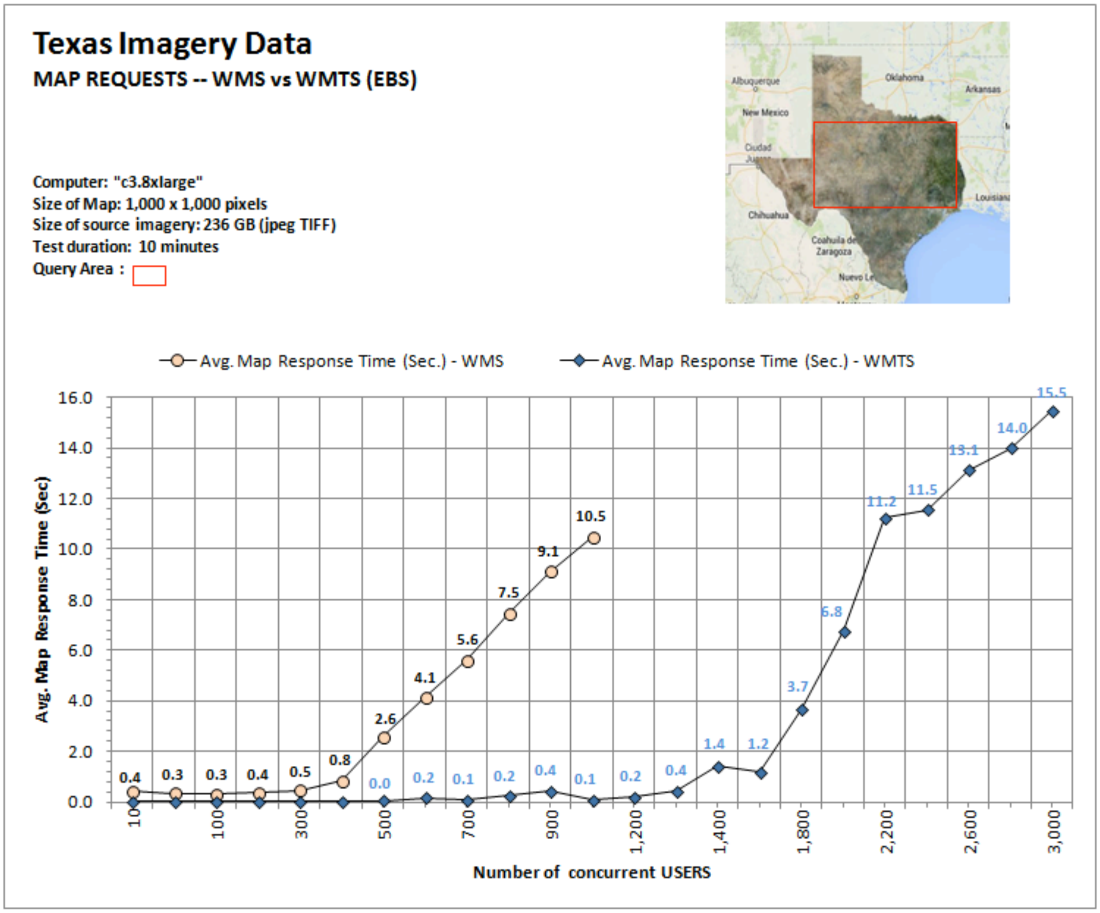


Figure 3 – Comparative average response time for serving maps from WMS and WMTS using a single “c3.8xlarge” computer instance

Additional statistics captured during the performance tests also indicate that the WMS service returned 35,170 maps within 10 minutes (to 400 users) while the WMTS returned 148,578 maps to 1,600 users within the same period of time. The WMS service peaked at 62 maps per second and could not return maps faster. Of course since more users were added on a continuous basis, the map service became overloaded and the average response time became unacceptable. With 1,000 users, the WMS server was still delivering maps but the average response time was 10.6 seconds and only 1.3% of all requests were returned within an acceptable time of 2 seconds.

During the same test period of 10 minutes, the WMTS service was able to serve 1,700 users and deliver 248 maps per second. The WMTS server was still returning maps with a performance of less than 2 seconds for 94% of all maps requested.

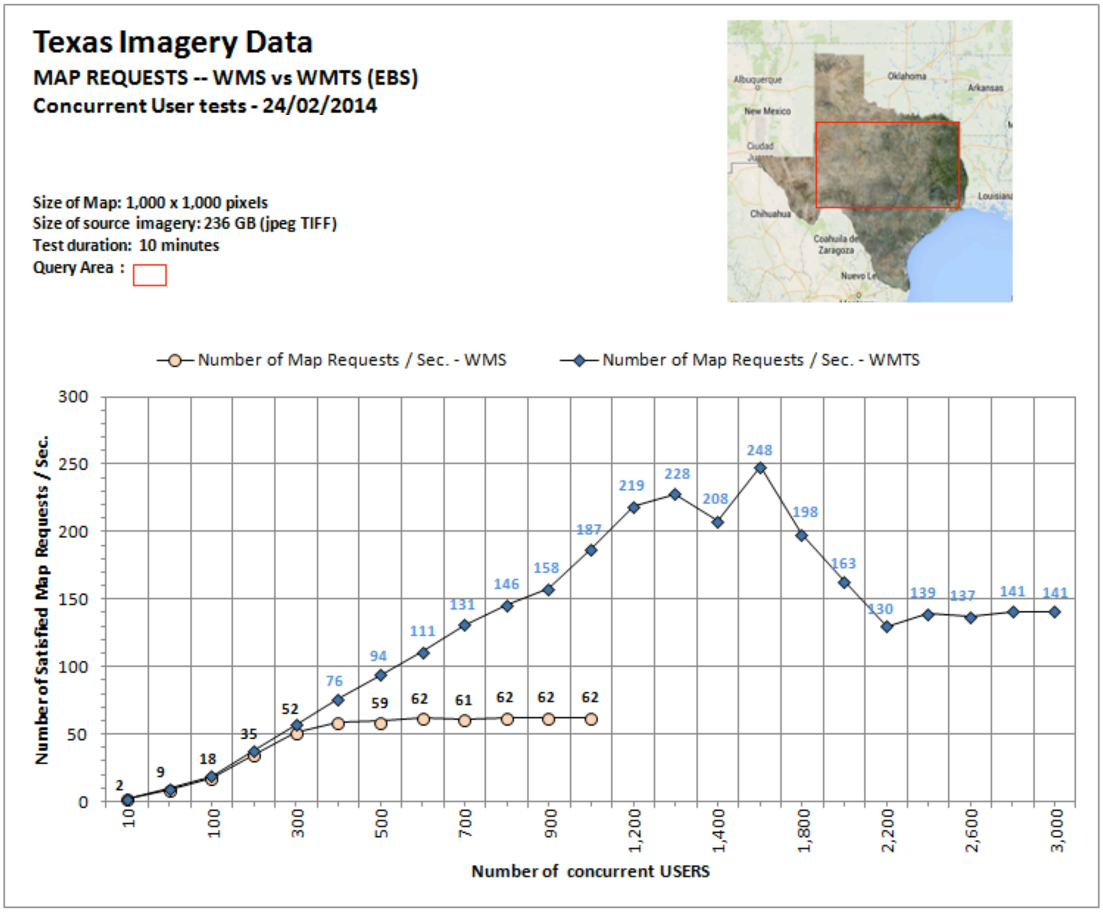


Figure 4 – Number of maps per seconds satisfied by the WMS and WMTS servers

Additional tests were performed on the WMTS to identify the map service breaking point with a single computer instance. Results in Figure 5 below indicate that a single Amazon “c3.x8large” instance operating with EBS data storage will stop functioning at around 10,000 concurrent users if the system administrator does not scale up that system. In practice there is a low probability that this limit would ever be reached because users will not likely wait on line for more than 10 seconds for a response from a map server, certainly not 95 seconds. This implies that in a real life scenario, the WMTS server may auto regulate itself between 1,700 and 1,900 concurrent users and the WMS may auto regulate itself between 400 and 500 concurrent users.

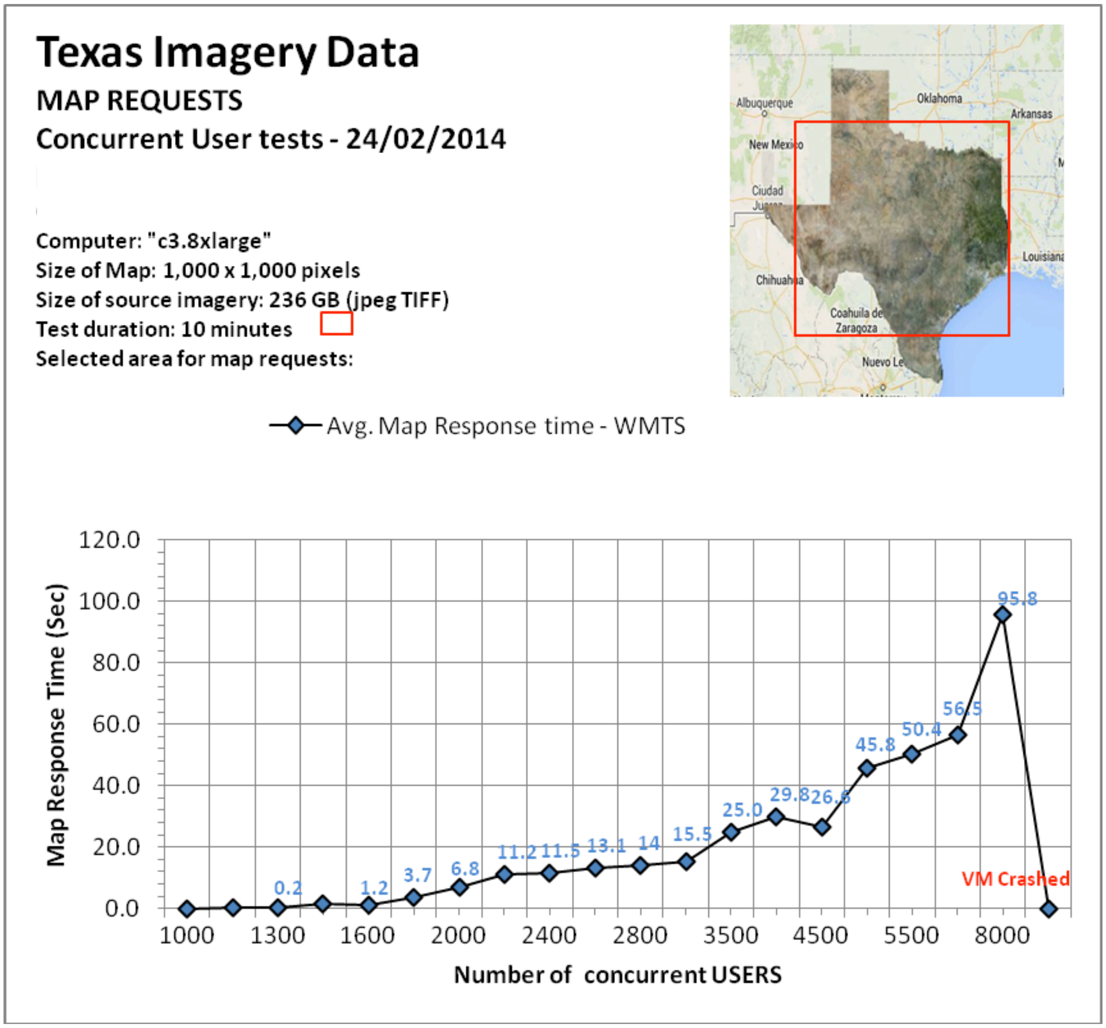


Figure 5 – Average response time for delivering maps from a WMTS service to a large number of concurrent users

5.1.7.2 Results from Amazon EC2 with Simple Storage Service (S3)

The first observation that can be made from the results in Figure 6 is that access to the S3 network storage scales a lot better than the EBS direct attached storage for the same WMTS service and the same data. This was somewhat expected but the difference is breathtaking. While the results show that the performance of access to a direct attached EBS environment offers better performance (0.03 sec.) for 500 or less concurrent users, access to maps from S3 shows a linear and very stable performance up to 20,000 concurrent users. Results show an average map response time of 0.2 seconds for all user groups up to 20,000 concurrent users with no sign of performance degradation.

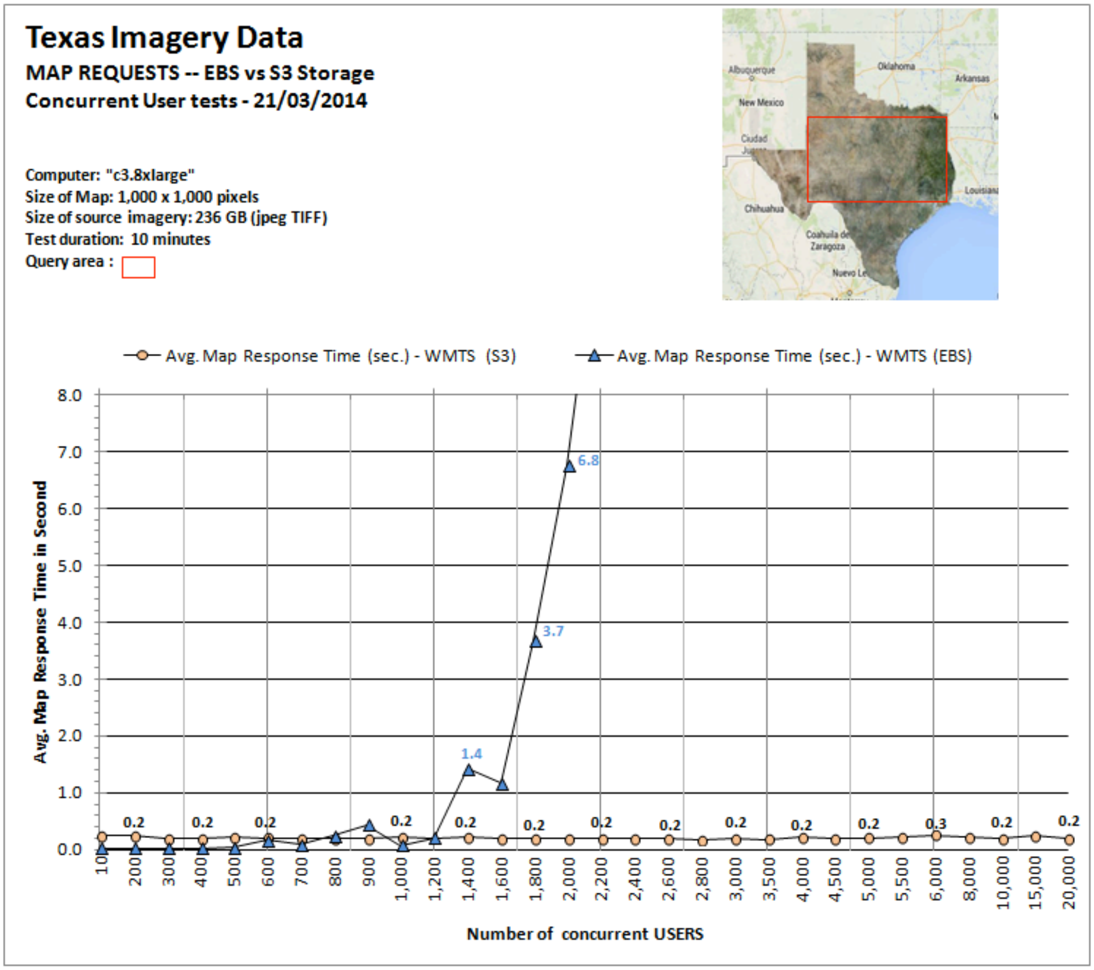


Figure 6 - Average response time for serving maps from a WMTS server using an EBS direct attached storage vs a S3 network attached storage service

The linearity of the performance is better shown in Figure 7 below, presenting the number of map requests satisfied by the WMTS server between the two different system configurations. While the EBS environment reached a peak at 248 maps per second with 1,700 users and stabilized at 141 maps per second up to 3,000 users, the S3 environment is still showing a straight line, delivering 3,670 maps per second with no sign of degradation with 20,000 concurrent users.

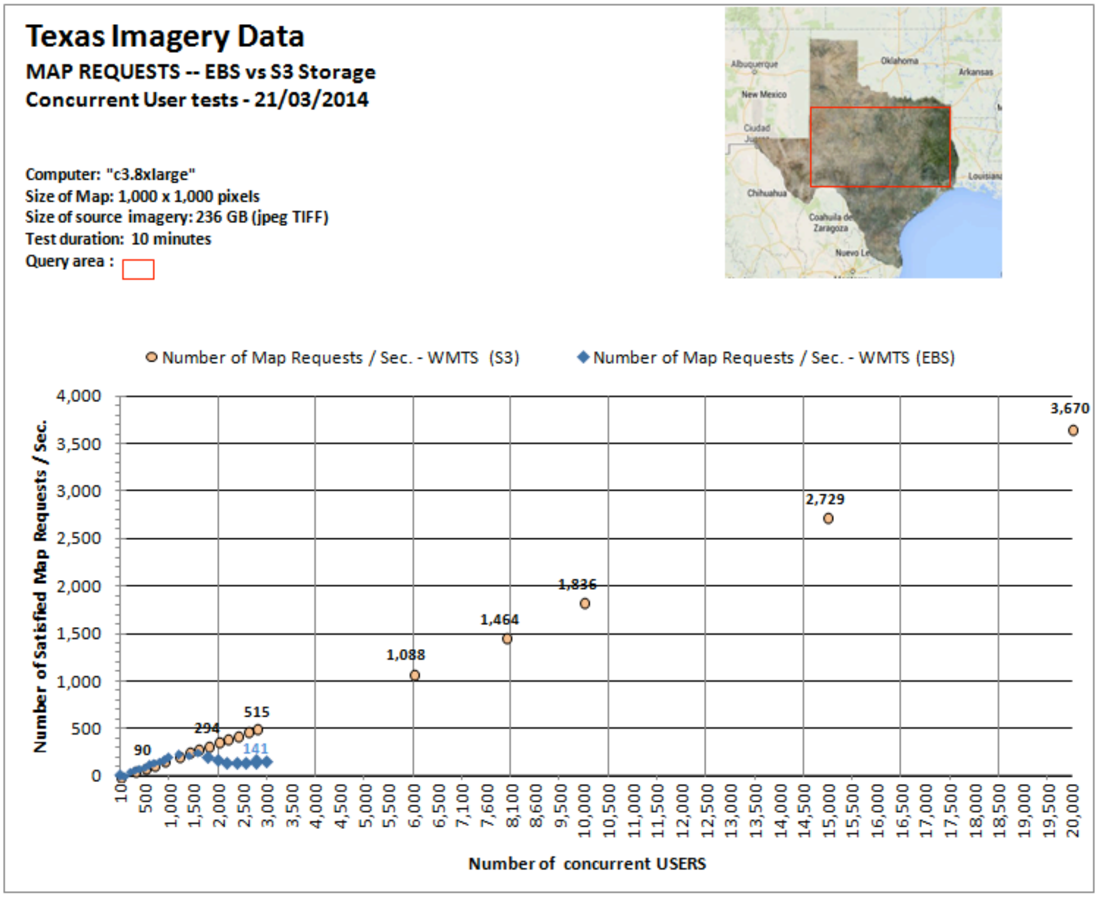


Figure 7 – Number of satisfied requests per second from a WMTS server using an EBS direct attached storage VS an S3 network attached storage environment

5.1.7.3 Additional tests using Amazon EC2 with Simple Storage Service (S3)

Following the amazing results above we decided to perform the largest concurrent user test we could, considering the number of computers we had at our disposal for submitting the performance jobs and monitoring the results.

The results presented below with 81,000 concurrent users required 72 m1.xlarge instances. Each instance was supporting 1,125 open connections with the c3.8xlarge instance hosting the WMTS server.

The map statistics presented below also indicate very little system degradation in an S3 environment – even with 81,000 concurrent users. The average response time of 1.7 seconds is still below our own threshold of an acceptable response time of 2.0 seconds.

Table 1 - Map Statistics from 81,000 concurrent users

Duration of the test	10 minutes
Instances used to generate concurrent map requests	72
Maps requested in 10 minutes	6.9 million
Number of maps satisfied per second	11,548
Average response time for all maps requested	1.7 seconds
Average map file size	589,453 bytes
Server bandwidth usage	6,807 MB/second

We have also compiled the statistics regarding access to map tiles (as opposed to maps). Since the size of the map requested was 1,000x1,000 pixels, the number of tiles required to fill up a map view was about 24 map tiles on average. The statistics below indicate that each tile was delivered from S3 at an average of 0.2 second/tile to 81,000 concurrent users.

Table 2 - Tile statistics from 81,000 concurrent users

Duration of the test	10 minutes
Instances used to generate concurrent map requests	72
Map tiles requested in 10 minutes	167 million
Number of map tile requests satisfied per second	278,023
Average response time for all tiles requested	0.20 seconds
Average tile file size	24,483 bytes
Server bandwidth usage	6,807 MB/second

5.1.8 Discussion on performance results

When to use a WMS vs a WMTS ?

Results in Figure 3 and Figure 4 above indicate that the WMTS service is at least 4x more efficient at serving maps than the WMS. This is to be expected since the WMTS server serves pre-rendered maps while the WMS generates each map either on-the-fly or renders the map based on end-user requirements. There is an obvious processing cost for generating and re-rendering a map. The trade-off for using the WMS versus the WMTS comes down to flexibility versus better performance and scalability. Both OGC WMS and WMTS map services meet important mapping requirements. In situations where a map is composed of a large number of geographic features and the properties of the features are important considerations for mapping, the WMS is still the best option. Using a WMTS in this situation would imply that all possible combinations of features and attributes would need to be pre-rendered. In most cases, this approach would not be realistic and would translate into larger storage costs for the tiled maps and data management problems for serving current maps.

WMTS services are best suited when the number of features is within reasonable limits. Most commercial map services provide at best a handful of layers with a single spatial reference system. In similar conditions, an OGC WMTS service can deliver, as demonstrated by the performance results above, performance and scalability characteristics that are on par with commercial map services. Even the OGC WMS can achieve similar performance for a limited number of concurrent users. But the WMS will not scale up to a level comparable to the OGC WMTS or its proprietary commercial equivalents.

When to use EBS vs S3 data storage ?

S3 is well suited for exchanging large volumes of geographic features and deploying OGC WMTS to serve very large numbers of concurrent users in a collaborative and interoperable enterprise-wide environment. Performance and scalability results presented above indicate that the Amazon S3 configuration offers geospatial data providers an infrastructure that can be used to meet map publishing requirements of both small and large data provider organizations.

An Amazon EBS solution will also deliver very good performance but will not scale up to the level offered by S3.

<u>Opportunities to develop more scalable and interoperable geospatial solutions:</u>

The combination of OGC services with easy access to a Cloud infrastructure is offering, for the first time, the opportunity to deliver new geospatial solutions. They can match the performance and scalability characteristics of commercial web mapping products, support service integration between OGC and private commercial data services, and the deployment of more robust service solutions in a distributed and collaborative environment.

5.1.9 Conclusion

Performance results presented above represent fantastic business opportunities to all players in the Geospatial Services industry including OGC.

First, these results should help dispel the false but persistent rumors regarding the poor performance of software products based on OGC standards. While it is true that each software implementation presents their own performance characteristics, results from these performance tests indicate that OGC-based service products can deliver performance equivalent to commercial, mass market map offerings.

Second, the Cloud infrastructure offers fantastic untapped business opportunities for all players in the Geospatial Services industry including Geospatial data providers (small and large organizations). The impact of the availability of Cloud infrastructures on the Geospatial Services industry is staggering. The Cloud infrastructure is opening up new business opportunities for all geospatial data providers. The following business opportunities should be considered:

- Deploying geospatial data (source data) at much lower costs.

  - Costs associated with preparing, packaging and shipping geospatial data can be considerably reduced or eliminated.
  - Effort and costs associated with the purchasing of equipment and preparation of geospatial data for shipping can be reduced or eliminated.
  - Management effort associated with the recovery of material costs for shipping geospatial data can be reduced or eliminated.
  - Because single copies of data can be securely shared in a Cloud environment, costs incurred by all partners for replicating geospatial data from other data providers can be considerably reduced or eliminated.
  - Data provider organizations offering their data for a price, or simply interested in off-loading the data transfer costs out of an AWS Region to the data-requestor, can use new Cloud concepts such as the S3 Bucket "requestor-pays" feature to allow the Cloud provider to bill the requestor for them. The requestor in this case can be either a client machine or a server. This allows for both the monetized and free distribution of very large data-sets, traditionally bottle-necked by ftp servers.
  - In general with the Cloud, geospatial data can be exchanged at much lower costs.

- Deploying robust and efficient Geospatial service products at much lower costs.
  - Pay only for the computer resources required to service your clients with the flexibility to scale your system up and down at any time.
  - Select OGC compliant software products that are demonstrating some level of efficiency.
  - Using a Cloud infrastructure for deploying Geospatial services is relatively easy but we recommend maintaining a focus on process efficiencies. There is a danger to hide current software inefficiencies behind the large availability of Cloud computing resources; this would have the opposite effect and will result in higher costs for the data publisher and/or its partners and in some cases all users of the system.
- Deploying innovative and collaborative geospatial solutions. This can be realized by the use of software products based on interoperable OGC standards.
  - Take advantage of geospatial services from other data providers by making their geospatial services part of your own offerings. Avoid the centralization of all data; each partner would benefit from significant

cost reductions by only serving their own data. Data integration from multiple OGC data services can be easily accomplished at the service level by any organization.

- Reduce your data production costs by reducing or eliminating data manipulation or unnecessary processing steps within your data production system. For example, imagery data can be directly pushed to the Cloud provider site by data collectors as soon as the data has been captured and/or orthorectified. Notifications can be sent to the data administrator and at the push of a button the map service can be maintained up to date.

- Deploy near real time imagery services by keeping your map services current. Uploading a 300 MB image online to an imagery service at a Cloud provider site takes less than 2 minutes and it takes only 10 seconds to generate the required map tiles that would keep the WMTS, WMS, WCS services up-to-date, regardless of the size of the existing tile set.

5.2 Performance enhancements of Geodata processing using a Hybrid Cloud (Section 2)

This section discusses and provides samples of cloud architectures in the context of web based geodata processing. More specifically, a Hybrid Cloud approach has been investigated as a way to perform coordinate transformation of road datasets.

5.2.1 Introduction

This project presents the architecture and a performance analysis of a Hybrid Cloud approach to enhance the performance of geospatial processing. A fixed number of in-house virtual machines, a so called private cloud, are coupled with a large number of virtual machines from a commercial cloud provider.

5.2.2 Project Plan

The Hybrid Cloud deployed for this project presents the use of private Hybrid Cloud components deployed at 52°North with Cloud resources deployed at Amazon using their public AWS infrastructure.

5.2.3 Performance criteria

The Hybrid Cloud setup was benchmarked by Baranski *et al.* in 2011 [2] against several Quality-Of-Service (QoS) requirements specified by INSPIRE. According to [2], "an INSPIRE Transformation Service must be available 99% of the time (availability), the maximum initial response time must be 0.5 seconds per each Megabyte (MB) of input data (performance) and a service instance must be able to fulfill both of these criteria even if the number of served simultaneous service requests is up to 5 per second (capacity).".

The 52°North WPS was extended to support INSPIRE compliant coordinate transformation by implementing a WPS Application profile. In our test setup, the Private Cloud consists of four VM instances, based on two servers with two cores each. The Public Cloud (Amazon EC2), consists of six "small" instances using 64 bit.

5.2.4 Architecture

The described Hybrid Cloud approach was presented by [2]. The elements of the proposed abstract Hybrid Cloud architecture (Figure 8) are presented in this section in an implementation-independent view. A concrete implementation of the abstract architecture is presented in the following section.

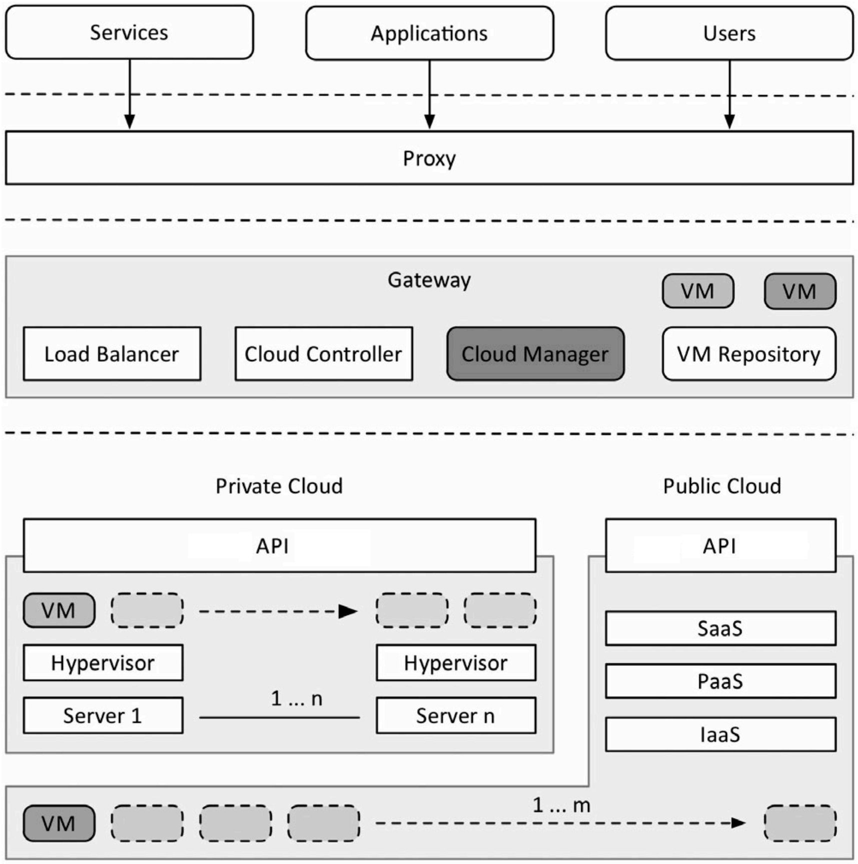


Figure 8 - Hybrid cloud conceptual architecture (source [2])

The architecture described in more detail according to [2]:

- The Proxy component is the main entry point for all clients (users, applications and other services) and it controls access to the whole (local and third-party) server infrastructure. It receives all incoming service requests, forwards them to the LoadBalancer at the Gateway, and returns the delivered response as if it was itself the origin.

The Gateway is an organizational unit containing a Load Balancer, a Cloud Controller, a Cloud Manager and a Virtual Machine (VM) Repository.

- The Load Balancer component contains a registry of all running service instances, the so-called IP Pool. The Load Balancer receives all forwarded requests from the Proxy and equally distributes them across all available service instances.

- The Virtual Machine (VM) Repository component produces a local storage containing a set of prepared Virtual Machine (VM) images. Each VM image belongs to an offered service and contains a guest operating system, all required software components and related configurations. In the proposed Hybrid Cloud architecture two different types of

VM images exists. One image type is dedicated for use in the local infrastructure. The other image type is dedicated for use at the Public Cloud. Anyway, for each offered service, one VM image for each of the two types must be provided at the VM Repository.

- The Cloud Controller component manages the virtualized local IT-infrastructure by providing an interface for starting and stopping VM instance on the local servers. Therefore, on each of the local servers a host operating system together with a Hypervisor must be installed. The only task for the Hypervisor is to run the guest operating systems (VM).

- The Cloud Manager component monitors the CPU load on each running VM in the architecture. If the overall CPU load of the system goes beyond a configured threshold, the Cloud Manager starts a new VM instance and adds the new running VM to the IP pool of the Load Balancer. In the ideal case, the VM is started via the Cloud Controller at a local IT-infrastructure. If all local servers are busy, the VM is started at the Public Cloud. If the overall CPU load of the system goes below a configured threshold, the Cloud Manager stops the running VM instance with the lowest CPU load (with a priority for running VM instances at the Public Cloud). Before the Cloud Manager stops a running VM, the VM is removed from the IP pool of the Load Balancer. Each time a new VM instance is added/removed from the IP pool of the Load Balancer, the Load Balancer must be restarted to notice the new resources. To avoid connection interruptions between the Proxy and the requesting clients (in the case the Load Balancer is not available for a short period of time), the Proxy component re-sends the forwarded requests to the Load Balancer until they can be processed successfully.

5.2.5 Implementation

The Figure 9 below illustrates the implementation of the current Hybrid Cloud architecture used to perform coordinate transformation of road datasets.

For the Proxy component Apache HTTP Server was chosen combined with the mod_proxy module.

The Load Balancer is realized by an nginx server, which can be easily configured to distribute incoming requests equally.

The underlying complexity of the Hybrid Cloud is hidden from clients by configuring the Apache and nginx server to act as a reverse proxy.

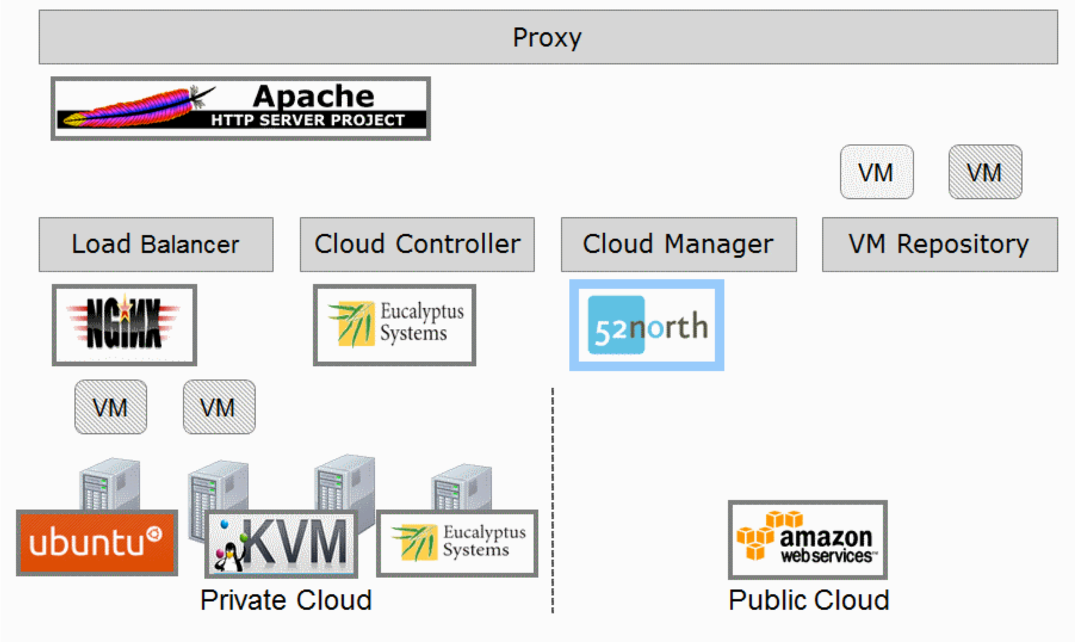
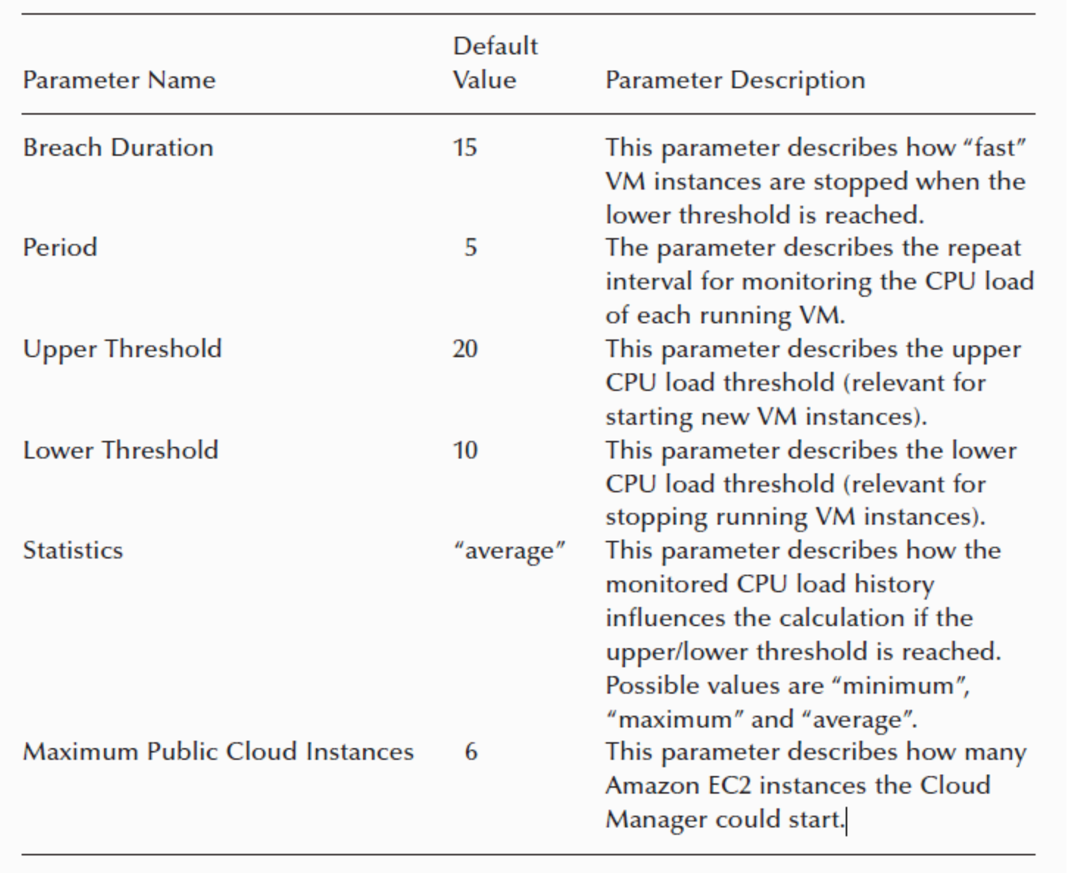


Figure 9 - Hybrid cloud implementation architecture (source [3])

For the hypervisor in the Private Cloud we are using the Kernel-based Virtual Machine (KVM). We are using KVM images running an Ubuntu guest operating system. For the Public Cloud we are using Amazon EC2 resources, which offer pre-configured image types for Amazon Machine Image (AMI). These two image types are stored in the VM Repository.

The Cloud Manager is available as Open Source at 52°North. The Cloud Manager can be configured using a set of parameters described in Table 3 below.

Table 3 - Cloud Manager parameters (source [2])



Parameter Name	Default Value	Parameter Description
Breach Duration	15	This parameter describes how "fast" VM instances are stopped when the lower threshold is reached.
Period	5	The parameter describes the repeat interval for monitoring the CPU load of each running VM.
Upper Threshold	20	This parameter describes the upper CPU load threshold (relevant for starting new VM instances).
Lower Threshold	10	This parameter describes the lower CPU load threshold (relevant for stopping running VM instances).
Statistics	"average"	This parameter describes how the monitored CPU load history influences the calculation if the upper/lower threshold is reached. Possible values are "minimum", "maximum" and "average".
Maximum Public Cloud Instances	6	This parameter describes how many Amazon EC2 instances the Cloud Manager could start.

With these parameters the scalability and efficiency of the system can be adapted to the particular geo-processing requirements. It is also possible to limit the financial expenses by specifying a maximum number of (pay-per-use) Public Cloud VM instances.

The images are preconfigured with WPS instances. A view of the Cloud Dashboard client application used to perform coordinate transformations is shown in Figure 10.

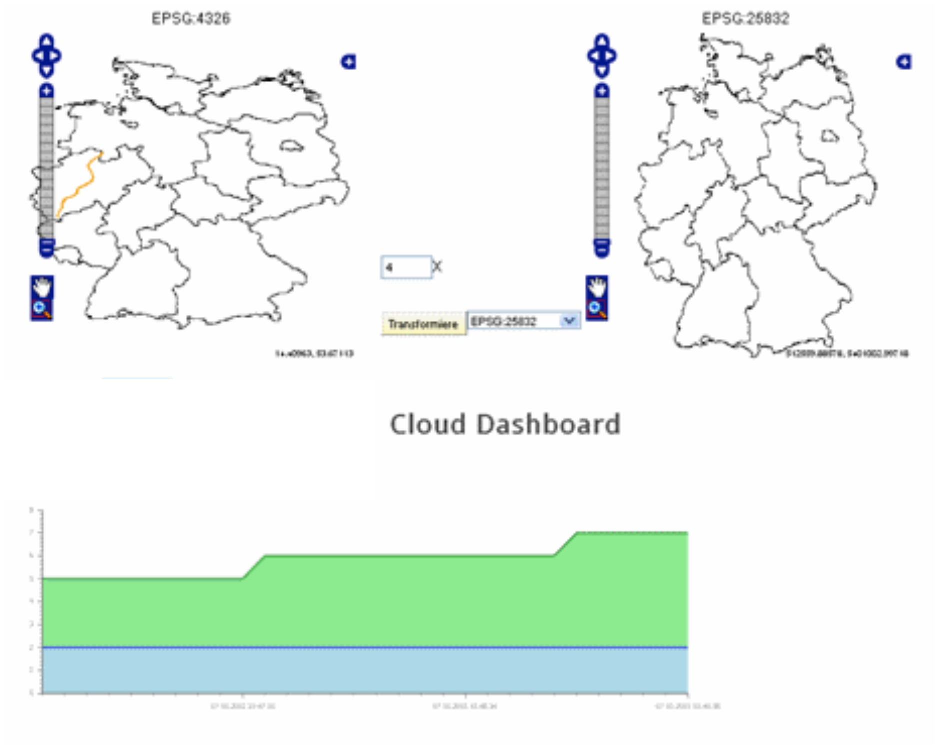


Figure 10 - Cloud Dashboard used for coordinate transformations

5.2.6 Performance enhancement use case

To illustrate the performance enhancement for coordinate transformations, the following three configurations were used:

- Single server deployment
- Private Cloud
- Hybrid Cloud

5.2.7 Performance enhancement results – Single server deployment

For this use case configuration, a single server of the Private Cloud was used. Figure 11 shows the average response time of a request send to the single server deployment.

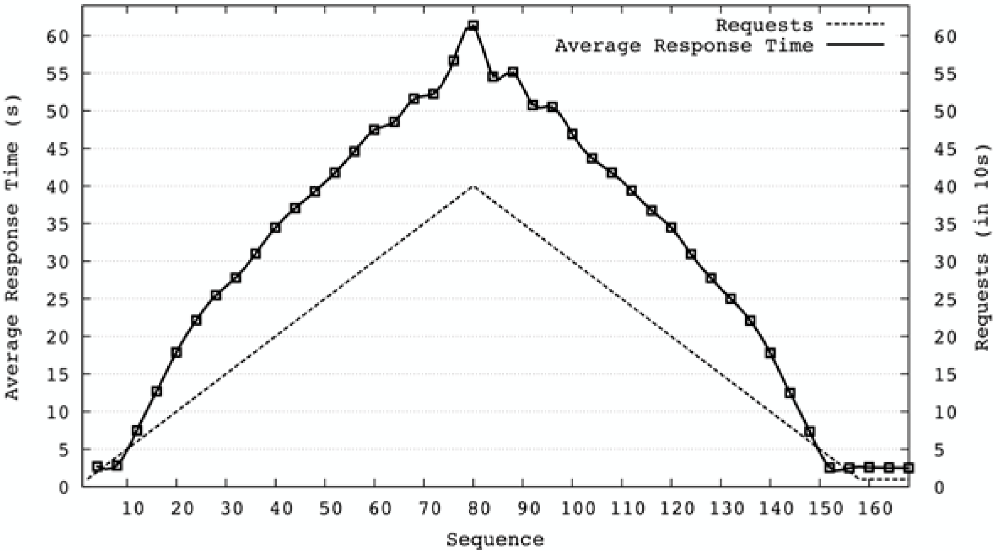


Figure 11 - Average response time according to the number of simultaneously served requests in a single server deployment (source [2])

The figure above shows that the average response time to all requests sent to a single server increases significantly with the number of simultaneously requests served. The average response time increases from 2.7 seconds (two requests in 10 seconds) up to 61.3 seconds (40 requests in 10 seconds). The CPU load of the server was monitored and it was averaging near 100% most of the time. The server was not able to handle more than five requests within 10 seconds without increasing the average response time significantly.

5.2.8 Performance enhancement results – Private Cloud

In the Private Cloud deployment setup, the Cloud Manager was configured to use four local instances and no Public Cloud instances. The average response time of a request sent to the Private Cloud together with the number of utilized local instances is shown in Figure 12.

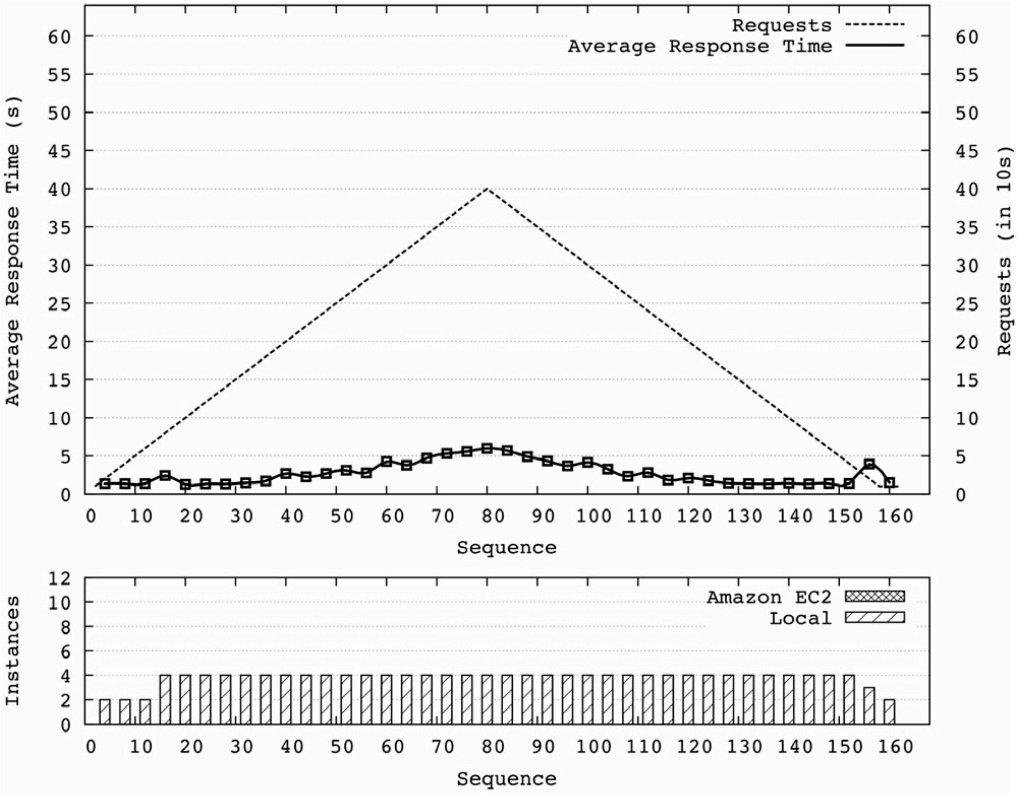


Figure 12 - Average response time according to the number of simultaneously served requests in a Private Cloud deployment (source [2])

We can see that the average response time increases from 1.6 seconds (four requests in 10 seconds) up to 5.9 seconds (40 requests in 10 seconds). All four local instances are used during peak loads.

5.2.9 Performance enhancement results – Hybrid Cloud

In the Hybrid Cloud deployment setup, the Cloud Manager was configured to use four local instances and six Public Cloud instances. The average response time of a request sent to the Hybrid Cloud together with the number of utilized local instances is shown in Figure 13.

For this configuration, the average response time increases from 1.7 seconds (four requests in 10 seconds) up to 3.3 seconds (40 requests in 10 seconds). Soon after all four local instances are busy, the Public Cloud instances are started and at peak load all available instances are running. In times of peak load, the average response time is a maximum of 1.9 times longer than in idle times (compared with 22.7 times longer for the single server deployment and 3.6 times longer for the Private Cloud deployment).

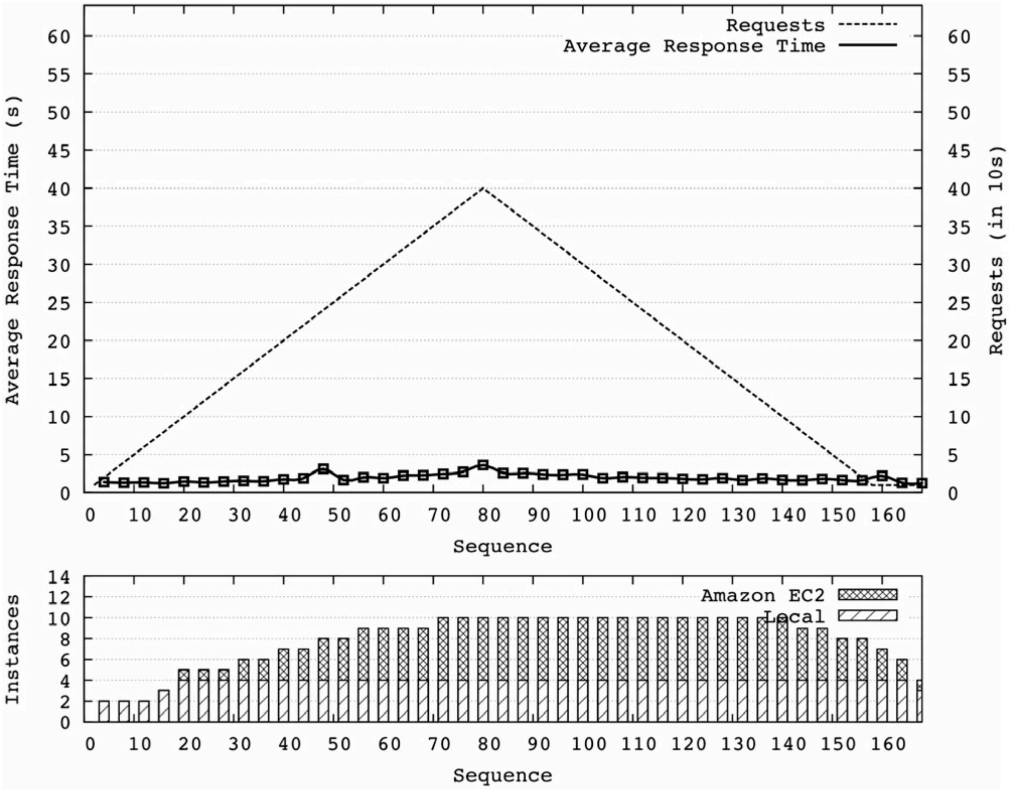


Figure 13 - Average response time according to the number of simultaneously served requests in a Hybrid Cloud deployment (source [2])

The experiments show that a significant performance enhancement can be reached by the Hybrid Cloud approach.

5.3 Performance enhancements of DinSAR processing using a Hybrid Cloud

The principle of the Differential SAR Interferometry (DinSAR) is illustrated Figure 14, and can require large storage and compute-intensive scientific processing, as it is the case for the Small Baseline Subset (SBAS) technique involved in this testbed deployment.

In this use case, we will exploit 64 differential SAR scenes for the generation of time series showing ground displacements over a decade in geological sensitive areas. This is part of an ongoing effort from ESA, CNR-IREA and Terradue partners to deliver updated and comprehensive time series over geologic phenomena, supporting scientific advising towards decision makers.

This SBAS Cloud deployment testbed is focusing on the Naples area in Italy, making use of about 80 GB of ENVISAT ASAR scenes, generating 300 GB of intermediary and output products, and representing a time series of 9 years (2002-2010) that will show the sensitivity to ground displacements in the region.

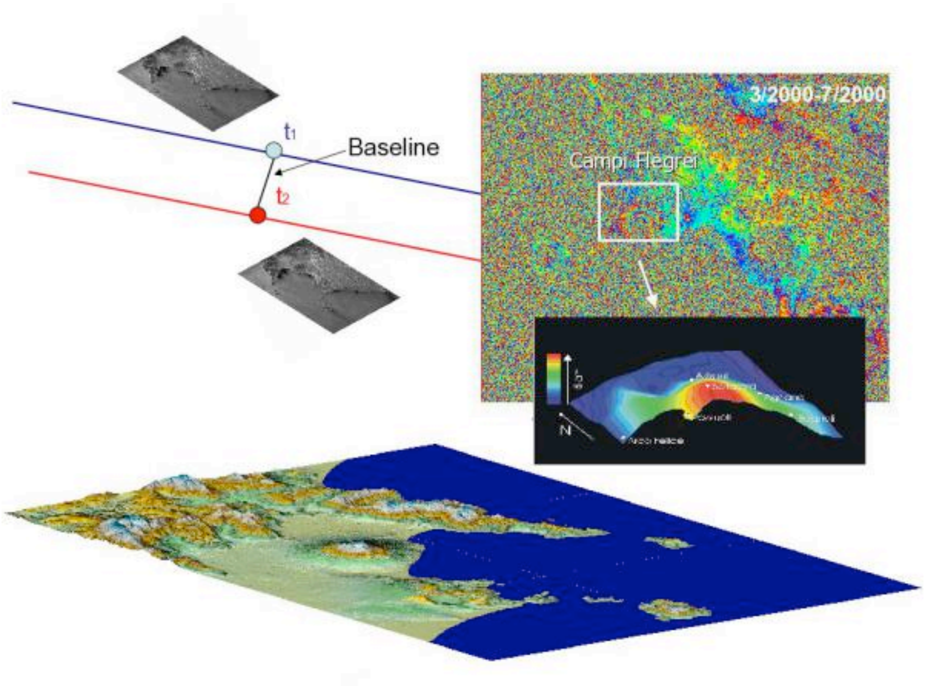


Figure 14 - The SAR Interferometry technique involved with the SBAS Cloud deployment

The Hybrid Cloud deployed by Terradue Srl for this project makes use of the private Cloud deployed at Terradue's facilities, along with public Cloud resources provisioned at the Amazon Cloud Compute infrastructure in Dublin, using their AWS API, and provisioned at the Interoute Cloud Storage Infrastructure in London, using Terradue's Virtual Archive Cloud Service (a SAR data archive deployed as the contribution of the European Space Agency to the GEO Supersites Exploitation Platform, http://eo-virtual-archive4.esa.int).

5.3.1 Scope of work

This work demonstrates performance enhancements for a Cloud deployment of the SBAS (Small Baseline Subset) processing application with the use of WPS and OpenSearch OGC Web Services for the production of On-demand Ground Deformation Maps.

The activity was conducted in OGC Testbed 10 by Terradue, in collaboration with CNR-IREA (SBAS processing chain) and with grant program from Amazon Web Services Education & Government Solutions. The deployment is exploiting resources from Terradue (Cloud Controller), AWS (public Cloud), Interoute (public Cloud), and the GEO Supersites Virtual Archive (Cloud Storage of massive ESA SAR data).

5.3.1.1 Scientific data processing leveraging Cloud Computing

The European Space Agency is a leading provider of Earth Observation scientific data. As a European contribution to GEO (http://www.earthobservations.org/), ESA is operating the SSEP Virtual Archive Service.

This service provides standard OGC CSW OpenSearch access to ENVISAT ASAR products, that can be exploited by a Differential SAR Interferometry processing. The CSW OpenSearch service endpoint for ASAR Level 0 products is described here: http://eo-virtual-archive4.esa.int/search/ASA_IM__0P/description

The Institute for Electromagnetic Sensing of the Environment (IREA), an institute of the Italian National Research Council (CNR), incorporates a Microwave Remote Sensing Group that is active since 1987. Their main research interest is Differential SAR interferometry (DInSAR), with two main aims:

- development of tools for detecting and monitoring of earth surface deformations;
- demonstration of applicability of the proposed techniques in real scenarios.

IREA-CNR is the initiator of the well-known Small Baseline Subset (SBAS) processing technique for generating deformation time series starting from SAR data.

From earlier collaboration, IREA-CNR has implemented its SBAS-DInSAR processing chain in the G-POD (http://gpod.eo.esa.int/) and GENESI-DEC (http://www.genesi-dec.eu/) processing platforms of ESA, permitting to process in an automatic way several hundreds of GB of satellite data (mostly ERS and ENVISAT).

SBAS is a complex, multi-staged set of data processors, that has been re-engineered for the SSEP Cloud platform, in order to leverage the power of the Hadoop MapReduce Streaming distributed processing framework on Terradue’s PaaS.

5.3.1.2 Interoperability goals and performance requirements

Within OGC Testbed 10, we investigated the exploitation of OGC Web Service for the SBAS / MapReduce enabled processing chain, and their performance enhancement through Cloud deployment.

The goal is to promote the use of OGC client applications that can interoperate in a distributed Web Services environment, to discover and access remote data resources, and trigger processing tasks on a selected Cloud, according to a set of service providers agreements (i.e. working with a multi-tenant solution).

The SBAS processing chain is composed of 25 data processing steps, implemented with Terradue’s PaaS, resulting in Mapper and Reducer tasks that are managed by the Hadoop framework as a distributed pool of jobs, running on a Compute Cluster of any size.

The connectivity between multi-tenant Clouds and the size of the selected processing cluster for the MapReduce operations are the main performance parameters for a time series production. For the producer of displacement maps, they have to fit with exploitation constraints that can vary in terms of production cost and processing time.

The availability of OGC standard interfaces at the data access and data processing levels offers more flexibility in matching performance parameters and the exploitation constraints. We describe in more detail these aspects in the following chapter.

5.3.1.3 Recommended approach

For virtualized infrastructures there is the concept of virtual computational resources. In particular AWS defines the concept of an EC2 Compute Unit, where the abstraction is in terms of computational power.

In the case of the SBAS processing chain, an approach can be to define the amount of RAM needed by a single process step and to setup accordingly the number of parallel processes.

For the interoperability testing and processing testbed, a stepped approach was followed in order to first validate the Cloud processing deployment on a selected Cloud (AWS) with manually staged input data, then the processing scalability (operation from the OpenNebula Cloud Controller), and then to involve the data staging from remote storage (SSEP Virtual Archive).

5.3.2 Project plan

The project plan for this deployment is as follows:

a) Exploit OGC-compliant WPS-Hadoop distributed data processing service, deployed on Amazon Compute Cloud in Dublin using two different configurations (using 16 and then 32 nodes),

b) Exploit OGC-compliant CSW OpenSearch Virtual Archive deployed on Interoute Cloud Storage in London,

c) Compare the data staging performance between multi-tenant Clouds, for instance between Interoute London (Storage) and AWS Dublin (Compute) Clouds,

d) Compare the performance of the distributed data processing service for each configuration successively deployed on the Amazon Cloud,

e) Discuss the results and trade-off that should be considered when deploying OGC data services on multi-tenant Cloud Service providers.

In summary, the plan leverages a Hybrid Cloud deployed for this project making use of private Cloud PaaS components deployed at Terradue and their APIs, along with public Cloud resources provisioned at Amazon using their IaaS APIs (EC2), and at Interoute using the SaaS APIs (OGC OpenSearch) provided by the SSEP Virtual Archive. For this testbed activity, OGC Client Applications will implement OGC WPS 1.0 and OGC OpenSearch Geo and Time extensions.

5.3.3 Architecture

The software architecture is based on 3 main components:

Terradue's Cloud Controller (IaaS brokering): based on OpenNebula (ONe) 4.2 distribution. OpenNebula is an open-source project developing the industry standard solution for building and managing virtualized enterprise data centers and enterprise private clouds. Terradue is a contributor to the OpenNebula open source baseline and it delivers native capabilities for Orchestration and Auto-Scaling of Cloud Multi-Tier Applications.

The Cloud Controller component offers a virtualized data center, where the administrator can define, execute and manage "services composed of interconnected Virtual Machines", with deployment dependencies between them. In this setting, a service is composed by roles, each one corresponding to one VM template, and each one with certain cardinality, i.e, the number of instances of the same VM template.

A role's cardinality can be adjusted manually, based on metrics, or based on a schedule, thus providing with auto-scaling policies. Service management offers the ability to recover from fault situations, the ability to apply operations to all the VMs belonging to certain role, the ability to define a cooldown period after a scaling operation. Scheduling actions can also be applied.

Terradue's Cloud platform (PaaS): based on Apache Hadoop Cloudera CDH3 distribution. Terradue is operating a Cloud processing service, leveraging the Apache Hadoop framework. The OGC-enabled WPS-Hadoop Cloud service, running on an OpenNebula-driven private Cloud, with:

- One appliance with WPS-Hadoop I/F
- Several Hadoop pseudo-clusters, configured from the Cloudera's Distribution
- Hadoop (CDH3) baseline

Terradue's Virtual Archive (SaaS): based on data repository technology and standard OpenSearch interface. It is delivered as a Cloud solution providing Storage-as-a-Service for earth data and is coupled with complementary services for user authentication and authorization, data discovery implementing simple OpenSearch interface exposing results in ATOM or RDF formats, and data access via common web protocols such as HTTP(s).

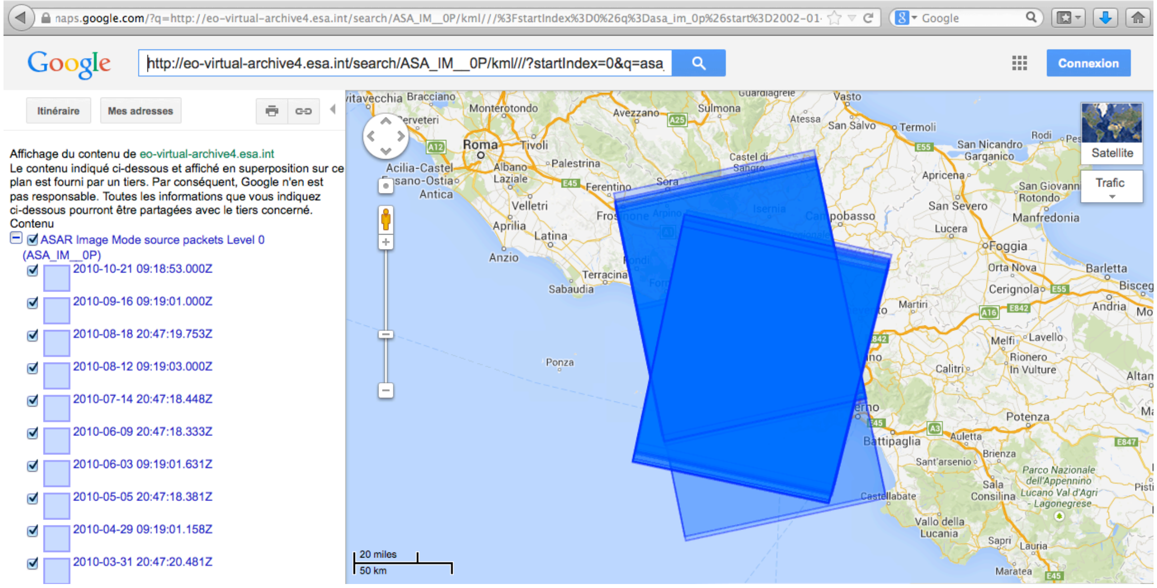
5.3.4 Implementation

A simple Application Descriptor file is edited from the PaaS environment, to describe all the steps of the SBAS processing workflow.

These processing steps can then be configured to operate over a set of nodes running their tasks in parallel (general case) or as a single node of the Cluster that will be in charge to aggregate some intermediary data.

5.3.4.1 Data casting service with OGC OpenSearch interface

The Catalogue search service performs spatial, temporal and other queries in the available products of the ENSISAT ASAR collection "ASA_IM_0P", as illustrated Figure 15 below. This search service provides a standard interface OGC SW OpenSearch Geo and Time extensions.



naps.google.com/?q=http://eo-virtual-archive4.esa.int/search/ASA_IM__0P/kml///%3FstartIndex%3D0%26q%3Dasa_im_0p%26start%3D2002-01-

http://eo-virtual-archive4.esa.int/search/ASA_IM__0P/kml///?startIndex=0&q=asa

Affichage du contenu de eo-virtual-archive4.esa.int
Le contenu indiqué ci-dessous et affiché en superposition sur ce plan est fourni par un tiers. Par conséquent, Google n'en est pas responsable. Toutes les informations que vous indiquez ci-dessous pourront être partagées avec le tiers concerné.
Contenu

☑ ASAR Image Mode source packets Level 0 (ASA_IM__0P)
- ☑ 2010-10-21 09:18:53.000Z
- ☑ 2010-09-16 09:19:01.000Z
- ☑ 2010-08-18 20:47:19.753Z
- ☑ 2010-08-12 09:19:03.000Z
- ☑ 2010-07-14 20:47:18.448Z
- ☑ 2010-06-09 20:47:18.333Z
- ☑ 2010-06-03 09:19:01.631Z
- ☑ 2010-05-05 20:47:18.381Z
- ☑ 2010-04-29 09:19:01.158Z
- ☑ 2010-03-31 20:47:20.481Z

Figure 15 – the GEO Supersites Virtual Archive area of interest (OpenSearch query result rendered in Google Maps), featuring a set of ENVISAT ASAR products used for the OWS-10 SBAS testbed

For the SBAS activity demonstrated in OGC Testbed 10, the user query on the OGC CSW OpenSearch with Geo and Time extension interface of the SSEP Virtual Archive is:

http://eo-virtual-archive4.esa.int/search/ASA_IM__0P/html//?startIndex=0&q=asa_im_0p&start=2002-01-01&stop=2010-12-31&bbox=14.05,40.80,14.33,40.92

5.3.4.2 Data staging service between multi-tenant Cloud resources

Once catalogue resources are discovered and selected, the processing application will access data resources via a dedicated protocol for data staging.

The data staging flow must be sufficient to feed the data processing rate once the initial tasks are distributed on the cluster nodes.

According to the query interface defined above, the processing chain has its first processing node defined to implement the data staging, via OGC CSW OpenSearch Geo and Time extension query parameters.

This processing node implements the stage-in process with an emulation of the quality control selection process defined by a CNR scientist. The input list of ASAR products produced by the OpenSearch query with date start, date stop and bounding box parameters, retrieved from the ESA Catalogue available at http://eo-virtual-archive4.esa.int, is filtered according to quality control criteria, before their stage-in, discarding the useless products.

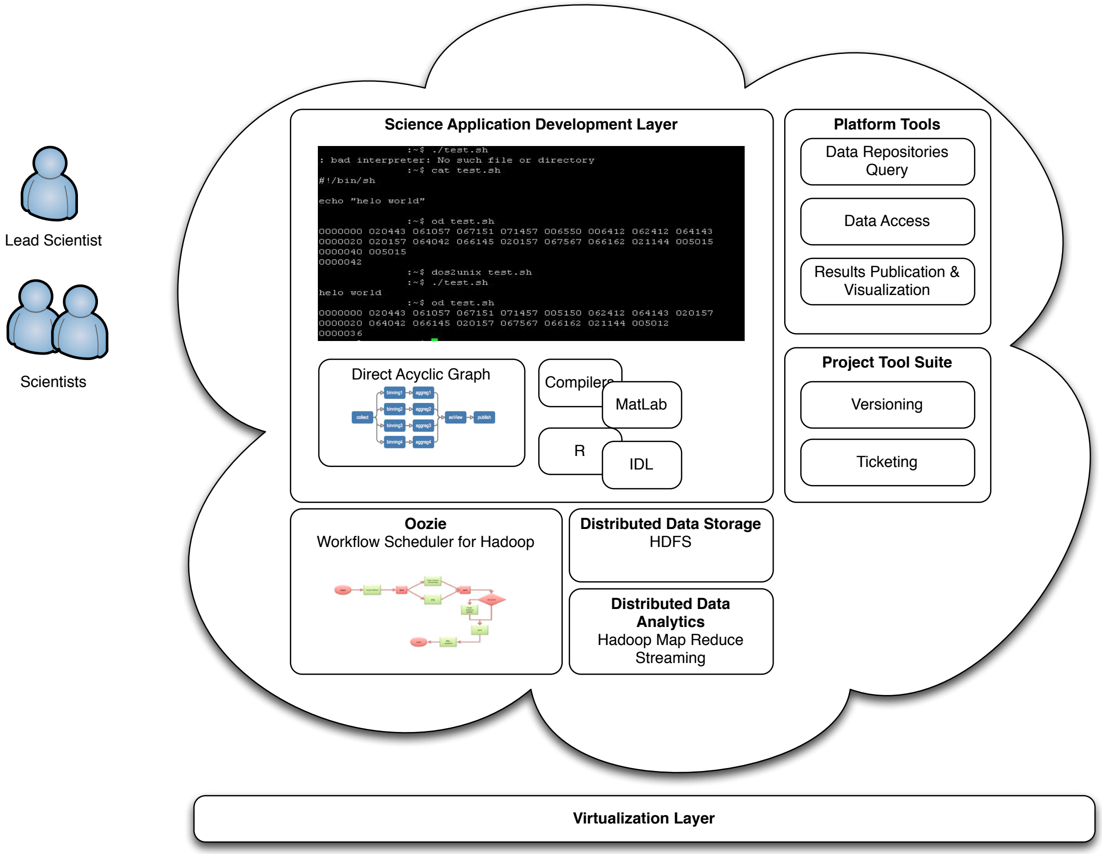
The second processing job as defined in the Application Descriptor file of the PaaS will be run as a set of tasks on a set of compute nodes monitored by the Hadoop framework. It will start the processing of an ensemble of input SAR data as a selection of products, downloaded and ingested by the SBAS processor. Then intermediary results are passed to the next processing step and so on.

5.3.4.3 Data processing service with OGC WPS-Hadoop

The PaaS service builds on technology designed for use cases having data-intensive requirements. CNR-IREA implemented the SBAS processing chain with full control of code, parameters & data flows, in a collaborative way within a shared Platform delivered as a Service (a "Developer Cloud Sandbox), and using Cloud APIs to stage data and deploy code on ad-hoc computing clusters.

Using Hadoop Streaming for applications integration, owners of processing algorithms are enabled to access distributed data holdings and to scale over computing clusters.

We present the main features of the PaaS in Figure 16 hereafter.



```
               :~$ ./test.sh
: bad interpreter: No such file or directory
               :~$ cat test.sh
#!/bin/sh

echo "helo world"

               :~$ od test.sh
0000000 020443 061057 067151 071457 006550 006412 062412 064143
0000020 020157 064042 066145 020157 067567 066162 021144 005015
0000040 005015
0000042
               :~$ dos2unix test.sh
               :~$ ./test.sh
helo world
               :~$ od test.sh
0000000 020443 061057 067151 071457 005150 062412 064143 020157
0000020 064042 066145 020157 067567 066162 021144 005012
0000036
```

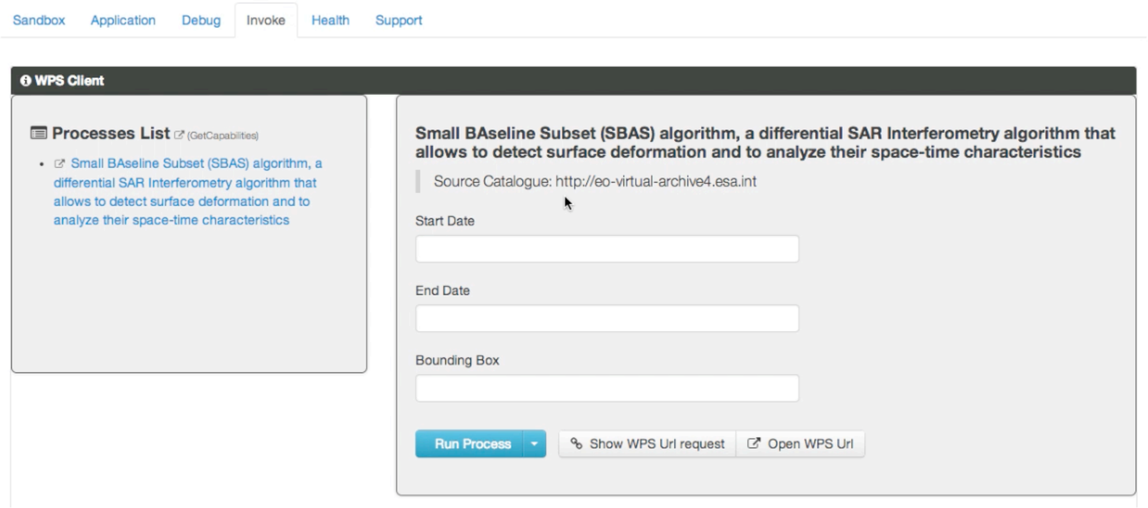
Figure 16 - Developer Cloud Sandboxes service: data processing with OGC WPS-Hadoop

The service is operated via the OpenNebula technology for managing virtualized computing nodes, and uses standard Cloud APIs (EC2, OCCI, JClouds) for the Cloud resources provisioning and Cloud Appliances deployment.

Client Applications interact with the processing layer via a simple OGC WPS interface, to trigger a processing, passing the selected processing parameters.

5.3.4.4 OGC-enabled Client application

A simple CSW OpenSearch and WPS client was integrated with the master node of the SBAS Cloud Appliance, so that users can configure a processing request over a selected area and for a selected time span. It offers an invocation interface for the user (cf. the "invoke" tab of the Cloud Appliance Dashboard in Figure 17 below).



- Small BAseline Subset (SBAS) algorithm, a differential SAR Interferometry algorithm that allows to detect surface deformation and to analyze their space-time characteristics

Small BAseline Subset (SBAS) algorithm, a differential SAR Interferometry algorithm that allows to detect surface deformation and to analyze their space-time characteristics

Source Catalogue: http://eo-virtual-archive4.esa.int

Figure 17 – The integrated OGC Client Application to configure a CSW OpenSearch query over a remote catalogue and stage data to the WPS triggered, Hadoop-enabled SBAS processing chain

This OGC Client application is interacting with a configured CSW OpenSearch endpoint (here the GEO Supersites Virtual Archive). The configuration is defined according to the type of inputs required by the processing chain, so that only the relevant query filters are available for the user (here the start and stop dates, and the bounding box).

5.3.4.5 Cloud Marketplace for OGC-enabled services

The SBAS Cloud Appliance is created using a snapshot of the OS and the Application disks of the SBAS Sandbox prepared under the Hadoop pseudo-cluster mode as presented earlier in Figure 16.

For the SBAS application, three different templates are defined for the Marketplace, one for the Hadoop Master node, one for the Hadoop Slave node, and one for the NFS server with an EBS storage. They are prepared with their related contextualization scripts.

This leads to a set of templates allowing to automatically configure a cluster, on a target Cloud where the Master has the Namenode, the secondary Namenode and the Jobtracker, while the Slaves will be in charge of the Datanode and the Tasktracker.

5.3.4.6 Cloud Appliance contextualization

The goal here is to automatically configure networking during the initialization process of the VM on the deployment Cloud. It consists in enabling the Virtual Machine images to use the contextualization information written by OpenNebula, via a series of scripts that will trigger the contextualization.

Testing it in with a simple scenario with the same SBAS Processor Appliance, in Master mode and in Slave Mode.

5.3.4.7 Cloud deployment on AWS

Resources provisioning is following the deployment plan: first a pool of 16 compute nodes to run a first processing, then a pool of 32 compute nodes to run the same processing.

The SBAS Appliance prepared with CentOS 6.4 vmdk disk format suitable for Amazon AWS is uploaded and tested on AWS Cloud.

5.3.5 Demo storyline and schedule

The storyline of the demo is structured in 4 phases, as summarized on Figure 18 below. The configuration and deployment tests occurred over March and April 2014.

5.3.5.1 The "Cloud Appliances Marketplace"

An OGC-enabled (WPS, CS-W OpenSearch) Cloud Appliance is defined as a template on Terradue's Cloud Platform, within a "Cloud Appliances Marketplace". From there, an authorized user (e.g. a customer) is requesting the service for using that appliance on a given Cloud, where he holds an account, for example on CNR-IREA private Cloud or on Amazon’s public Cloud.

5.3.5.2 The "Cloud Appliance contextualization"

This compute process (Cloud Appliance) is bursted from Terradue's Cloud Platform through a Cloud Controller component (OpenNebula powered), to the AWS Cloud Data Center via Cloud APIs. The Marketplace's API will trigger the following operations:

- Start a machine (a 'basic' Virtual Machine) on the AWS Cloud
- Point the machine at Terradue's Cloud Appliances Marketplace, for installing the required packages
- Start the contextualized appliance on that Cloud, for users to exploit it

5.3.5.3 The "data staging" from a Cloud storage third party

The compute process (Cloud Appliance) can now be accessed and ran by authorized users for processing datasets. Such datasets are typically hosted on a Cloud-enabled network storage. Here we leverage a scenario where a user asks to process Synthetic Aperture Radar (SAR) data from European Space Agency sensor, in order to monitor deformation phenomena of the earth's surface. Such ESA SAR data is hosted on an Interoute's Data Center (EU Cloud Provider).

- Data staging occurs between the compute and the storage Cloud units, as the connectivity / bandwidth between these Clouds allows for a "co-located resources" scenario (they benefit from a shared internet backbone, an established inter Data Center connectivity, etc...).

- Data is pipelined to the processing units, at the algorithm ingestion rate, with no additional persistence layer (only transient caching).
- Optional: the compute process (cloud appliance) is processing a dataset hosted on a storage unit attached to the processing cluster, potentially improving performance. This option was assessed during the OGC Testbed 10 timeframe as the initial condition (before remote data access testing).

5.3.5.4 The "results repatriation"

The processed SBAS end-products are based on so-called Interferograms, typically delivered as a "Displacement Map" (cf. http://bit.ly/L6jUFH).

- The resulting data is typically returned by the WPS service.
- Result data is stored back on a Cloud storage where the customer / requester has an account, e.g. stored back on Terradue's Cloud or Interoute's Cloud, or even a Dropbox user space.

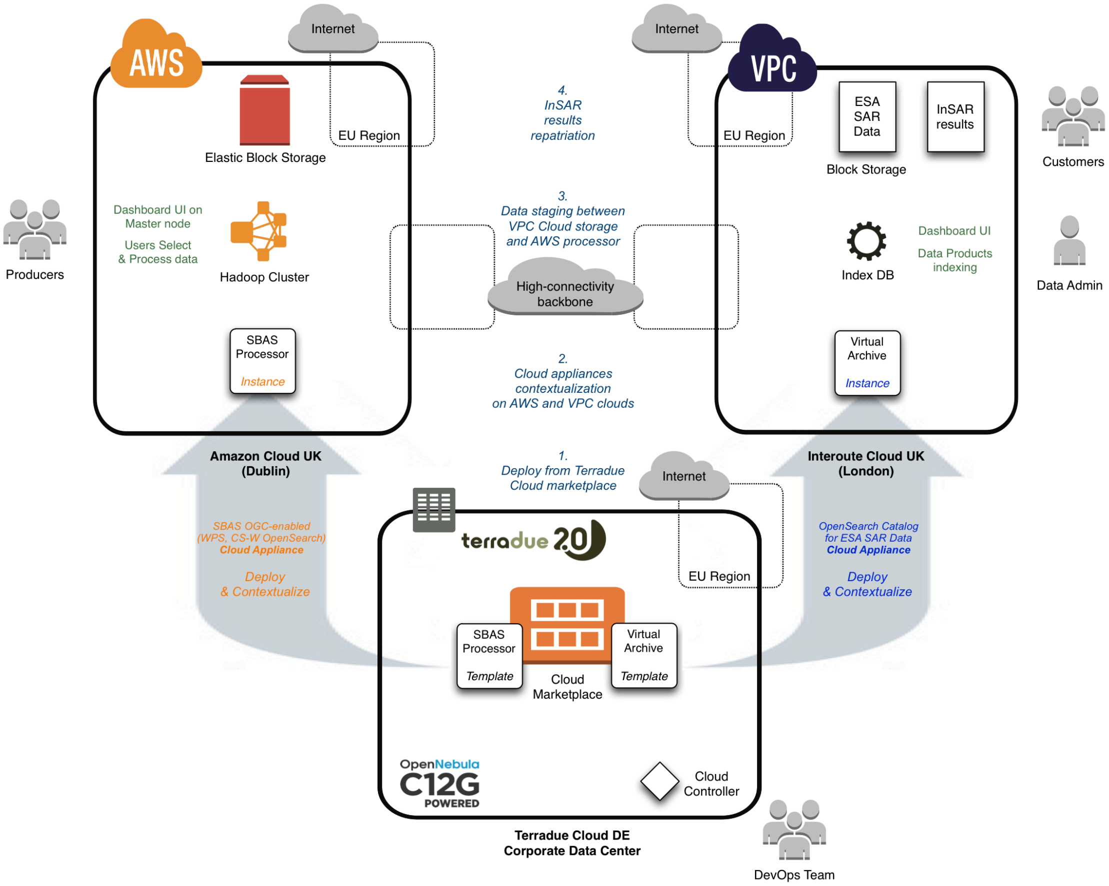


Figure 18 - The 4 phases of the OGC Testbed 10 SBAS Demo storyline

Cloud Broker role

In this scenario, Terradue operates as a Cloud Broker over hybrid-cloud Services, dedicated to the handling of complex Earth Sciences resources, like sensor data feeds and scientific processors. Such services enable end-to-end workflows (earth data catalogues, data staging, compute-intensive processing, value-added products delivery) across multi-tenant, distributed, computing infrastructures.

Data Services performance through Cloud deployments

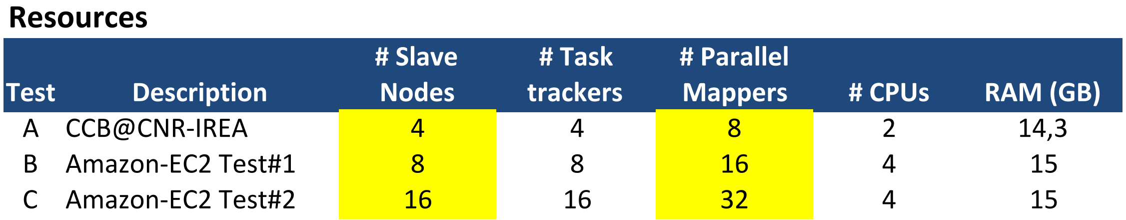
The SBAS application is leveraging the SSEP virtual archive. This archive represents ESA contribution to the GEO Supersites initiative: a huge amount of SAR data, today over thirty thousand (30,000) products, accessible to science communities dealing with interferometry, landslide and change detection. In this scenario, the performance of OGC-enabled Cloud services is studied, for accessing earth data catalogues (CSW OpenSearch, cf. http://www.opengeospatial.org/standards/opensearchgeo), and exposing Hadoop-enabled processor service capabilities to OGC Client applications (WPS-Hadoop, cf. http://www.opengeospatial.org/blog/1866 "Accessing the Cloud with OGC Services").

Benefits

The SBAS (Small BAseline Subset) application purpose is to process and feed data products (interferograms, typically delivered as "Displacement Maps") for the scientific monitoring of sensible geologic areas (volcano areas, geologic faults...). This allows the creation of comprehensive time series over geologic phenomena, supporting scientific advising towards decision makers.

5.3.6 Performance enhancement results

5.3.6.1 Cloud compute resources scaling



Resources

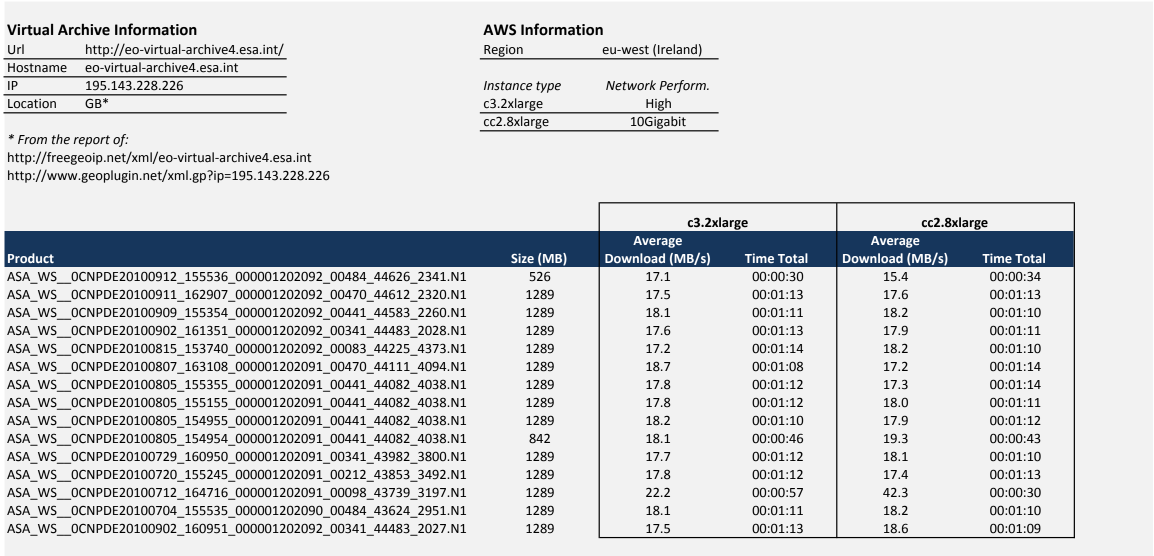
Test	Description	# Slave Nodes	# Task trackers	# Parallel Mappers	# CPUs	RAM (GB)
A	CCB@CNR-IREA	4	4	8	2	14,3
B	Amazon-EC2 Test#1	8	8	16	4	15
C	Amazon-EC2 Test#2	16	16	32	4	15

Figure 19 – Resources scaling scenarios for the SBAS processing

The Test A “CCB@CNR-IREA” is a reference test, ran before the OGC Testbed 10 Experiment on the CNR-IREA private Cloud.

The Test B is performed in order to verify the algorithm scalability at each of its processing steps (i.e. the nodes of the SBAS workflow). The compute resources are doubled from Test A to Test B. Same for the scaling from Test B to Test C, except that we keep the same number of CPU Cores per Server.

5.3.6.2 Connectivity for inter-Cloud data staging



Virtual Archive Information

Url	http://eo-virtual-archive4.esa.int/
Hostname	eo-virtual-archive4.esa.int
IP	195.143.228.226
Location	GB*

** From the report of:*
http://freegeoip.net/xml/eo-virtual-archive4.esa.int
http://www.geoplugin.net/xml.gp?ip=195.143.228.226

AWS Information

Region	eu-west (Ireland)

Instance type	*Network Perform.*
c3.2xlarge	High
cc2.8xlarge	10Gigabit

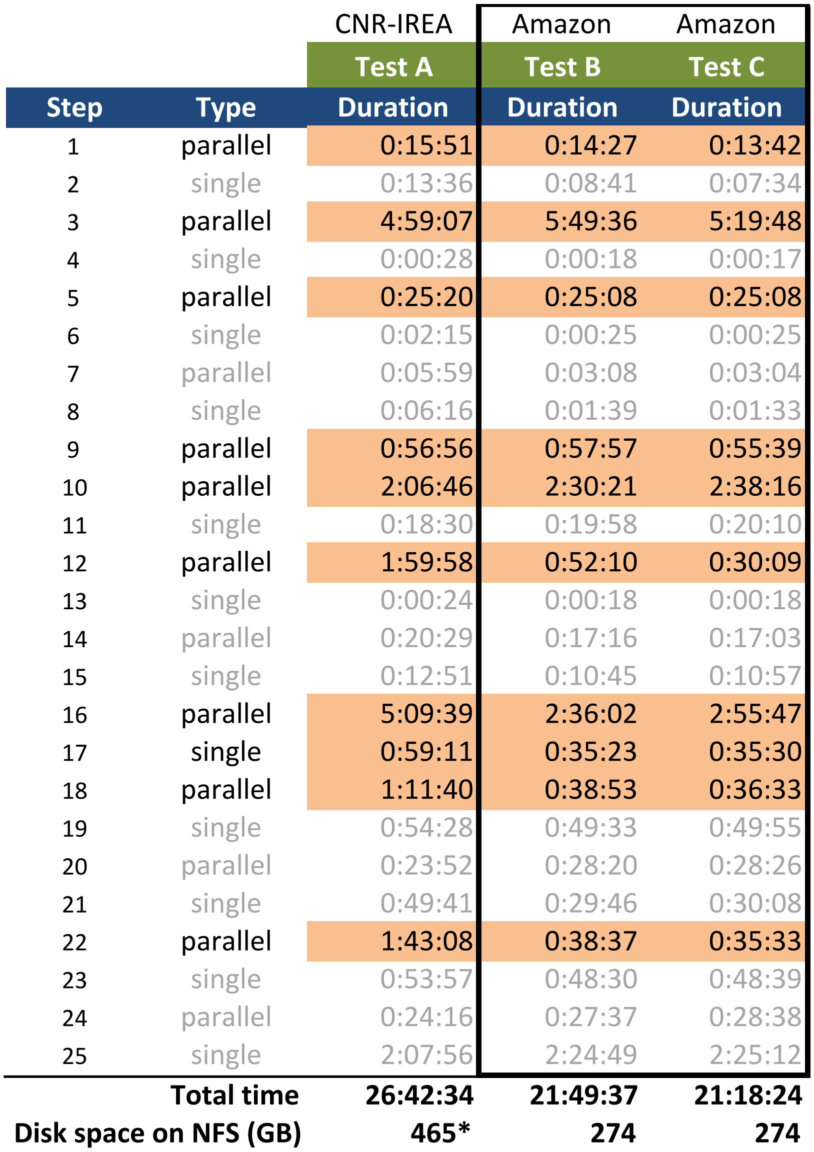
		c3.2xlarge		**cc2.8xlarge**	
Product	**Size (MB)**	**Average Download (MB/s)**	**Time Total**	**Average Download (MB/s)**	**Time Total**
ASA_WS__0CNPDE20100912_155536_000001202092_00484_44626_2341.N1	526	17.1	00:00:30	15.4	00:00:34
ASA_WS__0CNPDE20100911_162907_000001202092_00470_44612_2320.N1	1289	17.5	00:01:13	17.6	00:01:13
ASA_WS__0CNPDE20100909_155354_000001202092_00441_44583_2260.N1	1289	18.1	00:01:11	18.2	00:01:10
ASA_WS__0CNPDE20100902_161351_000001202092_00341_44483_2028.N1	1289	17.6	00:01:13	17.9	00:01:11
ASA_WS__0CNPDE20100815_153740_000001202092_00083_44225_4373.N1	1289	17.2	00:01:14	18.2	00:01:10
ASA_WS__0CNPDE20100807_163108_000001202091_00470_44111_4094.N1	1289	18.7	00:01:08	17.2	00:01:14
ASA_WS__0CNPDE20100805_155355_000001202091_00441_44082_4038.N1	1289	17.8	00:01:12	17.3	00:01:14
ASA_WS__0CNPDE20100805_155155_000001202091_00441_44082_4038.N1	1289	17.8	00:01:12	18.0	00:01:11
ASA_WS__0CNPDE20100805_154955_000001202091_00441_44082_4038.N1	1289	18.2	00:01:10	17.9	00:01:12
ASA_WS__0CNPDE20100805_154954_000001202091_00441_44082_4038.N1	842	18.1	00:00:46	19.3	00:00:43
ASA_WS__0CNPDE20100729_160950_000001202091_00341_43982_3800.N1	1289	17.7	00:01:12	18.1	00:01:10
ASA_WS__0CNPDE20100720_155245_000001202091_00212_43853_3492.N1	1289	17.8	00:01:12	17.4	00:01:13
ASA_WS__0CNPDE20100712_164716_000001202091_00098_43739_3197.N1	1289	22.2	00:00:57	42.3	00:00:30
ASA_WS__0CNPDE20100704_155535_000001202090_00484_43624_2951.N1	1289	18.1	00:01:11	18.2	00:01:10
ASA_WS__0CNPDE20100902_160951_000001202092_00341_44483_2027.N1	1289	17.5	00:01:13	18.6	00:01:09

Figure 20 - Inter-Cloud Data staging network assessment

The inter-Cloud network assessment illustrates the network performance between the ESA Virtual Archive @Interoute-London and a VM Client @AWS-Ireland.

It shows that the data staging time for ingesting products in the processing chain is negligible in comparison to the overall SBAS processing time (taken from the reference Test A "CCB@CNR-IREA", see the next section for the comparison of all the Tests processing times).

5.3.6.3 SBAS compute times per processing steps



		CNR-IREA	Amazon	Amazon
		Test A	Test B	Test C
Step	Type	Duration	Duration	Duration
1	parallel	0:15:51	0:14:27	0:13:42
2	single	0:13:36	0:08:41	0:07:34
3	parallel	4:59:07	5:49:36	5:19:48
4	single	0:00:28	0:00:18	0:00:17
5	parallel	0:25:20	0:25:08	0:25:08
6	single	0:02:15	0:00:25	0:00:25
7	parallel	0:05:59	0:03:08	0:03:04
8	single	0:06:16	0:01:39	0:01:33
9	parallel	0:56:56	0:57:57	0:55:39
10	parallel	2:06:46	2:30:21	2:38:16
11	single	0:18:30	0:19:58	0:20:10
12	parallel	1:59:58	0:52:10	0:30:09
13	single	0:00:24	0:00:18	0:00:18
14	parallel	0:20:29	0:17:16	0:17:03
15	single	0:12:51	0:10:45	0:10:57
16	parallel	5:09:39	2:36:02	2:55:47
17	single	0:59:11	0:35:23	0:35:30
18	parallel	1:11:40	0:38:53	0:36:33
19	single	0:54:28	0:49:33	0:49:55
20	parallel	0:23:52	0:28:20	0:28:26
21	single	0:49:41	0:29:46	0:30:08
22	parallel	1:43:08	0:38:37	0:35:33
23	single	0:53:57	0:48:30	0:48:39
24	parallel	0:24:16	0:27:37	0:28:38
25	single	2:07:56	2:24:49	2:25:12
	Total time	**26:42:34**	**21:49:37**	**21:18:24**
Disk space on NFS (GB)		**465***	**274**	**274**

Figure 21 – Comparison of SBAS Compute time per scalability scenario

The tests show that in such cases the scalability is offering interesting gains in processing time (e.g. step 10), while for other cases, there are performance issues specifically pointed out, that allow CNR researchers to investigate new strategies for the optimization of these processing steps.

Also to be considered are strategies in terms of architecture. For example this deployment had the NFS component as a single point of write operations. In the case of processing step 10 where there are only CPU-consuming operations, the elastic compute scalability is providing obvious gains (doubling the resources, the processing time halved). In other cases when the processes perform significant disk-access operations (on the NFS shared disk) the scalability gain can be diluted.

5.3.7 Lessons learned and future work

Distributed processing can be difficult to prototype and manage, and a cautious protocol is required in order to assess improvement areas. During the OGC Testbed 10, We proceeded with three phases of testing, with growing complexity in the way data staging and parallelization were handled.

For this production scenario, the overall processing time was a satisfaction for the CNR-IREA team, and Terradue communicated to CNR-IREA several possible improvement areas for the SBAS processing chain, that have been identified during the Testbed work, thus continuing our collaboration for improved scientific applications, both in terms of time to market and operational cost.

As a result of this testbed, user organizations are able to request service providers (data provider, algorithm provider) to operate under a multi-tenant Cloud environment with specific performance constraints, in order to build and run scientific applications that deliver added-value products.

Using the OpenNebula Hybrid Cloud management technology, a service provider can efficiently deploy its OGC-enabled resources on-demand, for Cloud Storage and Cloud Compute. The result is a fully distributed, interoperable, end-to-end Customer application running on a federated Cloud, allowing the exploitation of existing and disparate resources (large Earth data archives, compute-intensive algorithms).

As an illustrated benefit, the SBAS (Small BAseline Subset) application purpose is to process and feed data products (interferograms, typically delivered as "Displacement Maps") for the scientific monitoring of sensible geologic areas (volcano areas, geologic faults...). This contribution to the Testbed showed the technical principles allowing the creation of comprehensive time series (9 years) over geologic phenomena (Naples volcanic area), supporting scientific advising towards decision makers.