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Using Google Earth for Internet GIS

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“I declare that this dissertation represents my own work, and that where the work of others has been used it has been duly accredited. I further declare that the length of the components of this dissertation is 5132 words for the Research Paper and 4544 words for the Supporting Document.”

Name:

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USING GOOGLE EARTH FOR INTERNET GIS

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Abstract

The goal of this research is to investigate the potential of using Google Earth for Internet GIS applications. The study specifically examines the use of vector and attribute data and the potential of displaying and processing this data in new ways using the Google Earth platform. It has increasingly been recognised that future developments in GIS will centre on Internet GIS, and in three major areas: GIS data access, spatial information dissemination and GIS modelling/processing. Google Earth is a 3-D geobrowser that has been termed the 'the democratisation of GIS' and is one of a family of geobrowsers that offer a free and easy to use service that enable data with a spatial component to be overlain on top of a 3-D model of the Earth. This research creates a methodological framework to achieve its goal that consists of three major parts: a database tier, an application tier and a client tier. As proof of concept a web prototype has been developed, called VISQUE – VISualise and Query Using Earth, which integrates a diverse range of datasets from 18th century Iceland and lets users direct queries and create visualisations of this custom data. The results revealed that both vector and attribute data can be effectively represented and visualised using Google Earth. Moreover, the functionality to query custom data and visualise results has been added to the Google Earth platform.

1 Introduction

The purpose of this research is to examine the potential of using Google Earth for developing Internet GIS applications. This study explores the possibility of extending the existing capabilities of Google Earth in displaying and processing vector and attribute data. An original web prototype, called VISQUE – VISualise and Query Using Earth, has been developed as proof of concept which enables multiple historical and modelled datasets about 18th century Iceland to be combined, visualised and analysed in novel and easily accessible ways. The recent development of powerful and intuitive Geobrowsers

and Map APIs¹ (Application Programming Interfaces) have dramatically contributed to the growing interest in the development and implementation of distributed GIS through the Internet.

“Since the emergence of the Internet in the 1990s, there has been a paradigmatic shift in all aspects of Geographic Information Systems (GIS). The conceptual model (and hence its technology) of GIS has undergone a trend of transformation – from an isolated architecture to an interoperable framework, from a standalone solution to a distributed approach, from individual proprietary data formats to open specification exchange of data, from a desktop platform to an Internet environment.”

(Chow, 2008)

In recent times traditional GIS² have become exclusionary, expensive and increasingly technocratic (Miller, 2006), while at the same time much literature has acknowledged the importance of recent advances in web services, geobrowsers and Map APIs. Smiatek has (2005) described the implementation of web services as a platform for climate models accessing GIS databases. Tait (2005) discusses the evolution of geoportal applications into truly distributed GIS using web services technology. Butler (2006), Nourbakhsh (2006) and Pearce (2007) have praised Google Earth in conducting research in 3D space for a range of scientific projects and the use of Google Maps API and GML (Geographic Mark-up Language) have been shown to have great potential for developing Internet GIS solutions (Chow, 2008). Although Internet GIS have been widely accepted as representing an important advancement over the traditional desktop GIS and internet-based GIS software is being developed to fill various needs and demands (Peng and Tsou, 2003), geobrowsers are not considered to be true GIS as they have limited capabilities and lack many of the tools to support analytic, modelling, and inferential operations of traditional GIS (Goodchild, 2008; Patterson, 2007).

In order to tackle the shortcomings of virtual globes this paper describes how a new development, called VISQUE, enhances Google Earth and adds greater capabilities for data display and processing. It is shown that data stored in a spatial database can be effectively visualised, graphed and queried through the use of the Google Earth platform. The approach taken illustrates the potential for developing Internet GIS solutions with Google Earth and provides useful insights into the future development of Google Earth for Internet GIS applications.

2 Background

Internet GIS is a research and application area that utilises the internet to facilitate the access, processing, and distribution of geographic data and spatial analysis knowledge. The Internet is affecting GIS in three major areas: GIS data access, spatial information dissemination and GIS modelling/processing (Peng and Tsou, 2003). It has increasingly been recognised that future developments in GIS will centre on Internet GIS (Peng and Tsou, 2003; Plewe, 1997) Most GIS vendors have developed their own Internet GIS Software, including ESRI's ArcIMS and ArcGIS Server, Intergraph's Geomedia Web

¹ APIs give web developers access to the map functionalities.

² Traditional GIS here refers to comprehensive desktop systems generally acquired through licensing agreements.

Map, Autodesk's MapGuide, MapInfo's MapXtreme and GE SmallWorld Internet GIS Application Server. These Internet GIS provide proprietary ways to allow users to access, display and query spatial data over the web but can be expensive. Google Earth is one of a family of 3-D geobrowsers (that includes Microsoft's Virtual Earth, NASA's World Wind and ESRI's ArcGIS Explorer) that offer a free and easy to use service for visualising a 3D digital model of the earth via the Internet. It is readily extended to act as an output medium for a wide range of products that contain spatial data and facilitates data access and spatial information dissemination.

Google Earth has been termed 'the democratisation of GIS', as it has exposed geographic information technology to virtually everyone and geobrowsers are now used by a growing number of scientists as they enable data with a spatial component to be overlain on top of remotely sensed imagery (Butler, 2006; Goodchild, 2008). The release of the KML (Keyhole Mark-up Language) grammar specifications has allowed more sophisticated use of the service. KML is an XML language focused on geographic visualization, including annotation of maps and images. KML Version 2.2 has been adopted as an OGC³ implementation standard and is complementary to most of the key existing OGC standards including GML (Geography Markup Language), WFS (Web Feature Service) and WMS (Web Map Service). Currently, KML 2.2 utilizes certain geometry elements derived from GML 2.1.2, including, line string, linear ring, and polygon. The OGC and Google have agreed that there can be additional harmonization of KML with GML (e.g. to use the same geometry representation) in the future (Wilson, 2008).

Table 1: Common 3-D geobrowsers with supported technologies. By supporting these technologies geobrowsers have the potential to be used for Internet GIS. Only Google Earth supports all 3 enabling technologies.

Geobrowser	KML Support	JavaScript Support	Full HTML Support	Flash Support
Google Earth	Full	Yes	Yes	Yes
Google Earth Plug-in	Intermediate	Yes	No	Yes
NASA World Wind	Limited	No	No	No
ArcGIS Explorer	Limited	No	No	No
Microsoft Virtual Earth	Limited	Yes	No	No
ossimPlanet	Limited	No	No	No

Access to and transfer of spatial data over the internet are the first steps toward true Internet GIS. The ability to access GIS analysis functions and to conduct GIS analysis anywhere over the internet is the next important step (Peng and Zhang, 2004). This research takes Google Earth towards 'the next important step', that is, adding the ability to access GIS analysis functions over the Internet. The adoption of KML as an OGC standard has meant that GIS vendors have added the tools to export layers as KML. This means that more people can easily combine their own data with various other data

³ The Open Geospatial Consortium is a non-profit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location based services.

sources, both qualitative and quantitative, in a geobrowser and create new insight. Unlike other 3-D geobrowsers Google Earth supports a number of technologies that enable its use for Internet GIS. Table 1 lists the common 3-D geobrowsers and their support for the enabling technologies. The proposed framework, described in the following section, is reliant on Google Earth's full support of HTML, JavaScript and Flash, and they provide the means of achieving the research goals.

Human vision and domain expertise are powerful tools that (together with computational tools) make it possible to turn large heterogeneous data volumes into information and, subsequently, into knowledge (understanding derived from integrating information) (MacEachren and Kraak, 2001). 3-D geobrowsers are powerful visualisation tools that can assist in an interactive search for trends, support information exploration and knowledge construction, and prompt hypotheses. Since the vision of Digital Earth⁴ put forward by former American Vice-President Al Gore 10 years ago (Gore, 1999), rapid technological advancements have meant that many of the elements contained within that vision are now freely available to the public. The vision was that of a system providing access to our combined knowledge of the planet and human activities, for any point in history, via responses to queries and exploratory tools. Furthermore, it would accommodate modelling extensions for predicting future conditions.

Some recent literature has focused on the vision for next-generation Digital Earth (Craglia et al., 2008; Davis Jr. et al., 2009; Grossner et al., 2008) which Grossner et al (2008) contend to be a worth while "Grand Challenge" for the GIScience community. This challenge involves the development of an application that will help to increase our collective understanding of the state of our planet and the interactions between physical and societal environments on it (Craglia et al., 2008). To direct queries and create visualizations of uploaded data is implicit in Gore's vision and an essential element of the next-generation Digital Earth. This research aims to enhance the capabilities of Google Earth so the user can direct queries and create visualisations of custom data. A number of key questions need to be addressed to achieve these goals: (1) How can the ability to query custom data be built into Google Earth; (2) How can visualisations of custom data be achieved; and (3) how best can Google Earth be exploited to visualise spatial patterns changing through time. These questions are used to set three specific objectives: (1) implement a database tier; (2) develop an application tier; and (3) and develop a client tier.

3 Approach and Methods

To accomplish the specified objectives of this research and develop the utility of Google Earth for Internet GIS applications this research creates a methodological framework for processing vector and attribute data and visualising it. The conceptual model used here consists of three major parts: (1) the database tier; (2) VISQUE, the application tier; and (3) client tier. Figure 1 illustrates the system overview with associated technology.

⁴ Digital Earth here is reserved for the vision of next generation 3-D browsers.

3.1 Database Tier

The foundation of the system is a spatial database and all data is stored here. The database used is an Oracle⁵ relational database and it is accessed using SQL.

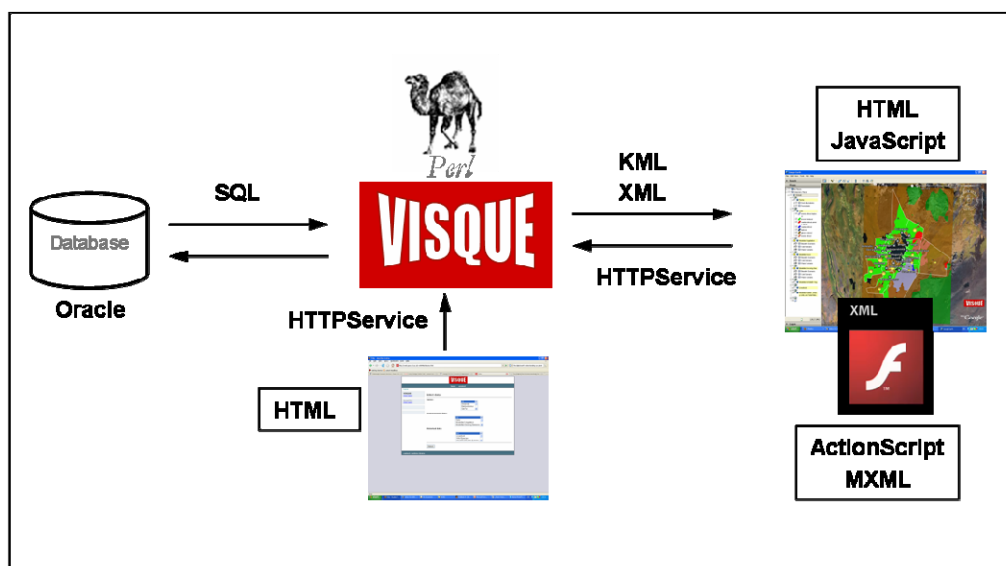


Figure 1: System overview.

The Oracle RDMS is used because it has superior spatial support. PostgreSQL/PostGIS⁶, has much of the functionality, however, at this time it lacks geodetic support. The Oracle database is a proprietary system; in the future PostgreSQL/PostGIS could be used, as geodetic support is being developed (PostGIS, 2009), to make this system a completely open-access and open-source solution. The case study for this research involves the use temporal data (discussed in the next section), therefore it is essential that all data has an associated timestamp. Furthermore, it is require that the system be scalable and so no restrictions exist in the data model that could impede expansion. An important aspect of Google Earth is the projection system it uses. Google Earth is a tool based on global coverage and has adopted the WGS84⁷ geographic coordinate system of latitude and longitude. Hence, for geospatial datasets that are in a projected map coordinate system, it is essential to pre-process the data by transforming the map projection into latitude and longitude before loading geometries into the database. A full description of the data processing procedure is described in the supporting document (Henry, 2009).

⁵ <http://www.oracle.com/>

⁶ PostgreSQL is a open source object-relational database system. PostGIS adds support for geographic objects to the PostgreSQL database (<http://postgis.refrations.net>).

⁷ World Geodetic System 1984 Co-ordinate Reference System.

3.2 Design and Implementation of VISQUE

VISQUE is the middleware application of the system. It enables communication between the tiers, and processes system inputs and outputs. VISQUE comprises a number of modules which: (1) parse user selections from the web interface and initialise features; (2) access and query the database via a web server and generate files for use in Google Earth and Flash; and (3) parse further user queries generated from within Google Earth. User selections made through the web interface are used to query the database and result in individual data layers being rendered in Google Earth. The process involves a Perl script parsing user selections, querying the database and generating KML. The KML <NetworkLink> element is used to invoke individual Perl scripts through specified URL's which initialise each feature.

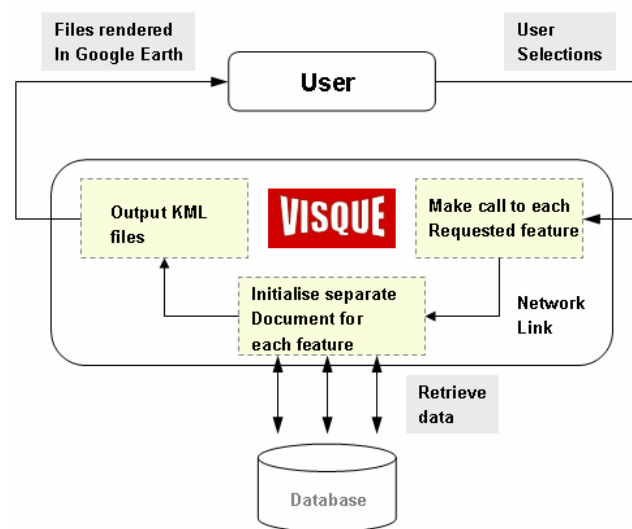


Figure 2: Schema demonstrating VISQUE's production of KML files.

In turn, each NetworkLink is established and the script creates a KML document to hold the generated feature. Through use of the DBI, the standard database interface module for Perl, the database is queried for the individual features. Many of the data layers model real world objects and the geometries are sophisticated. GML is capable of encoding complicated geometries and with no native support for KML in Oracle 10g geometries are queried so as return GML. To duplicate the GML encoding with KML encoding the query was written so that the GML syntax elements were replaced with KML syntax on the fly. Examples of the query syntax are available in the supporting document (Henry, 2009). Figures 3 and 4 illustrate the similarities between the two formats.

```

<gml:Polygon srsName="SDO:8307" xmlns:gml="http://www.opengis.net/gml">
  <gml:outerBoundaryIs>
    <gml:LinearRing>
      <gml:coordinates decimal="." cs="," ts=" ">
        -16.8774, 65.763437
        -16.867331, 65.776268
        -16.868998, 65.78385
        -16.907922, 65.782401
        -16.898054, 65.770712
        -16.8774, 65.763437
      </gml:coordinates>
    </gml:LinearRing>
  </gml:outerBoundaryIs>
</gml:Polygon>

```

Figure 3: Sample GML encoding of snow cover geometry.

VISQUE controls the generation of all features, including data layers, models and attribute data, and the styling of all features. VISQUE also adds charting and querying functionalities to Google Earth and are described in the next section.

```

<Polygon>
  <tessellate>1</tessellate>
  <altitudeMode>clampToGround</altitudeMode>
  <outerBoundaryIs>
    <LinearRing>
      <coordinates>
        -16.8774,65.763437
        -16.867331,65.776268
        -16.868998,65.78385
        -16.907922,65.782401
        -16.898054,65.770712
        -16.8774,65.763437
      </coordinates>
    </LinearRing>
  </outerBoundaryIs>
</Polygon>

```

Figure 4: Sample output of query representing the same geometry as in figure 3 but with GML encoding replaced with KML encoding.

3.3 Charting Functionality

Since Google Earth release 4.2 (Sept. 2007) it has been possible to embed Flash video inside description balloons. To enhance Google Earth's capabilities (and user interaction) a charting application was developed using Adobe Flex and was embedded inside a description balloon. Adobe Flex produces SWF files, a format which is supported by Adobe Flash Player and consequently by Google Earth. The SWF file format is an open specification and in this case delivers vector graphics and text (but can also deliver video and sound).

Flex is a framework for developing rich internet applications and is built around ActionScript and Flash Player. Like JavaScript, ActionScript is based upon the

ECMAScript specifications and both languages share a similar syntax. Within Flash, ActionScript is designed to be asynchronous, allowing for greater processing speed when executing code and passing data (Korhonen et al., 2008). The framework also supports an XML-based language called MXML that can be used in the specification and development of user interfaces.

Once opened, the graphing tool's HTTPService component allows for a HTTP request to be made and response data to be retrieved. Figure 5 illustrates the communication between VISQUE and the graphing tool. A HTTP request is made to VISQUE, the database is queried and an XML document is produced containing the requested data. This document is retrieved by the graphing tool and the application is rendered within a balloon. This research utilises the Flex Scatter Plot charting component and a Radar Chart component developed by a third party, Kaplab⁸, although, a greater number of components could be integrated without affecting performance (Korhonen et al., 2008).

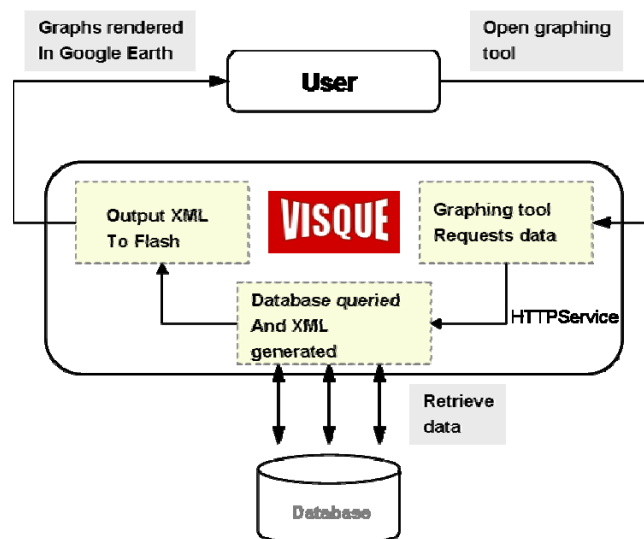


Figure 5: Scheme demonstrating VISQUE's production of XML for the graphing tool.

3.4 Data Query

Many Maps API provide the functionality to query data, however, the ability to query custom data in Google Earth is absent. Google Earth 5.0 supports plain text content, as well as full HTML and JavaScript within description balloons. Contents of the description tag are rendered by the WebKit⁹ open source web browser engine, and are displayed as they would be in any WebKit-based browser. This feature has been exploited to enable the querying of the underlying spatial database from within the Google Earth service. When VISQUE produces KML documents containing data layers and attribute data it also creates an additional document which generates a balloon containing the query window. The query window comprises a JavaScript-enhanced form that allows the user to create queries. These queries are passed to VISQUE, parsed and passed to the database.

⁸ <http://labs.kapit.fr/display/kaplabhome/Home>

⁹ <http://webkit.org/>

Depending on the query type, VISQUE will generated output as a table in HTML or as a layer in KML.

3.5 Data Visualisation in KML

VISQUE adopts a number of visualisation techniques to handle the diverse set of data types used in the case study. Polygon overlay, 3-D models and extruded polygons have been utilised to visualise spatial data. 3-D Collada models are used as proportional symbols to represent attribute data. Collada is an XML schema that enables 3-D authoring applications to freely exchange digital assets (Collada, 2007). As models cannot be contained in the KML document, they had to be created separately using Google Sketchup, authoring software for creating 3-D models, and stored on a remote web server. The models were then referenced from within the KML document. Collada models are loaded and proportionally scaled using the values they represent. Stacked 3-D bars are also used to visualise spatial data. A custom technique was used to achieve this. Extruded polygons can be used to create 3-D bars but these have to be a continuous colour. By assigning a number of bars the same location, giving them cumulative values and differing styles they appear to be one stacked bar. The size of each *stack* is proportional to the attribute value it represents.

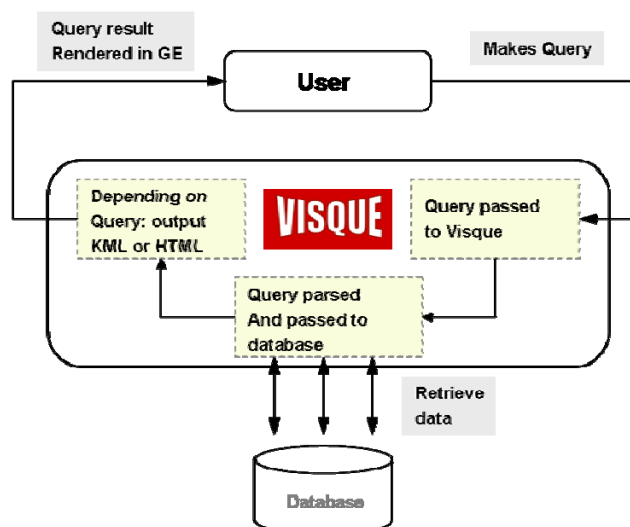


Figure 6: VISQUE's handling of user defined queries.

3.6 Summary

Through its adoption of supporting technologies and full implementation of KML Google Earth has the potential as a platform for Internet GIS. This research developed a web prototype that disseminates spatiotemporal data to demonstrate this. In the following section a case study of 18th century Iceland is described.

4 Prototype Implementation

In the last 20 years the North Atlantic has become an arena for much interdisciplinary research into long-term, human-environment interactions and their connection with present issues of rapid environmental change and human response (McGovern et al., 2007). The regional research cooperative North Atlantic Biocultural Organisation (NABO¹⁰) was born out of such research and formally established in 1992. NABO promotes investigations throughout the North Atlantic region in areas such as archaeology, palaeoecology, palaeoeconomy, zooarchaeology and tephrochronology but to name a few. However, the effective integration of these diverse data sets remains challenging, and the appropriate weighting to be given to different categories of evidence is unclear (Vésteinsson et al., 2002). This indicates the need for a widely available GIS that can be used by a variety of researchers (from academics and institutions to members of the public) from many different backgrounds in the sciences, arts and humanities. This GIS needs to be able to span disciplinary and international boundaries, appeal to both technical and non-technical users, and be available free at the point of use. Therefore, this research uses Google Earth to integrate a diverse set of data sources and provide graphing and querying capabilities of the data sets. The web prototype developed aims to provide the NABO research community, and hopefully a much wider community, with a set of interactive tools which will enhance their ability to visualise and hypothesise in four dimensions; those of topography and time.

4.1 Study Area and Datasets

The area chosen for this research is a district in NE Iceland known as the Mývatn district or Mývatnssveit. This volcanically active region has provided evidence that suggests it was colonised in the first wave of Landnám¹¹ in Iceland, c. 871 AD (McGovern et al., 2007). The first settlers practiced a subsistence economy based upon domestic animals, some cereal cultivation and the exploitation of wild resources (Amorosi et al., 1997). Rapid deforestation and grazing pressures by imported domesticates has been followed by dramatic levels of soil erosion from which the landscape is still suffering today. The immediate area around Mývatn suffers little or no erosion, however, the extensive barren areas to the north and south suffer from erosion that is classed as severe or extremely severe (Arnalds et al., 2001). A key question is how this has come to be; was it the result of human agency, climate change, volcanic impacts, or some combination of all these? The ability to visualise the timing and pattern of change can help to better understand human-environment interaction and assess how communities create or lose resilience (Diamond, 2005; Dugmore et al., In Press).

This research uses historical and modelled data from the early modern period. This was chosen because it presents some of the earliest high resolution data on farming practice and is sufficiently far enough into the past to have created a distinct physical environmental record. In addition climate conditions were very different, so numerically

¹⁰ www.nabohome.org

¹¹ Landnám is old Norse for 'land taking' and is used to describe Norse colonisation of North Atlantic islands.

modelled climates contrast markedly with today. The readily available Jarðabók¹² data from 1712, farm boundaries and farmstead locations, modelled scenarios of vegetation cover, growing season and snow cover, and soil data have all been integrated. This example poses an ideal case study for this application development: how to visualise and query complex data to tackle non-trivial questions.

The web prototype adopted the proposed framework outlined in the previous section. All data was stored on a remote database, program logic (e.g. Perl scripts) and presentation tiers (HTML, JavaScript, SWF, CSS) were stored in a web server. The application is available at: <http://xweb.geos.ed.ac.uk/~s0898629/home.html>

5 Results

A selection of examples are used here to illustrate the capabilities of Google Earth with the VISQUE application tier. Figure 7 shows the study area with all layers that have been added displayed in the contents window.

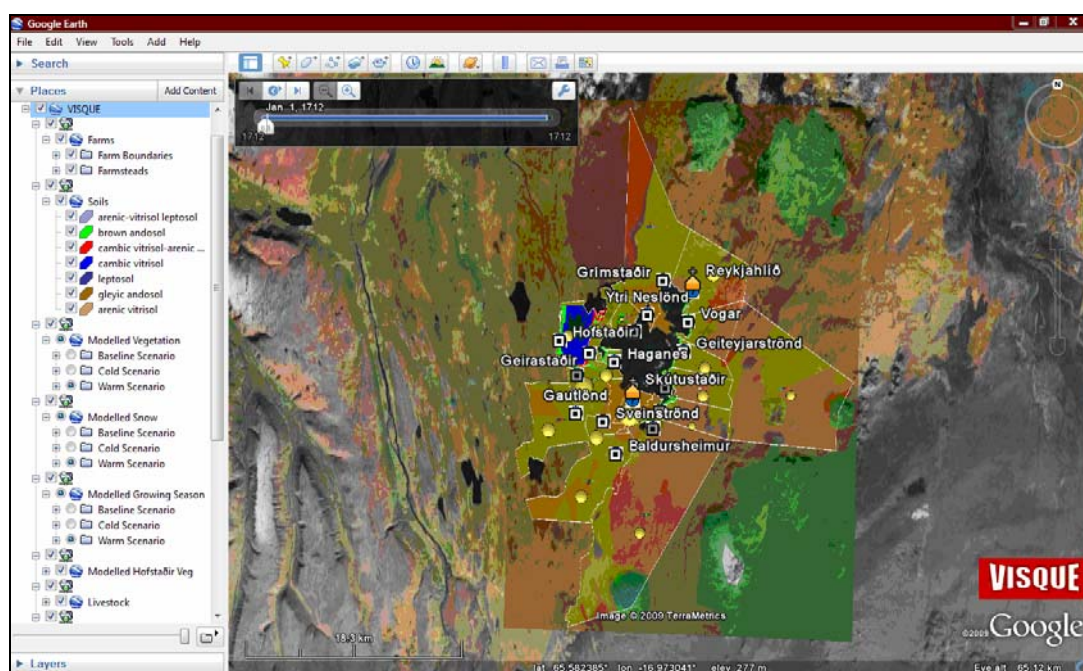


Figure 7: Extent of study area with various layers open in the contents window.

This figure illustrates a variety of data types including: points and polygons representing farmsteads and farm boundaries; styled polygons which represent different soil types; empirical livestock data is represented by 3-D stacked bars and modelled fodder data is visualised using simple spherical models positioned above each farm.

¹² The first national farm census of Iceland undertaken between 1706 and 1714 on behalf of the Danish colonial government.

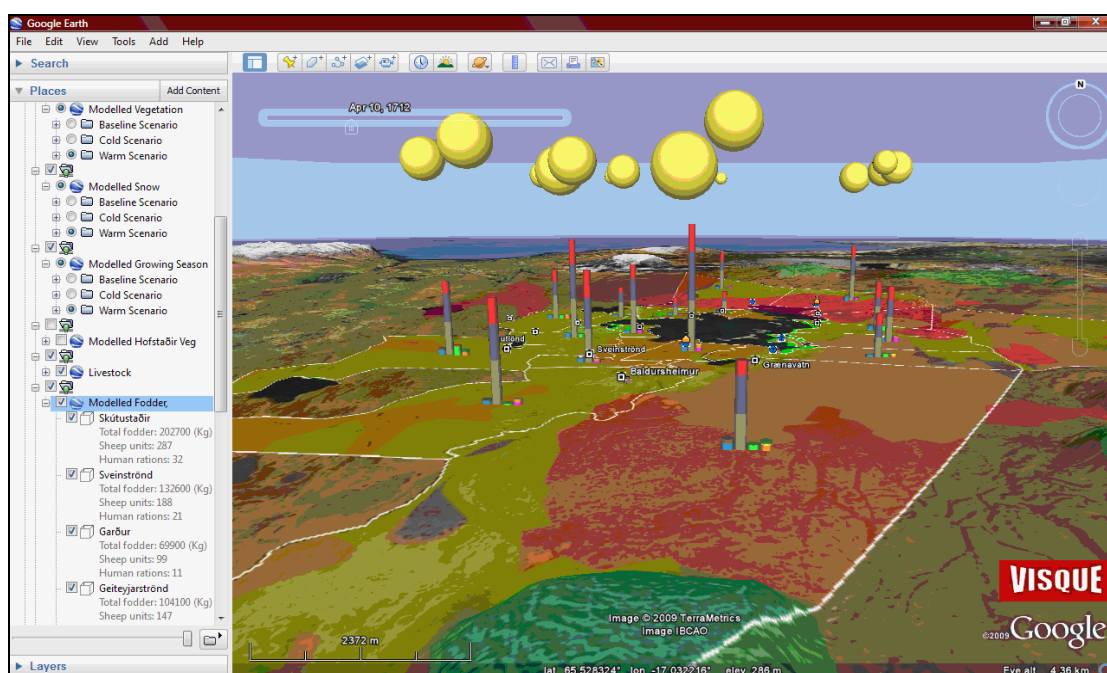


Figure 8: Farm boundaries are indicated by the white polygons, the stacked bars represent livestock numbers and the sphere's represent Modelled Fodder (indicated on left).

Figures 8 and 9 demonstrate the use of the third dimension in Google Earth. Proportionally sized spheres are used to represent the Modelled Fodder layer. This layer includes the attributes: total fodder, sheep units and human rations, for each farm (displayed in the contents window). Extruded polygons are used to represent livestock numbers in each farm. Figure 9 shows a view of Hofstaðir farm with 3-D stacked bars which visualise livestock numbers. The values relating to each bar are displayed in the contents window.

Historical livestock numbers, modelled snow cover and modelled vegetation are visualised in figure 9. Details of livestock numbers, depth of snow and types of vegetation are combined. Snow is important because it constrains grazing in the spring time. Here we can see snow depths of 8 – 16 cm covering the ground on the 29th March. Increased snow cover late in the spring can potentially mean more livestock fatalities. Interestingly, a portion of the farms hayfield and an adjacent area of grassy heath is clear of snow at this time.

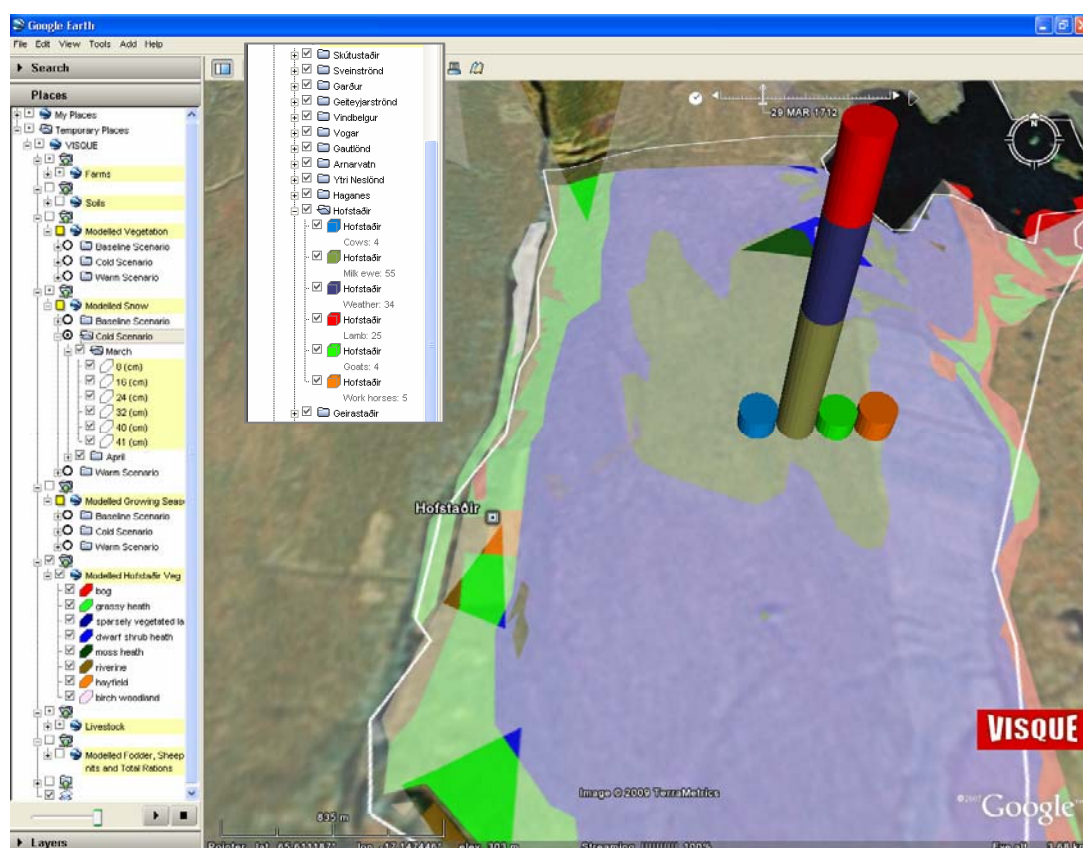


Figure 9: View of Hofstaðir farm. Number of animals represented by the stacked bars are listed in the inset window. Snow and vegetation attributes are listed in the contents window.

An example use of the query feature is illustrated in figures 10 and 11. Here the user queries the database and has selected snow depths of 30cm or greater in march for the cold scenario. The result, figure 11, shows the polygons representing snow of 30cm depth or greater highlighted in red.

The Charts tool is illustrated in figures 12 and 13. Both charts are interactive and offer complimentary techniques to visualise farm attribute data. The radar chart, figure 12, provides a powerful tool for assessing differences between farms. It conveys a range of attributes at once and the graph communicates the ‘flavour’ of each farm: contrasting status and success. The radar chart shows, for example, that large farms do not simply have more of everything. The scatter plot, figure 13, can reveal systematic variations between, for example, farm areas and farm values.

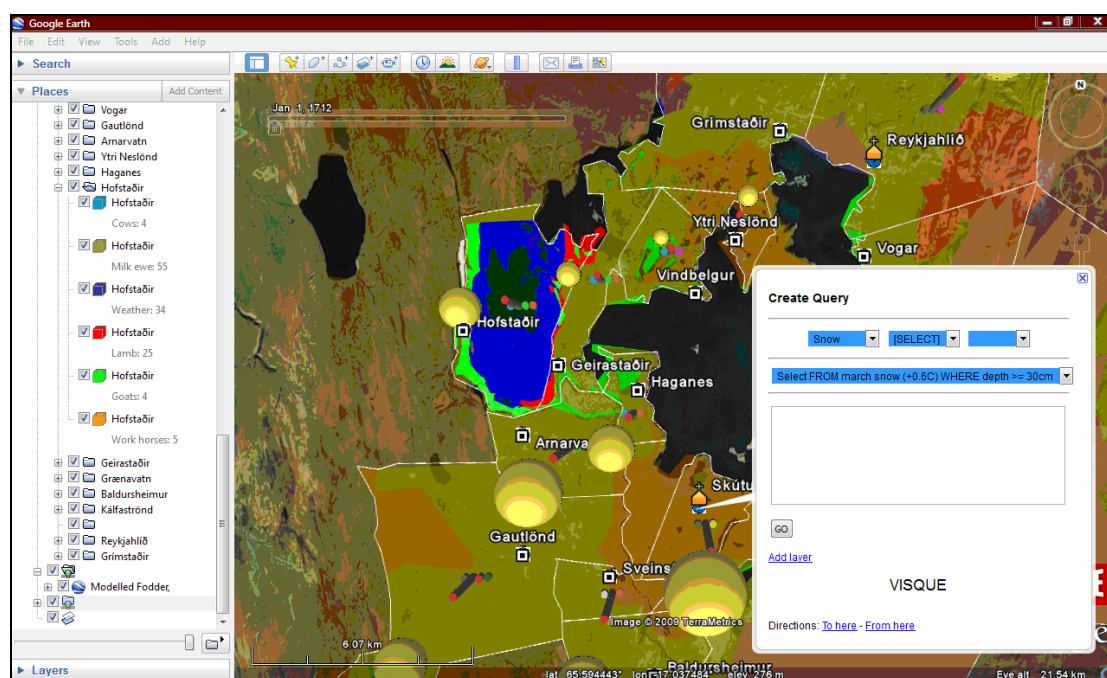


Figure 10: Query window. Query is selecting snow depth of 30cm or greater in march from the cold scenario.

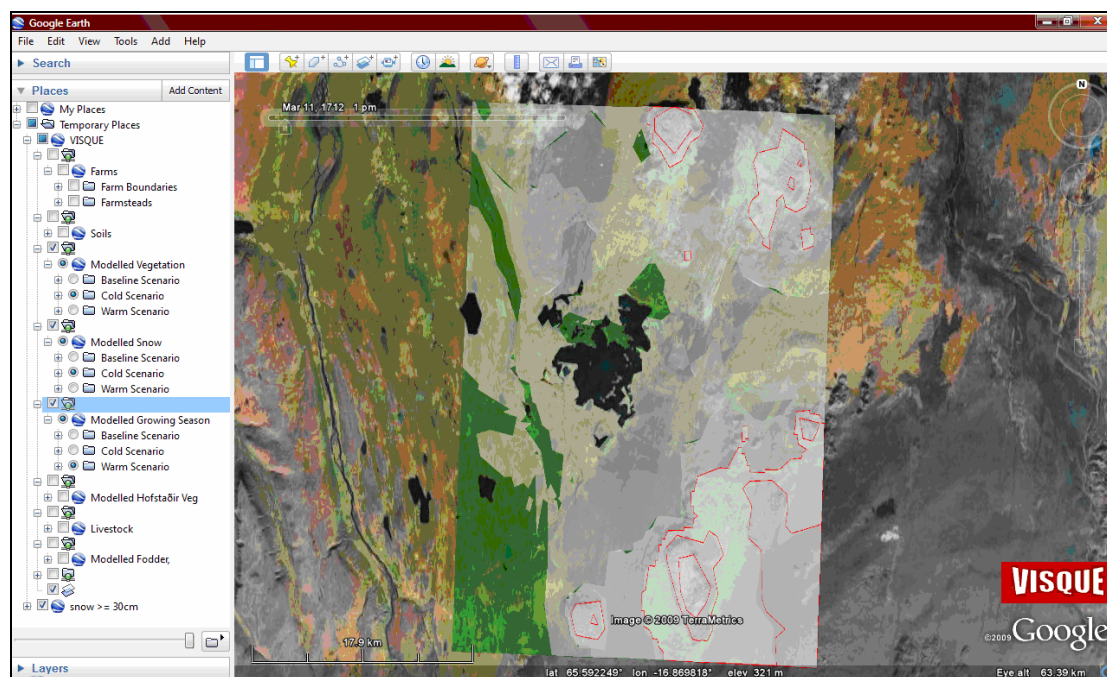


Figure 11: Result of query. Areas where snow is 30cm or greater deep are indicated in red.

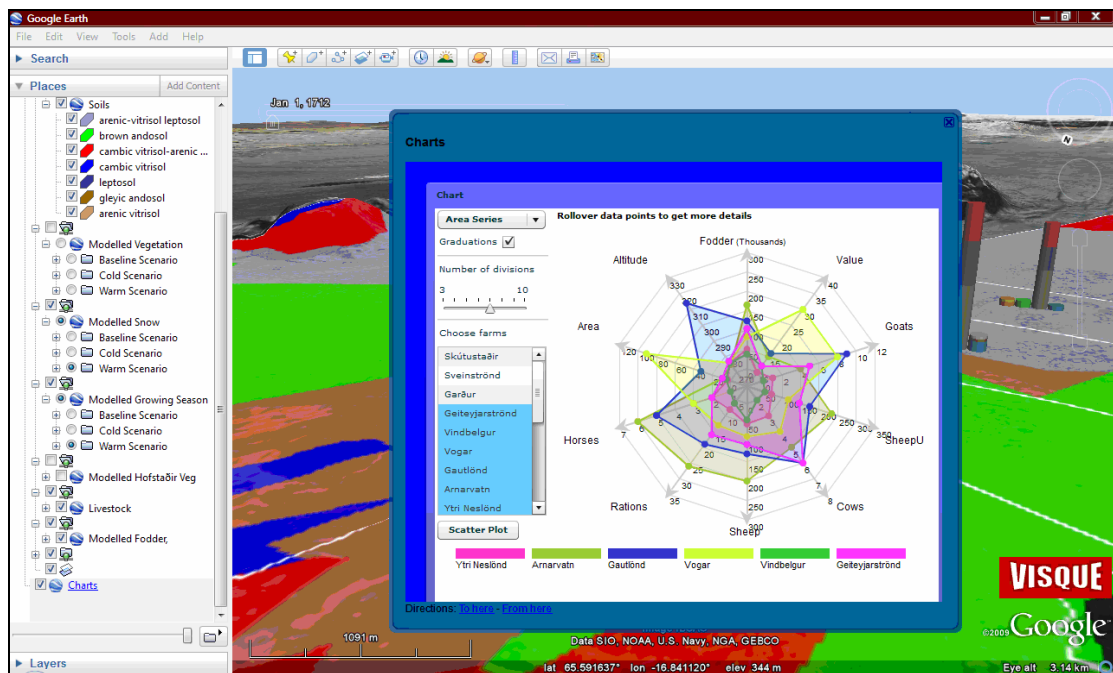


Figure 12: The Charts tool with the radar chart.

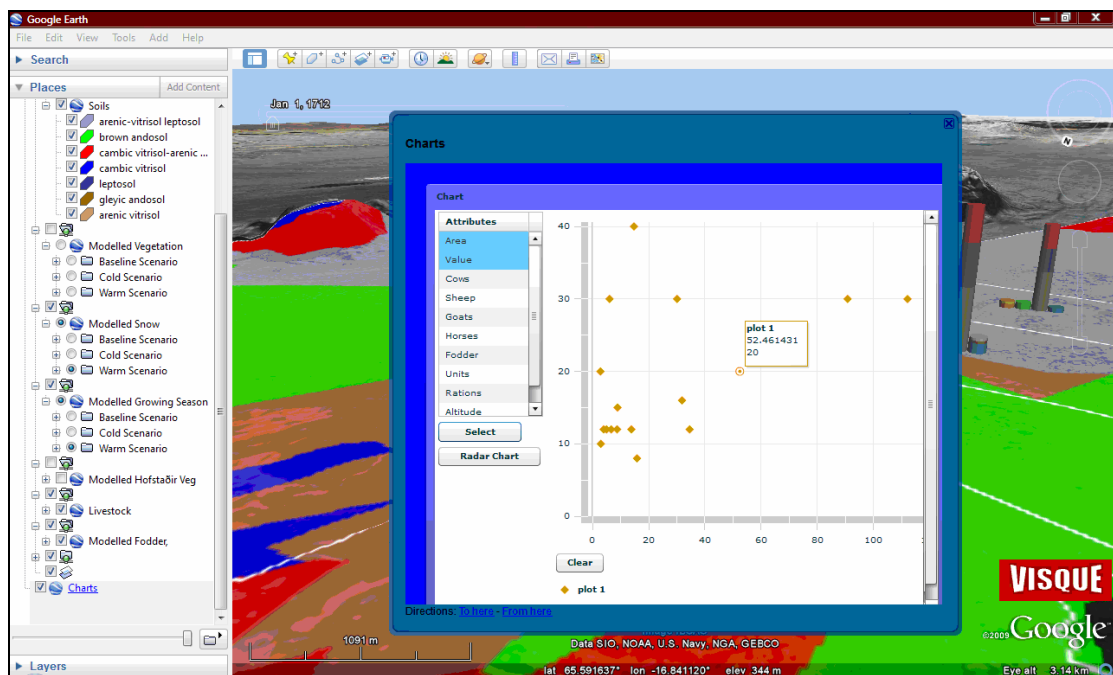


Figure 13: The Charts tool showing the scatter plot.

6 Discussion

This research prototype can be defined as a technology stack, comprising a lightweight client, a high-speed network connection and server infrastructure. Data and processing resources are managed on remote servers and accessed over the Internet, a type of computer system architecture now being referred to as ‘cloud computing’. Web protocols,

http and XML, are most frequently used by major technology providers (Craglia et al., 2008) and provide the means of communication in this research. An advantage of this prototype is the demonstration that Internet GIS can be provided by open-access and open-source solutions. However, developing flexible and robust GIS tools is a challenge. Meeting this challenge often requires trade-offs between functionality and ease of construction (Steiner et al., 2001). Whilst the stated mass-market orientation of geobrowsers means they are less concerned with scientific domains, their use for Internet GIS undeniably facilitates ease of construction. Google Earth and other geobrowsers afford tremendous ease of access and use which no traditional GIS has ever managed to achieve (Goodchild, 2008), and whilst its orientation is not scientific, there is no lengthy period of search, licensing, download, format conversion, and import that would be necessary if comparable imagery were to be combined with traditional GIS.

The dissemination of data is a fundamental aspect of Internet GIS and Google Earth supports this to a certain extent. All features generated by VISQUE and visualised in Google Earth can be copied as KML by the user and saved in their personal space. Viewing the contents of this feature can be easily done using a text editor. However, this would not satisfy everyone's needs. Another approach would involve providing user access to the raw data. This could be accomplished with a modification to the application tier allowing users to select datasets for direct download. The application tier would write the dataset to a file and give the user the option to download the file to their personal computer.

KML has no built-in support for charts. One method to overcome this is to use an external charting service like the Google Charts API. However, the returned charts are static images and provide minimum interaction. By exploiting Google Earth's support of Flash, it is possible to create and use interactive charts and graph data through the geobrowser platform. In their research Koua et al. (2006) found maps were more effective for certain visual tasks such as locate and distinguish, but less effective for the tasks of comparison, correlation, and for relating many attributes. By integrating a scatter plot and radar chart (like a radial parallel coordinate plot) with Google Earth the tasks of comparison, correlation and relating many attributes is achieved. KML does allow for some powerful visualisation techniques and the utilisation of the third dimension increases the volume of data objects that can be comfortably displayed on the screen (Shepherd, 2008). Livestock data which existed in tabular form is visualised as 3-D solids and georeferenced to the central point of each respective farm. Likewise, each sphere representing modelled fodder is set to float above the farm to prevent symbol occlusion, a problem 3-D visualisations suffer from due to the alignment of objects within a scene in relation to the user's viewpoint (Shepherd, 2008). As well as being visually effective, these techniques were also chosen as they allow for the animation of successive datasets. MacEachren et al. (1998) have shown that animation can reveal subtle space-time patterns that are not evident in static representations, even to expert users who are highly familiar with the data.

The adoption of KML by the OGC as an official standard will broaden its use and general acceptance, and most importantly increase interoperability. Although not experienced in this research, the use of KML may have has implications for the performance of the web application. Since KML data are text-based, they are relatively larger in size than their binary counterparts (Chow, 2008). The KML file size is dependent on the number of

features and the complexity of feature geometries, subsequently, the transportation of large files over the Internet may be slow. However, KML does provide a method to create a hierarchy of regions and network links that can be used to efficiently serve a large dataset. Super-overlays take advantage of network links and their ability to determine (1) whether a given region is within view and (2) whether its projected size is appropriate to the view area. If both conditions are met, the region is “active” and the network link loads the data associated with the region. If the region is inactive no data is loaded (Wernecke, 2008). KML can also be zipped up into a KMZ archive and being a compressed version of the file(s) is smaller than the original file(s). A further limitation of Google Earth is its exclusive support of the geographic coordinate system WGS84. This means that data layers using any other projection system have to be first transformed and projected as latitude and longitude before being used in Google Earth. The definition of latitude and longitude, however, require some assumed mathematical function for the shape of the Earth and although it is approximated to an oblate spheroid topography does deviate from this idealised model (Snyder, 1987). Many countries still maintain their own systems, for example in Iceland alone there exists three different local systems: *ISN93*, *Hjörsey55* and *Reykjavík1900*. GPS receivers will often provide a number of options, including WGS84 and local variations, and the differences can amount to hundreds of metres of displacement in some cases (Snyder, 1987). Thus data exported from a mapping package or GIS may well not fit properly over the Google Earth base. Future research into Digital Earth will quite possibly focus some of its effort on developing the technology to allow for the integration of datasets with multiple different projections.

Server-side solutions for Internet GIS have been criticised for having limited user interfaces and poor performance (Huang et al., 2001). Often the mapping interface is viewed in a web browser and information transmitted in HTML format meaning that basic map operations such as zooming and querying require a new request to the server each time. This results in many requests, possibly causing an over-loaded server. Apart from the initialisation of Google Earth and data loading when first launched basic map operations are almost instantaneous. Querying of the underlying spatial database uses the Common Gateway Interface (CGI) and is dependant on broadband connection speed but testing to date has revealed very positive results. A limitation of Google Earth is its lack of built-in spatial and analytical functionality essential in proprietary Internet Mapping Services like ESRI's ArcIMS. Currently the only built-in classes for spatial operations is a measuring tool which will measure distances and calculate areas, and routing. There is no API like its maps counterpart which provide *MapMouseEvent* handlers which provide the *point* and *click* capabilities, and increase interactivity and functionality. Due to the fact that Google Earth lacks such event handlers interaction can only be sought through the use of balloons and innovation. Google Earth will quite possibly never rival the spatial extensions of desktop GIS, however, by utilising a spatial database, with its integrated spatial operators, and an application tier, with its mathematical and logical functions, the implementation of a sophisticated spatial model for Internet GIS applications is possible. This proposed framework is capable of spatial operations that are fundamental in GIS, such as buffering, geoprocessing and geometry interaction with results rendered in Google Earth. This research uses a number of essential GIS operations: the containment relationship between a point and polygon; nearest neighbour analysis; querying features by attribute; and arithmetic functions. These operations are examples of the essential components needed for data exploration, analysis and modelling in discovering the spatial relationship of geographic phenomena. However, to build a more sophisticated Internet

GIS application using Google Earth, future research may emphasise the development and implementation of more spatial operations.

7 Conclusion

This research examines the potential of using Google Earth for visualising and processing vector and attribute data. The web prototype produced for this research is effective in visualising and representing spatiotemporal data on the Internet. It provides an intuitive and dynamic interface for domain experts who can easily explore distributed geographic information and demonstrates the potential for future development. The use of a database tier and development of an application tier, VISQUE, has enhanced Google Earth and added the functionality to query custom data and visualise results. The ability to integrate interactive charting applications as part of the application tier and ‘plug’ them into Google Earth is a powerful tool for tasks of comparison, correlation, and for simultaneously relating many attributes. Despite its great potential, there were limitations in this approach that require more research and experimentation. In utilising Google Earth and consequently text-based KML, large file size may prolong the processing time of data transportation, parsing and rendering. The absence of point and click functionality is also a draw back and hinders interactivity. The use of a spatial database and application tier adds the functionality that Google Earth lacks, however, there is the need to develop and implement further spatial operations. It is expected that the ever-growing attention and demand from the research community for the development of a Digital Earth will result in further developments and improvement of future versions of Google Earth.

REFERENCES

- Amorosi, T., Buckland, P., Dugmore, A., Ingimundarson, J.H., and McGovern, T.H., 1997, *Raiding the Landscape: Human Impact in the Scandinavian North Atlantic: Human Ecology*, v. 25, p. 491-517.
- Arnalds, Ó., Þorainsdóttir, E., Metusalemsson, S., Jonsson, A., Gretarsson, E., and Arnason, A., 2001, *Soil erosion in Iceland: Reykjavík, Soil Conservation Service, Agricultural Research Institute, Iceland.*
- Butler, D., 2006, Virtual Globes: The web-wide world: *Nature*, v. 439, p. 776-778.
- Chow, T., E., 2008, The Potential of Maps APIs for Internet GIS Applications: *Transactions in GIS*, v. 12, p. 179-191.
- Collada, 2007, COLLADA, The Khronos Group Inc.
- Craglia, M., Goodchild, M.F., Annoni, A., Camara, G., Gould, M., Kuhn, M., Mark, D., Masser, I., Maguire, D., Liang, S., and Parsons, E., 2008, Next Generation Digital Earth: *International Journal of Spatial Data Infrastructures Research*, v. 3, p. 146-167.
- Davis Jr., C.A., Fonseca, F.T., and Gilberto, C., 2009, Beyond SDI: Integrating Science and Communities to Create Environmental Policies for the Sustainability of the Amazon: *International Journal of Spatial Data Infrastructures Research*, v. 4, p. 156-174.
- Diamond, J., 2005, *Collapse: How Societies Choose to Fail or Survive*: London, Allen Lane.
- Dugmore, A., Keller, C., McGovern, T.H., Casely, A.F., and Smiarowski, K., In Press, *Norse Greenland Settlement and Limits to Adaptation.*
- Goodchild, M.F., 2008, The use cases of digital earth: *International Journal of Digital Earth*, v. 1, p. 31-42.
- Gore, A., 1999, *The Digital Earth: Understanding our Planet in the 21st Century: Photogrammetric Engineering and Remote Sensing*, v. 65, p. 528.
- Grossner, Karl, E., Goodchild, Michael, F., Clarke, and Keith, C., 2008, Defining a Digital Earth System: *Transactions in GIS*, v. 12, p. 145-160.
- Henry, A., 2009, *Supporting Document: Using Google Earth for Light-Weight Internet GIS*, MSc Dissertation, University of Edinburgh.
- Huang, B., Jiang, B., and Li, H., 2001, An Integration of GIS, virtual reality and the Internet for Visualization, Analysis and Exploration of Spatial Data: *International Journal of Geographical Information Science*, v. 15, p. 439-456.

- Korhonen, C., Hassoun, D., and Crosby, J., 2008, *Creating Mashups with Adobe Flex and Air*: New York, friends of ED.
- Koua, E.L., MacEachren, A., and Kraak, M.-J., 2006, Evaluating the Usability of Visualization Methods in an Exploratory Geovisualization Environment: *International Journal of Geographical Information Science*, v. 2, p. 425-448.
- MacEachren, A., Boscoe, F.P., Haug, D., and Pickle, L.W., 1998, Geographic Visualization: Designing Manipulable Maps for Exploring Temporally Varying Georeferenced Statistics, *Proceedings of the IEEE Information Visualisation Symposium*: Research Triangle Park, NC, p. 87-94.
- MacEachren, A.M., and Kraak, M.-J., 2001, Research Challenges in Geovisualization: *Cartography and Geographic Information Science*, v. 28, p. 1-11.
- McGovern, T.H., Vésteinsson, O., Friðriksson, A., Church, M.J., Lawson, I.T., Simpson, I.A., Einarsson, A., Dugmore, A.J., Cook, G.T., Perdikaris, S., Edwards, K.J., Thomson, A.M., Adderley, W.P., Newton, A.J., Lucas, G., Edvardsson, R., Aldred, O., and Dunbar, E., 2007, Landscapes of Settlement in Northern Iceland: Historical Ecology of Human Impact and Climate Fluctuation on the Millennial Scale: *American Anthropologist*, v. 109, p. 27-51.
- Miller, C.C., 2006, A Beast in the Field: The Google Maps Mashup as GIS/2: *Cartographica: The International Journal for Geographic Information and Geovisualization*, v. 41, p. 187-199.
- Nourbakhsh, I., Sargent, R., Wright, A., Cramer, K., McClendon, B., and LJones, M., 2006, Mapping Disaster Zones: *Nature*, v. 439, p. 787-788.
- Patterson, T.C., 2007, Google Earth as a (Not Just) Geography Education Tool: *Journal of Geography*, v. 106, p. 145-152.
- Pearce, J.M., Johnson, S.J., and Grant, G.B., 2007, 3D-mapping optimization of embodied energy of transportation: *Resources, Conservation and Recycling*, v. 51, p. 435-453.
- Peng, Z.R., and Tsou, M.H., 2003, *Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks*: Hoboken, NY, John Wiley and Sons.
- Peng, Z.R., and Zhang, C., 2004, The Roles of Geography Markup Language (GML), Scaleable Vector Graphics (SVG), and Web Feature Service (WFS) Specifications in the Development of Internet Geographic Information Systems (GIS): *Journal of Geographical Systems*, v. 6, p. 95-116.
- Plewe, B., 1997, *GIS Online: Information Retrieval, Mapping, and the Internet*: Santa Fe, OnWord Press.
- PostGIS, 2009, <http://postgis.refrations.net/>.

- Shepherd, I.D.H., 2008, Travails in the Third Dimension: A Critical Evaluation of Three-dimensional Geographical Visualization, *in* Dodge, M., McDerby, M., and Turner, M., eds., *Geographic Visualization: Concepts, Tools and Applications*: Chichester, John Wiley & Sons, Ltd.
- Smiatek, G., 2005, SOAP-based web services in GIS/RDBMS environment: *Environmental Modelling & Software*, v. 20, p. 775-782.
- Snyder, J.P., 1987, *Map Projections - A Working Manual*: U.S. Geological Survey Professional Paper 1395.
- Steiner, E., MacEachren, A.M., and Guo, D., 2001, Developing and Assessing Light-Weight Data-Driven Exploratory Geovisualization Tools for the Web, *Workshop on Geovisualization for the Web*: Taupo, New Zealand, ICA Commission on Visualization & Virtual Environments.
- Tait, M.G., 2005, Implementing geoportals: applications of distributed GIS: *Computers, Environment and Urban Systems*, v. 29, p. 33-47.
- Vésteinsson, O., McGovern, T.H., and Keller, C., 2002, Enduring Impacts: Social and Environmental Aspects of Viking Age Settlement in Iceland and Greenland: *Archaeologia Islandica*, v. 2, p. 98-136.
- Wernecke, J., 2008, *The KML Handbook*: Boston, Addison-Wesley.
- Wilson, T., 2008, OGC KML 2.2.0, OGC.