Tracking Trends in Earthquakes and Tropical Storms: A Web GIS Application

by

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To Charlie, you challenge (and spoil) me more than I could ever have imagined.

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List of Abbreviations

API	Application Programming Interface
CSV	Comma Separated Values
CRED	Centre for Research on the Epidemiology of Disasters
EM-DAT	Emergency Events Database
GIS	Geographic information system
GUI	Graphical User Interface
IRB	Institutional Review Board
NHC	National Hurricane Center
NOAA	National Oceanic Atmospheric Administration
NWS	National Weather Service
OGC	Open Geospatial Consortium
REST	Representational State Transfer
RWS	RESTful Web Services
SQL	Structured Query Language
SSI	Spatial Sciences Institute
UCD	User Centered Design
UI	User Interface
USC	University of Southern California
USGS	United States Geologic Survey
UX	User Experience
WFS	Web Feature Service
WMS	Web Map Service Interface Standard

Abstract

Natural disaster events such as tropical storms and earthquakes have gained widespread attention from the general public. While pictures provided by the media may tell a convincing story, data, statistics, and maps provide the foundation for a more empirical approach to trend analysis. This web GIS application provides users the ability to explore earthquake and tropical storm events over the last 30 years and analyze trends in frequency and intensity of the events. The web application consists of time-enabled maps and charts displaying global statistics in earthquake and tropical storm frequency and intensity over the last 30 years. It is designed for members of the general public who have a working knowledge of earthquake and hurricane science and an interest in exploring whether there or not there are increasing trends in severe earthquake and tropical storm events.

Chapter 1 Introduction

Images of catastrophic earthquakes and tropical storms across the globe have gained widespread attention in the media. Mass media plays a pervasive role in captivating the audience by means of a panic stimulus (Korstanje 2010). Mass media sensationalism is routinely seen during disastrous events and is a type of journalistic bias in which events are over-hyped to increase audience readership (Walters 2016). Terrifying pictures and dramatic headlines encourage shock value within the general public who may be far removed from horror of the events as the 8.2 earthquake in Mexico during 2017 (Figure 1). But while images raise our awareness of the struggles many across the world are facing, they also can imply that the disasters are growing larger, more intense, and more devastating every year.

Figure 1. Dramatic devastation from 2017 Mexico 8.2 earthquake

Conclusions about precise trends cannot be drawn from images such as the line up of three category 4 cyclones (hurricanes) in the Pacific Basin in 2015 (Figure 2). Catastrophic events can be tracked using data science, such as quantitatively measuring the number of events, size of events (with agreed upon measuring scales), and impact of said events. Organizing event data into geospatial databases facilitates visualizing the numbers behind the events in an accessible format, e.g, a web GIS application. A GIS application allows viewers to perform analysis in an online environment and draw their own conclusions as to whether events such as hurricanes and earthquakes have increased in size and frequency over the last thirty years.

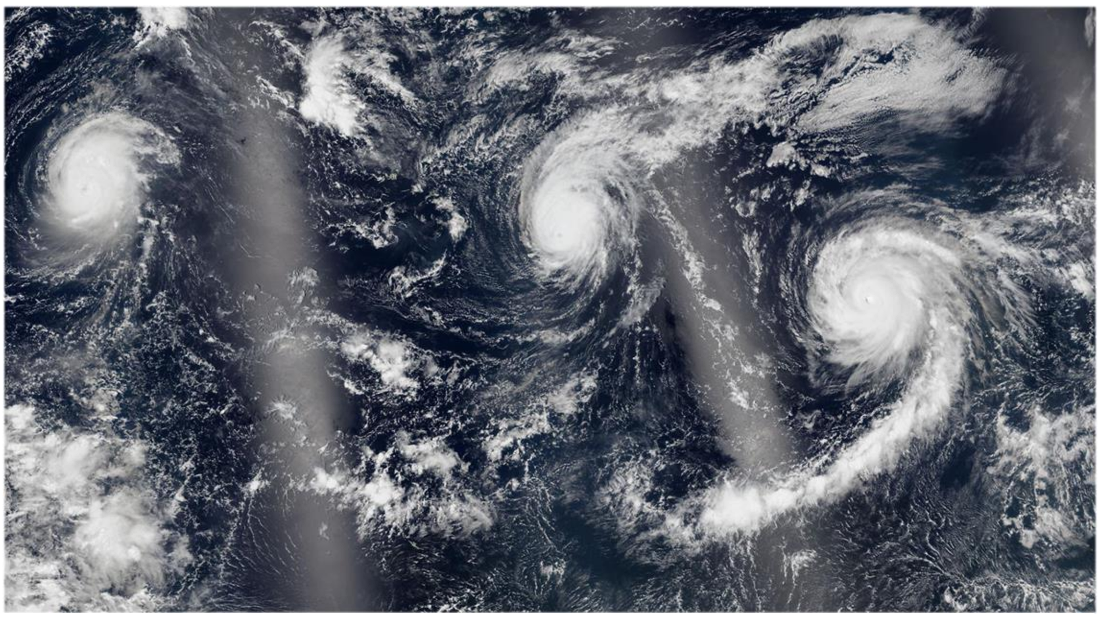


Figure 2. Cyclones Kilo, Ignacio and Jimena moving simultaneously across the Pacific in 2015

1.1. Motivation

Extreme storm and earthquake events worldwide have gained attention from the general public due to media reports showing the massive death and economic tolls over the years (Korstanje 2010). Even last century there were powerful earthquakes in the news such as the

1906 San Francisco 7.9 magnitude quake. The general public who did not experience the event may have had trouble processing the hundreds of black and white images published in newspapers and books such as the image of total devastation featured in Arnold Genthe's "...As I Remember" publication (Genthe 1936) of a series of photographs he took in the immediate aftermath of the earthquake in 1906 (Figure 3). Most people rarely are aware of the actual trends in earthquakes and tropical storms beyond the apocalyptic images they see.

Figure 3. Total devastation in the 1906 San Francisco ~7.9 earthquake

There are numerous theories perpetuated by media reports, YouTube alarmists, and conspiracy theorists that natural disasters such as earthquakes and tropical storms are growing more intense and increasing in frequency. Conspiracy theories allow people to vent their frustrations at their feelings of powerlessness, but they also provide a mixture of anxiety and comfort in conceiving how power works (Sturken 2001). A cursory search on YouTube reveals several channels dedicated to Earth inhabitants of doom. YouTube channels dedicated to "End of the World" such as Jason A carry over one million subscribers and hosts videos viewed a staggering two million times (Jason 2019). Directed imagery searches result in powerful images that range from the artistic then-and-now blends of the ~7.9 San Francisco 1906 earthquake (Figure 4) to the 2016; 7.0 Earthquake in Japan with disintegrating highways (Figure 5). The general public has few options to understand whether such events are continuing as they always have, or if there is an actual upwards trend in frequency and intensity. With few ways to interact with data in a user-friendly format, the general public is unable to determine trends for themselves.

Figure 4. Photographer Shawn Clover's "Fade to 1906" image blend showing then and now images of the 1906 San Francisco ~7.9 earthquake

Figure 5. Road damage from the 2016 Japanese 7.0 earthquake

The website created for this thesis and the analytic tools it contains allow users to investigate trends in large earthquakes and tropical storms, namely whether they have increased in frequency and intensity in the last thirty years. Users do this by interacting with online maps and charting widgets. The time sliders on the maps allow the user to determine spatial patterns in events over time. The charting widgets have user controls that enable the user to zoom in to time frames, looking for increasing or decreasing trends in frequency of the events over time. Users can draw their own conclusions driven by data and spatial science rather than media alarmism and dramatic images.

1.2. Development Overview

The project included several stages: data acquisition, curation, and display; map development; and finally, web application development. It utilized earthquake and tropical storm data sets from authoritative federal archives maintained in large data bases and freely available for download to the public. It is important to note that while in federal hurricane databases the terms tropical cyclone or tropical storm are often used interchangeably and include what are also known as hurricanes and typhoons. All are the same weather phenomenon, but hurricanes originate in the North Atlantic, central North Pacific and eastern North Pacific. Typhoons originate in the western North Pacific. The generic term “tropical cyclone” is often used to refer to a “rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has closed, low-level circulation” (NOAA - National Ocean Service 2019). Once downloaded from federal archives, all datasets were curated to display category, strength, and data/time fields in a way that the web application could easily interact with and present to the user in easily understood categories The datasets were reduced to the essential information through multiple attribute queries, enabling optimized web map services (also called map services throughout this thesis) designed to cycle large data sets through web interfaces.

The web maps were symbolized map services that were temporally accurate and optimized to display at several different scales and various thematic views in order to speed the interaction time between server and user. They were grouped by theme to enable several different views of natural disaster maps. They were shared with the public through the University of Southern California (USC) Spatial Science Institute (SSI) ArcGIS Portal, enabling broad access to the individual components feeding the web application. At the time of writing, the website was currently available at https://uscssi.maps.arcgis.com/apps/MapSeries/index.html?appid=c5294847fe2841f2972bf34684c06d9c.

The website has a User Interface (UI) designed to enhance User Experience (UX). It consists of several time-enabled maps and charts displaying large data sets, curated to enable web streaming, and showing frequency and intensity of the natural disaster events from the last 30 years. The intended audience was interested members of the general public who have a basic knowledge of earthquake and hurricane science but who are unable to acquire, curate, query, analyze and present the data in an easily accessible web GIS format for themselves.

1.3. Thesis Organization

This thesis is divided into six chapters along with lists of tables, figures, abbreviations and references. The first of the six chapters is the introduction, which contains motivating factors and a summary of the application design and subsequent process for data acquisition/curation/display, web map and web application development. The second chapter discusses related work broken into several categories: earthquake and tropical storm web maps, earthquakes and tropical storms as natural disasters, web application user interface and user experience, and web map services. The third chapter outlines the thesis requirements including the application purpose, the user requirements, and the development choices. The fourth chapter examines the development of the application including the data sources and the three main application development phases: data, map services, and web interface. The fifth chapter reviews the results of the application. The sixth chapter reviews the outcome of an application assessment and user feedback through a survey of the web mapping application. The seventh chapter draws conclusions on the success of the application, the limitations, and potential for further development.

Chapter 2 Related Work

This chapter presents a literature review of this Tracking Trends in Earthquakes and Tropical Storms Web GIS Application. There are numerous peer-reviewed articles and reports discussing web maps, natural disaster data, user experience and web services. The chapter is divided into four sections. Section 2.1 discusses web maps. Section 2.2 discusses earthquakes and tropical storms as natural disaster data. Section 2.3 discusses the web application user interface and user experience. Section 2.4 is an overview of web map services.

2.1. Earthquake and Tropical Storm Web Maps

The primary sources for data on earthquakes and tropical storms are the US government offices of the United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the National Weather Service (NWS). The NWS has a division focused entirely on predicting, analyzing, and warning the general public about hurricane activity that affects the United States (and its territories) called the National Hurricane Center (NHC Data in GIS Format n.d.). These organizations offer a plethora of data to download for use by the general public and academia.

While both these government offices are world-renowned for maintaining robust and authoritative datasets on historic events, they are limited in the visualization and analytic tool options they provide. The USGS has a basic browser map application that allows the user to view earthquake events based on user-driven queries (USGS n.d.), but does not have time-enabled data streams or time-slider widgets available (Figure 6). USGS' strength lies in its capacity to provide large data downloads in multiple formats relying on others to analyze the data and program custom visualization applications with enhanced UI/UX. The UI does not allow for the user to adjust symbology for custom visualization needs nor is there any analytic, graphing, or charting capacity. There are also limited export options for the mapping application interface other than the user taking a screen shot of the map.

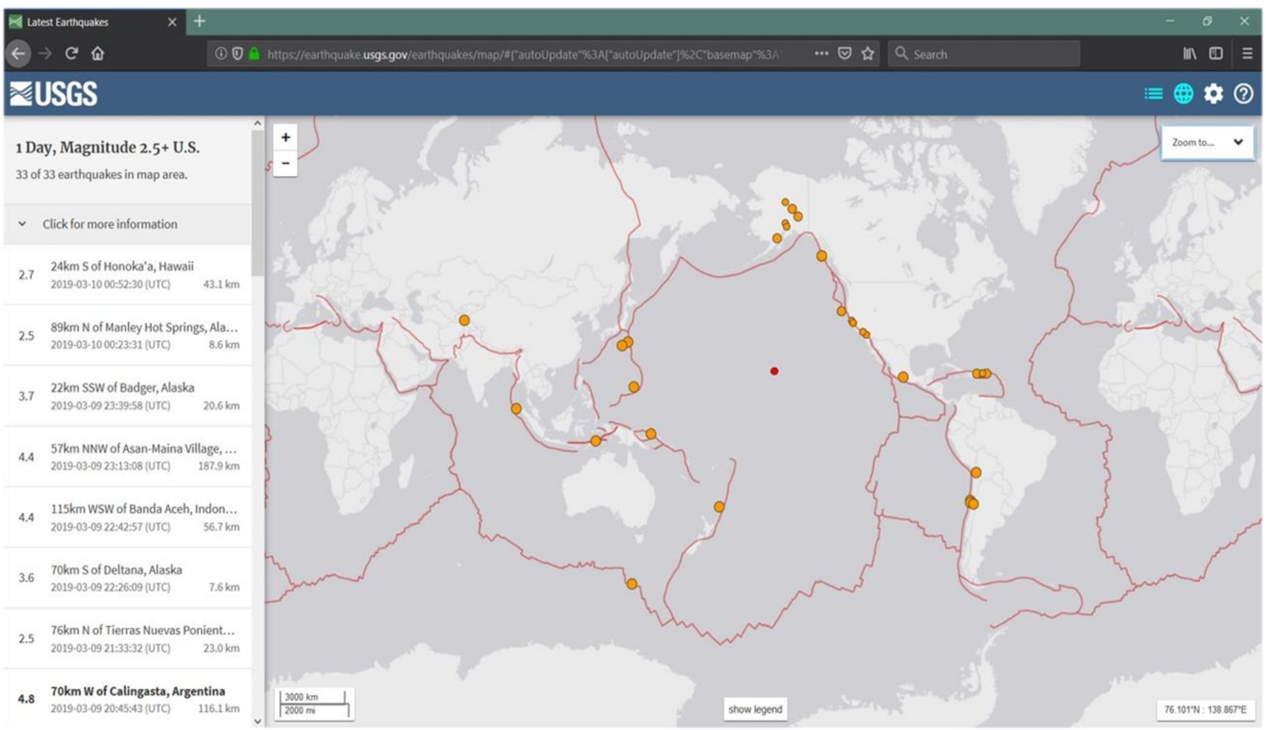


Figure 6. USGS Earthquake basic browser map application with minimal toolsets enabled

The NHC has an even more rudimentary web map embedded in their home page (NHC n.d.). Its UI (Figure 7) is tailored to inform the viewer about current and predicted storms but does not allow for loading custom queries from their archived datasets, nor does it have even some of the basic mapping application tools that USGS has such as zoom-to-locations, zoom in/out, scalebar, or legend. Much of what appears to be map applications on the NHC site are merely embedded pdf thumbnails that, when clicked, launch a separate document discussing the event rather than an actual web mapping application with a UI.

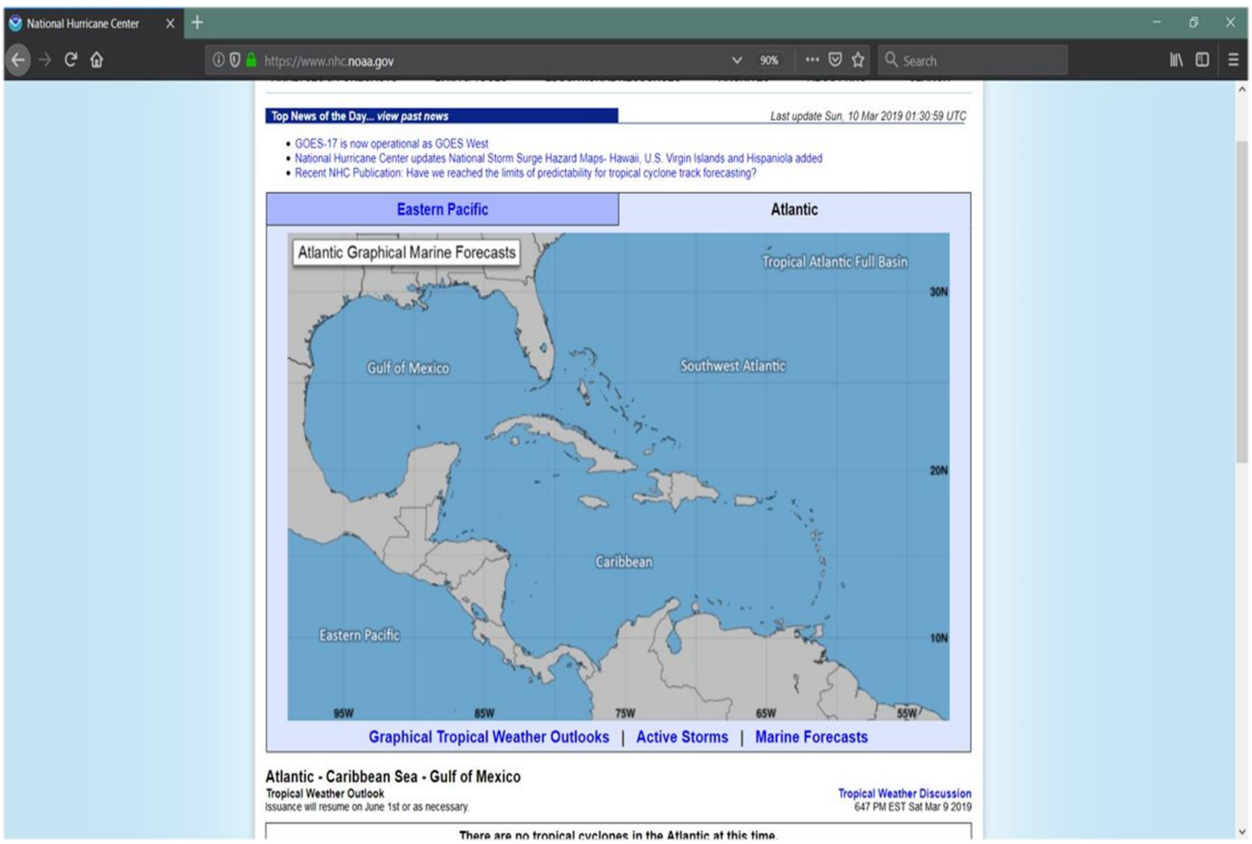


Figure 7. NHC rudimentary embedded web map with minimal interactive mapping tools

There are other earthquake and tropical storm-themed web maps and databases available. The differences primarily revolve around the goals of the applications: some are simply informative rather than interactive in nature, driving toward better understanding of trends as the multimedia video embedded in a news article displayed (Figure 8) (Kuzoian, Animated map 2016). While it appears to be a map, it is merely a video that does not allow the user to interact with the data or control the map. While it is useful for showing where earthquakes have occurred at what time, there is no way to click on each event and further investigate the data. Some are predictive, showing how future events could impact populations enabling mitigation efforts. Others focus on assembling a variety of resources to alleviate humanitarian crises (Quakes Live Earthquakes Map n.d.).

Figure 8. Screenshot of a multimedia video that shows EQs >8.0 Mag since 1900

Many web applications use open source tools or Esri's proprietary formatting and tools. Shared maps embedded in web pages with various user interfaces and tools are becoming more and more popular as the tools become easier to use and implement. Despite the ease of use of the web programming tools and the freely available datasets from both USGS and NOAA – NHC, there is a noticeable lack of well-designed GIS web applications designed for users to explore trends in natural disasters, combining earthquakes and hurricanes together in a flexible and dynamic interface. The previously mentioned "web maps" were merely images or videos of a map on a web page, they were not actual mapping applications that allowed the user to interact with the map or data. NOAA does host a web mapping interface which allows users to explore historic hurricane tracks (NOAA Office for Coastal Management 2018). It is very powerful, however, the interface (Figure 9) is not intuitive for the average user. The application is designed to support research on specific events, not necessarily view all the events over time. There is no time slider widget available, and due to the large amount of data passed through the interface, the user must insert a query to limit the data to a subset which can be confusing.

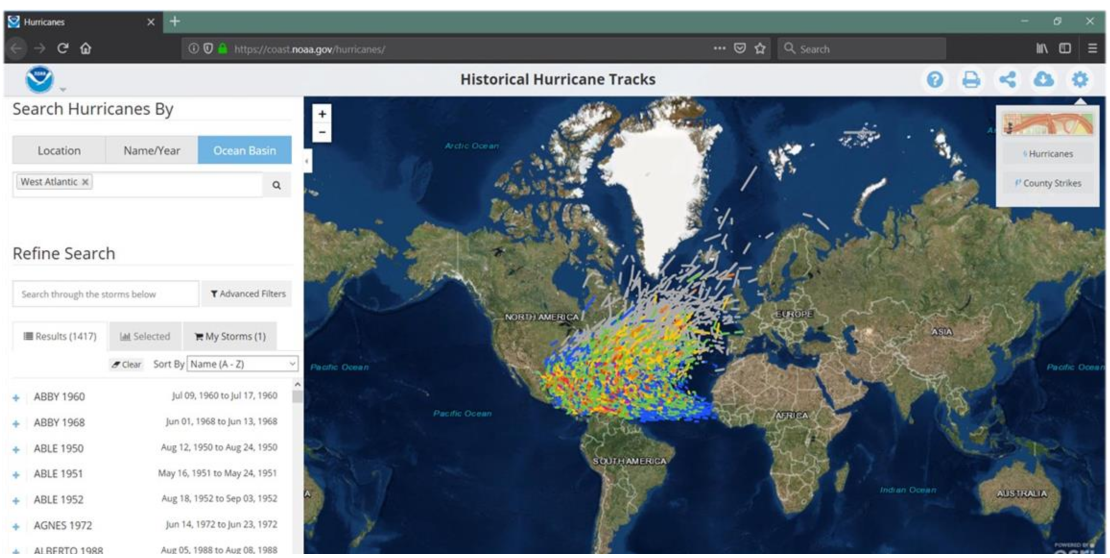


Figure 9. NOAA's "Historical Hurricane Tracks" web mapping application with un-intuitive interface

2.2. Earthquakes and Tropical Storms as Natural Disaster Data

Earthquakes and tropical storms, if strong enough to cause significant damage to life or property, can be considered a natural disaster. One of the leading international natural disaster data collections is hosted by the Centre for Research on the Epidemiology of Disasters (CRED) at the Université Catholique de Louvain in Belgium. While initially their earthquake and tropical storm data sets initially appeared to be valid as a primary data source for this project, after a cursory comparison of the datasets to their respective USGS and NOAA datasets, there were significant gaps in the completeness of the EM-DAT data. For example, USGS shows 11 earthquakes Magnitude 7.0-7.9 occurred in 1998. The EM-DAT database only had one 7.0-7.9 earthquake that year. There were also issues with completeness in the attribute fields. For example, of their 1376 total earthquakes listed from 1900-2019, 253 had no magnitude recorded, and 176 had no location (latitude, longitude) listed other than "possible country of origin".

CRED sets specific criteria for what type of earthquake can be considered for inclusion in the EM-DAT database (School of Public Health Université Catholique de Louvain n.d.). Per the CRED supporting documentation, EM-DAT includes all disasters from 1900 until the present, meeting the requirements of at least one of the following criteria:

- 10 or more people dead
- 100 or more people affected
- The declaration of a state of emergency
- A call for international assistance

These criteria significantly limit the total number of earthquakes that show an accurate trend over time of decreasing or increasing total number of events. While the EM-DAT database is significantly powerful, it exists to explore natural disasters from a public health standpoint, rather than tracking an accurate number of earthquake (or tropical storm) events, regardless of impact on surrounding population centers. Because of the limiting nature of the criteria, the USGS and NOAA datasets provided a more reliable completeness for total number and magnitude of the events than CRED's EM-DAT data set.

One limitation of the CRED EM-DATA data set is the stringent database license agreement (Appendix A – CRED EM-DAT Database License Agreement). Before accessing the database, an account had to be established with detailed justification for why and how the data would be used, and finally an agreement had to be signed stating that the user would follow the database license agreement. There were several levels of authorized access allowed, called "Limited Access", "Extended Authorized Use", and "Commercial Access" (School of Public Health Université Catholique de Louvain n.d.). Very simply, once an account request was approved, Limited Access authorized students and researchers to download only 8,000 records. (Note, a cursory search of the database's set of earthquake records to do a general comparison with USGS earthquake records required downloading 1,376 records). Extended Authorized Use allowed students and researchers to access the database for one year provided they pay a significant fee. Commercial Access was approved only through separate, private agreements with the University.

2.3. Web Application User Interface and User Experience

UI and UX are important concepts when designing a web mapping application. Several key concepts to include, specifically in web mapping applications design, are strong cartographic and spatial science principles, such as implementing map projections correctly and using appropriate color schemes. While in-depth study of UI/UX principles can form the foundation for entire academic programs for software engineers, there are six principles of usability for basic user interface design: structure, simplicity, visibility, feedback, tolerance, and reuse (Constantine 1999). Presented by Larry Constantine and Lucy Lockwood in their 1999 book "*Software for Use a Practical Guide to the Models and Methods of Usage-Centered Design*", the six principles are applicable to a web mapping environment:

1. **Structure Principle**—Organize the user interface purposefully, in meaningful and useful ways that put related objects together and separate unrelated objects based on clear, consistent models that are apparent and recognizable to users.

2. **Simplicity Principle**—Make simple, common tasks simple to do, communicating clearly in the user's own language and providing shortcuts that are meaningfully related to longer procedures.

3. **Visibility Principle**—Keep all needed tools and materials for a given task visible without distracting the user with extraneous or redundant information: What You See Is What You Need (WYSIWYN).

4. **Feedback Principle**—Through clear, concise, and unambiguous communication, keep the user informed of actions or interpretations, changes of state or condition, and errors or exceptions. These are relevant and of interest to the user in performing tasks.

5. **Tolerance Principle**—Be flexible and tolerant, reducing the cost of mistakes and misuse by allowing undoing and redoing while also preventing errors wherever possible by tolerating varied inputs and sequences and by interpreting all reasonable actions reasonably.

6. **Reuse Principle**—Reduce the need for users to rethink, remember, and rediscover by reusing internal and external components and behaviors, maintaining consistency with purpose rather than merely arbitrary consistency.

One standard UX principle specifically in the web mapping arena that falls within Usability Principle 6 is ensuring the user has rapid access to large datasets, particularly when using background base map services. These tiled and cached map services, when premade (e.g., not rendered live) and stored on a server, then are cached client-side for reuse after the initial network call. This significantly improves UX by not forcing the user to wait while each tile loads repeatedly (a frustrating symptom of early-era web maps). Pre-rendering tiles in response to user requests leverages web storage concepts to store objects in the background, thus providing a much better UX in a web mapping environment (Freire 2014).

Taking the basic UI/UX principles one step further includes a concept called "User-Centered Design" (UCD) referring to the concept of guaranteeing web application success by acquiring user reactions throughout the design and development phases (Roth 2015). When developers are implementing UCD, their principal focus should be on providing value to their end users (Kramer 2000). Following UCD principles creates engaging, efficient user experiences and seems surprisingly simple: Take the user into account throughout every development step. However, the implications of this simple concept, can be surprisingly complex (Garrett 2010).

In order to ensure UCD principles are met in any web application, the application designer must work through a series of user - utility - usability loops throughout design and implementation. This enables the target users to provide input and feedback on needs and designs (user), which prompts the developer to revise the concepts and functions of the interface (utility), ultimately leading to new versions of the interface (usability) for additional evaluation by target users (Roth 2015). UCD principles are often implemented using user-feedback forms, whether embedded in the actual web application or set up as a side function, such as emailing the development team or launching an informal chat function. Feedback does not have to be time-consuming or expensive; it can be as simple as reading through server logs to understand the user's experience on the web application or set up unofficial testing sessions with friends or colleagues (Garrett 2010). To fulfill UCD principles, the earthquake and tropical storm web mapping application needed to enable visual exploration and both spatial and attribute analysis of large, complex data sets, while remaining approachable and intuitive to non-technical target user groups.

2.4. Web Map Services

Given the pivotal role of web map services to the overall web mapping application design, it is important to understand a little of the history and overall background of web map services. Since the 1980s, and particularly since the raise in popularity of Google Maps there is an enormous amount of GIS data stored in geospatial databases. A method was required to pull or share the spatial information over the internet. The Open Geospatial Consortium (OGC) is an international industry consortium of hundreds of companies, government agencies and universities participating to develop publicly and freely available interface standards. In the late 1990s the OGC defined a set of standards for distributing geographic data with the intent of making multiple layers of information quickly and easily available to Internet users (OGC 2019).

Originally accessing data was a cumbersome process but the OGC standardized process allowed for the majority of the workload to be carried by the server rather than the user (Peterson 2012). The OGC established the web mapping service to have two primary functions: (1)

GetCapablites defines the server capabilities (such as map layers, method of display or file formats) and (2) *GetMap* that tells the database what specifically is needed in the map request. There are other functions frequently available like the *GetLegendGraphic* function (defines the map symbols) or the *GetFeatureInfo* function which give more attribute information about the feature in questions, such as a road name in the case of a road feature or an earthquake magnitude in the case of an earthquake feature.

Web Map Services (WMS) and Keyhole Markup Language (KML) are the two most widely implemented spatial data infrastructure standards (ISO, IHO, OGC 2018). WMS provides access and display of geospatial information as a raster image. This very widely implemented OGC/ISO standard provides access to hundreds of thousands of geospatial information layers worldwide (ISO, IHO, OGC 2018) and is the primary choice for the map services published during the application development for this thesis. KML is an XML language focused on geographic visualization, including annotation of maps and images, originally designed as a proprietary format by Google, but there is more work to be done on bringing the KML format into harmony with the other OGC standards such as WMS and others (OGC 2019). As WMS is a more established and mature standard than KML, it was a natural choice for the map services created for both the earthquakes and tropical storms portions of the web map application and is discussed further in the Development Choices section.

The Representational State Transfer (REST) architectural style is another common service sharing format. When used to share spatial data it is called GIS RESTful Web Services. (RWS) are particularly useful for web map applications as there is an associated API developed specifically for REST and is heavily used by Esri Portal software. Rather than a basic XML based service, REST emphasizes scalability of component interactions, independent deployment of components, and importantly for map services, intermediary components to reduce latency and enforce security (Fielding 2000). The advantages and disadvantages between using OGC compliant map services (OGC 2019) such as WMS and WFS versus REST services are beyond the scope of this document.

In building web map services, it is important to take symbology into careful consideration. Data sets that are quantitative in nature should be displayed focusing on symbol size and/or color lightness or saturation (Esri 2011). The eye intuitively sees larger and darker symbols as a higher value. Hierarchical symbology principle states that symbols for a single, quantitative variable (such as earthquake magnitude and tropical storm levels) should be sized proportionally to match the data values as sized symbols are useful for presenting a better understanding of the differences in magnitude (Campbell 2011). A large, dark red symbol implies a higher magnitude than a small, light yellow symbol.

Chapter 3 Requirements

This chapter describes the requirements for the Tracking Trends in Earthquakes and Tropical Storms Web GIS Application. Section 3.1 discusses the application's purpose, Section 3.2 outlines the user requirements, and Section 3.3 explores the main choices involved in the development process.

3.1. Application Purpose

The object of the application is to provide users the ability to explore earthquake and tropical storm events from 1988-2018 and analyze trends in frequency and intensity of the events. The web application should be accessible through a variety of devices, including desktop and laptop computers, as well as tablet and smart-phone type mobile devices. The application also needs to allow the user to view the earthquake and tropical storm events spatially on a map and temporally with a time slider that cycles the events across the map by years. The application should give the users the opportunity to determine increasing and decreasing trends in the earthquake and tropical storm events throughout the thirty-year time frame.

3.2. User Requirements

The users of the web mapping application should be able to:

- Answer their spatial and temporal questions about trends in earthquake and tropical storm events frequency and intensity in a GIS-enabled browser setting
- Access the application from any standard web browser, including Firefox, Chrome, Edge, Internet Explorer, and Safari
- Access the application using a computer, tablet, or mobile device

- Interact with the application using tools that were once primarily available only to GIS practitioners in specialized software
- Not need any specialized GIS software, skill or education to function
- Interact with a user-friendly interface with easy to find tools such as zoom, pan, layer toggle, time slider and legend

By implementing these requirements, the users will be able to easily interact with the tools should be presented in a simple, easy to use format for the general public, putting spatial earthquake and hurricane events, in a browser- and device-agnostic format.

3.3. Development Choices

The application was developed using Esri's desktop GIS software and the Esri online cloud-based mapping and analysis solution called ArcGIS Online. ArcGIS Online was designed to make maps, analyze data, and to share and collaborate in a fully online environment with no need for desktop software (Esri n.d.). It provides the web application developer access to templates and widgets for creating web applications that are customizable and shareable with public or private audiences, based on sharing rules the developer implements throughout the design process.

The platform on which the web mapping application is hosted is the USC SSI web GIS portal currently available at https://uscssi.maps.arcgis.com and a web server suite maintained by the USC SSI staff. The platform provides access to the front end of the web application (the user interface) as well as the server that hosts the map services that feed the web mapping application's map interfaces. The map services are published from the USC SSI server using ArcGIS Server software. ArcGIS Server provides geographic information available to anyone with an Internet connection through web mapping services. These map services allow a powerful server to rapidly receive and process requests for the mapping information sent by user devices alleviating the need for the (slower) processing on the user's device (Esri 2019).

ArcGIS Server on the USC SSI server allows for publishing various geographic information in a variety of OGC compliant map services including WMS Interface Standard and Web Feature Service (WFS) formats. A very basic definition of OGC map services is an open-web standard that provides a simple HTTP interface for requesting geo-registered map image or data from one or more distributed geospatial databases (OGC 2019). That is, map services are a common way to share georeferenced maps across the internet. The earthquake and tropical storm web application relies on WMS map service format for the earthquake and tropical storm data feeds that are visible in the web map interface.

The USC SSI web GIS portal based on the ArcGIS Online cloud-based mapping and analysis solution provides a wide variety of map application templates from which to start the web mapping application development process. The primary templates chosen for the earthquake and tropical storm web mapping application were the tabbed story map and web application dashboard templates.

Chapter 4 Development

This chapter describes the development process in the earthquake and tropical storm web mapping application. Section 4.1 describes the earthquake and tropical storm data used in the application. Section 4.2 gives a high-level overview of the application design, including the concept of nesting the web applications by building individual web applications for each of the themes (earthquake and tropical storm) then nesting them within a larger application’s series of tabs.

4.1. Data Description

The primary earthquake and storm data required to feed the map services, infographic widgets, and web map application primarily came from two authoritative sources. The USGS and NOAA-NWS are the primary authoritative sources for global data on earthquake and hurricane/typhoons. They both maintain robust archives covering over the last hundred years. Several cached map services provided through the ArcGIS portal were aesthetically pleasing basemaps but did not contribute to the actual earthquake and tropical storm data and subsequent trend analysis (Table 1). Because the time frame selected was static (30 years), the data was pulled from archived databases at USGS and NOAA rather than pulling from USGS and NOAA’s live data streams. This simplified development significantly by limiting the number of events to a constant amount and allowed the map services to be optimized for that amount rather than adjusting to live sequences of events and potentially facing server overload issues in the future.

Table 1. Final data sources used in primary data feeds for web mapping interface

DATA SOURCE	CONTENTS	PROJECTION	PURPOSE	SCALE
USGS – https://earthquake.usgs.gov/earthquakes/	Points displaying earthquake events for last 30 years, describing magnitude, lat/long, depth, impact, place, type (earthquake vs. non-earthquake), time, significance, associated tsunami event, etc.	GCS_WGS84 (unprojected, data provided in raw latitude, longitude)	The data feeds were queried out various ways based on attributes to feed both the earthquake map interface and the earthquake themed chart widgets	Global
NWS - https://www.nhc.noaa.gov/gis/	Various GIS data feeds concerning hurricanes; GIS REST links and CSV data feeds with live and historic hurricane information	GCS_WGS84 (unprojected, data provided in raw latitude, longitude)	The data feeds were queried out various ways based on attributes to feed both the tropical storm map interface and the tropical storm themed chart widgets	World-wide: all basins

4.1.1. Earthquake Data Discussion

The earthquake data used for the map services and infographic widgets in the web map application consist of historic (archived) data streams from USGS (USGS n.d.). The data had to be queried down to just the “large” earthquakes (large defined for the purpose of this project as 6.0 magnitude on the Richter scale and larger).

The USGS datasets were available in several formats, including GeoJSON, Comma Separated Values (CSV), GeoRSS, “QuakeML” (a type of XML), and KML (USGS n.d.). CSV is convenient format to quickly move across servers and easiest to edit, since once downloaded, the dataset had to be queried based on magnitude (Magnitude 6.x, 7.x, 8.x, and 9.x respectively) and have columns added to separate the date/time stamps into specific years and decades for symbolization; this step allowed for further analysis and charting and to simplify the infographic creation process. It was easier to query against a custom-created date field to feed a simple graph widget or map symbology than parse out the temporal information from a complex date/time string every time. All these initial queries were performed using Microsoft Access and Structured Query Language (SQL) and beginning with data in the CSV format allowed the data to be imported and exported easily

4.1.2. Tropical Storm Data Discussion

NOAA hosts their tropical storm data several ways including REST services and zipped CSV files (NOAA Office for Coastal Management 2018).

The NOAA-provided REST, WMS, and WFS map services were useful to quickly determine global coverage, time scale and accompanying attribute information, but limit the user to their published symbology and formatting. While WFS does allow for user download, it was much slower to download data over a WFS feed than accessing the data through CSV format. Downloading the raw CSV files and creating custom map services using ArcServer publishing software provided a greater range of flexibility and control over the data and resulting maps and graphics rather than being limited to OGC map services. NOAA provided the storm CSV files divided several ways:

- By storm (each storm in a separate file)
- All storms (all storms in one file)
- Storms by basin (all storms for all years for an individual basin)
- Storms by year (all storms for a particular year in all basins)

- Storms by hemisphere (all storms for an individual hemisphere)

The all storms file was ideal to query the data and symbolize the features in a way that best suited the web map application overall UX/UI design. The hurricane tracks did not have line geometry with one line per storm but were a *series of points for every storm*. This presented more challenges in analyzing trends in frequency, duration, and intensity that required more complex SQL queries for the infographic and charting widgets, as well as symbology and time slider features.

The following queries helped to shrink the initial 220,552 event points down to just the required events:

- All storms since 1980 (brought total number of storm event points down to 108,436 points)
- Nature category* set to 0,1,2 as Tropical, Subtropical, Extratropical (brought total number of storm event points down to 77,885)

The metadata defined the first three nature categories (0, 1, and 2) as actual hurricane strength storms with hurricane defined as anything that reaches >64 knots windspeed (~74 mph).

In order to begin initial speed tests on the map service (necessary due to the immense volume of the feature classes) the symbology was tested two ways: by displaying the results based on named storm in one layer and by basin in another feature. Each layer was time enabled and time awareness turned on in the map document. This setting enabled the resulting map service to carry the time awareness, thus enabling web map tools on the USC SSI enterprise portal to recognize the time fields in the map service to drive the time slider widget.

4.2. Application Development Phases

The web mapping application utilizes HTML, CSS, and JavaScript, and references the ArcGIS JavaScript and REST APIs through the framework of ArcGIS Online web application templates. It is hosted on the USC SSI enterprise portal using Esri's Portal for ArcGIS software and is fed by several OGC web maps, also hosted on the USC SSI enterprise server. The web maps each contain at a minimum two map services: The Terrain with Labels basemap from Esri's basemap gallery, and either the earthquakes or tropical storm map services containing several datasets broken out by magnitude (for earthquakes) or category (for tropical storms). The map services are published from the USC SSI server (gis-server-02.usc.edu) using ArcServer utilizing both the REST architecture and OGC standards. The application was developed in three primary phases: data, map services, and web application.

4.2.1. Data Phase

The data phase involved acquiring, analyzing, and curating the authoritative earthquake and tropical storm data. The data was downloaded from the respective sites (USGS and NOAA) as CSV files, and eventually imported into ArcGIS Desktop using the ArcMap application. Before the data could be read in ArcMap it was imported into Microsoft Excel as an intermediary step simply to clean up the header information and column names, query the points to just the 1988-2018 time period, and separate the magnitude 7.x, 8.x, and 9.x earthquakes and category 3, 4, and 5 tropical storms.

Once the earthquake data sets were conditioned, they were exported into Microsoft Excel worksheets, and imported into Esri's ArcMap as X, Y Event Layers; finally, they were exported into a file geodatabase as feature classes and added to the map to be symbolized. The map symbology was chosen based on standard cartographic principles focusing on size and color saturation to show differences in magnitude and intensity. Once map symbology was ready, the map was made time aware by enabling the time settings in each layer's properties. The time function was set to reference the appropriate attribute field in the data layers that contained the date/time stamp. The symbolized and time aware maps were then published using ArcServer as time aware map services.

Initially the Mag 5 and Mag 6 earthquakes for the last 100 years were planned to be included. USGS would not allow a download of that many earthquakes at one time and produced an error requiring the total number of events be limited. This problem reinforced the decision to limit the overall study to only the last 7.x-9.x over the last 100 years. Thirty years of Mag 5 and Mag 6 earthquakes was well over 50,000 earthquakes event points. The Esri Portal software initially had difficulty pushing that volume through their charting and graphing widgets. To resolve the issue for future iterations of the map services, the feeds would need to be broken apart by decade or restricted another way so as not to overload any of the web map application elements. The charting and infographic widgets are more light weight that the other widgets and cannot handle that volume of data.

4.2.2. Map Services Phase

The map services phase consisted of turning the map documents into map services that would be accessible on the internet. This was accomplished using the "share as map service" command in the file menu in ArcMap. By using a publisher role login to the USC SSI ArcServer instance, the maps were published as REST and WMS map services. This resulted in URLs that could then be used in the USC SSI enterprise portal as a web map. The map services were time-enabled and optimized to show a larger number of points at one time.

To show a larger number of points as one time a default setting in ArcServer had to be changed. ArcServer normally only allows 2,000 features to be displayed by default. That was resolved by increasing the display setting to the software's help documentation highest recommended setting of 5,000 features. Optimally, the map services can handle between 4,000 and 5,000 features at a time before the server displays sluggishness that could be noticed by a user. The setting is accessed during the map service publishing steps. Once the "share as map service" command in the file menu in ArcMap tool was initiated, a map service publishing Graphical User Interface (GUI) opened with several options for changing default map service settings. In the "Parameters" section, the setting was called "Maximum number of records returned by the server" and was set to 5,000 as shown in Figure 10.

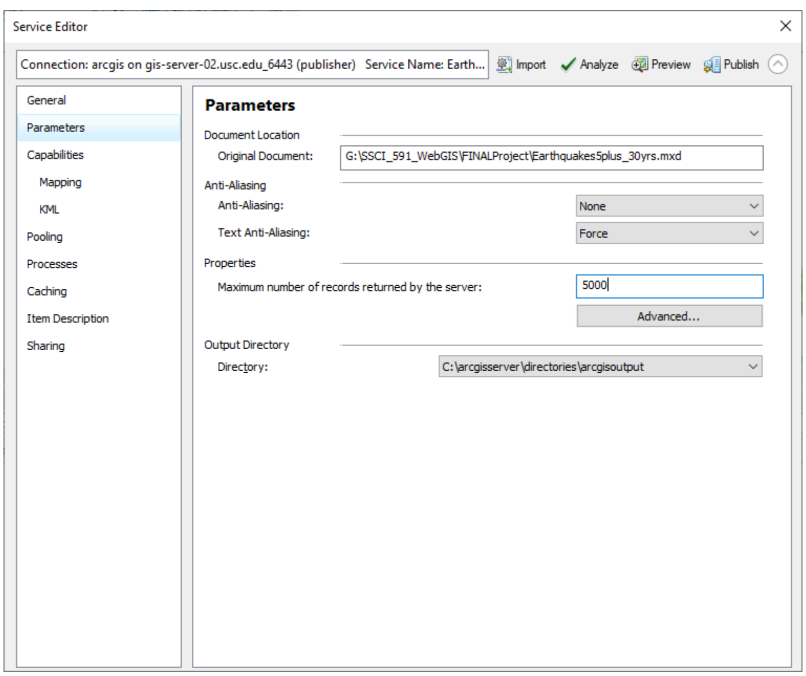


Figure 10. Parameters setting in map service publishing phase with maximum number of records set to 5000.

4.2.3. Web Application Phase

The web application phase involved designing an intuitive web application based on the JavaScript API that incorporated the map services already published through USC SSI's ArcServer. This phase was broken down into two parts. First, individual web applications were built using the web mapping application dashboard template on the USC SSI GIS portal. Secondly the two individual web applications were nested in a web application built from the tabbed Story Map template, also on the USC SSI GIS portal

4.2.3.1. Individual Web Applications

Creation of the individual web applications was accomplished by logging in to the USC SSI GIS portal and creating two individual web maps with the respective earthquake and tropical storm map services discussed previously that were created using ArcServer. The web maps inherited the symbology, layers and initial global scale (that is, zoom level) from the map services (Figure 11) Once each web map was saved in the GIS portal, their settings were set to share with the public. This was a very important step to ensure the data and maps embedded in the web application would be visible to the public, regardless of if they had an ArcGIS Online or USC SSI portal account.

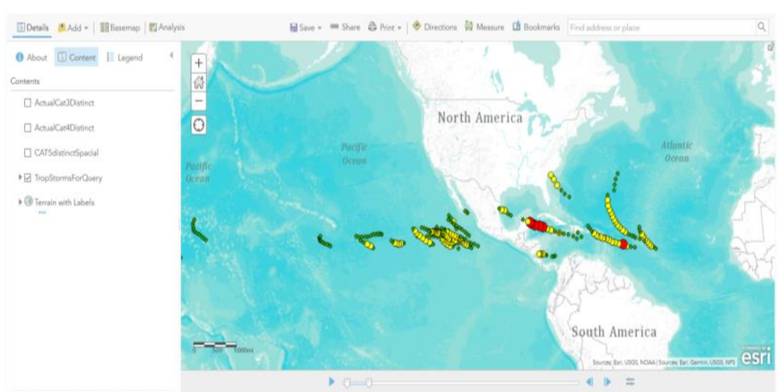


Figure 11. Tropical Storms web map created on the USC SSI GIS Portal with time slider.

After creating the web maps, each were individually turned into their own respective web applications. This was done from the web maps' overview page by clicking "create web app" and selecting "use the web app builder" option.

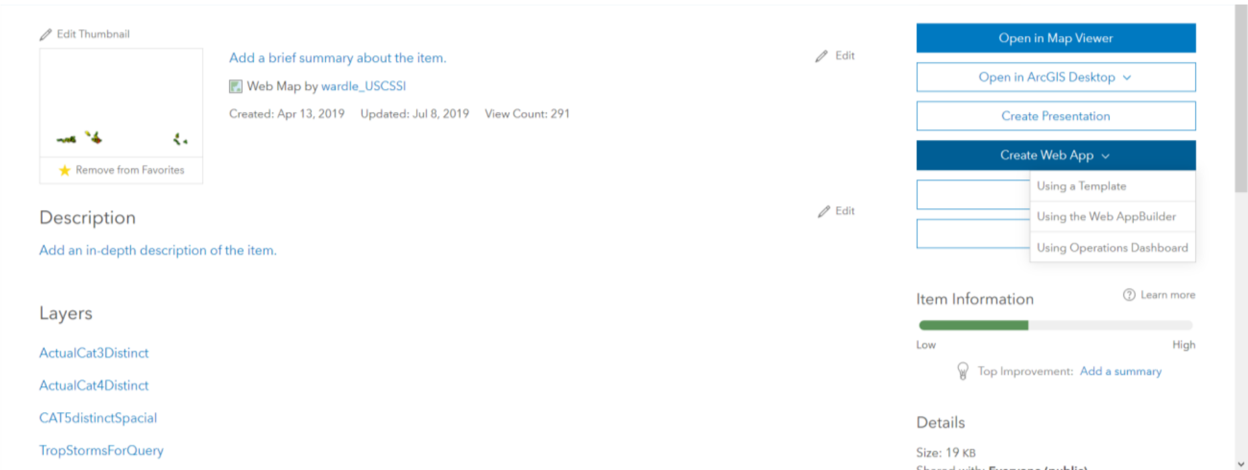


Figure 12. Web map overview page showing Create Web App function with drop down options.

The web app builder on the portal takes the developer through a series of GUIs that allow for a wide variety of application settings to be established and customized. The four main steps include "theme", "map", "widget" and "attribute" settings. In each tab the design of the web application unfolds. For both the earthquake and tropical storm web applications, the theme was set to "foldable" as that layout provided most basic tools already enabled. The map settings were set to inherit the initial extent and visible scales from the web map. Once all the settings were saved for both the earthquake and tropical storm web applications, they were ready for the final step in the web application development phase.

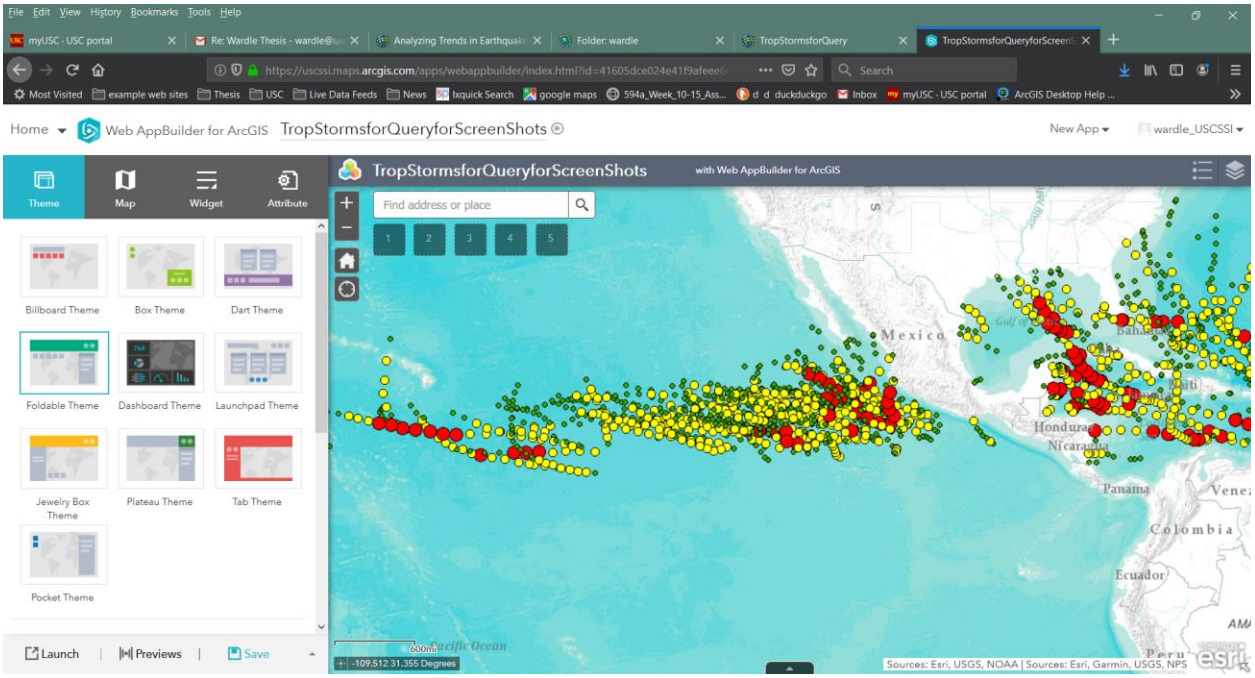


Figure 13. Web application interface with Theme, Map, Widget and Attribute options.

4.2.3.2. Expanded nested design to enhance User Experience

The two web applications were nested together in a tabbed story map so that the users could access both application from one location. This was done by browsing to the “content” page of the portal and selecting “create using the web app builder” option. This step launched a GUI describing numerous templates from which to begin application development. By selecting the “Story Map Series” the two earthquake and tropical storm pre-built web applications could be nested together in a tabbed application (Figure 14). By working through the GUI, both web applications were added to their respective tabs.

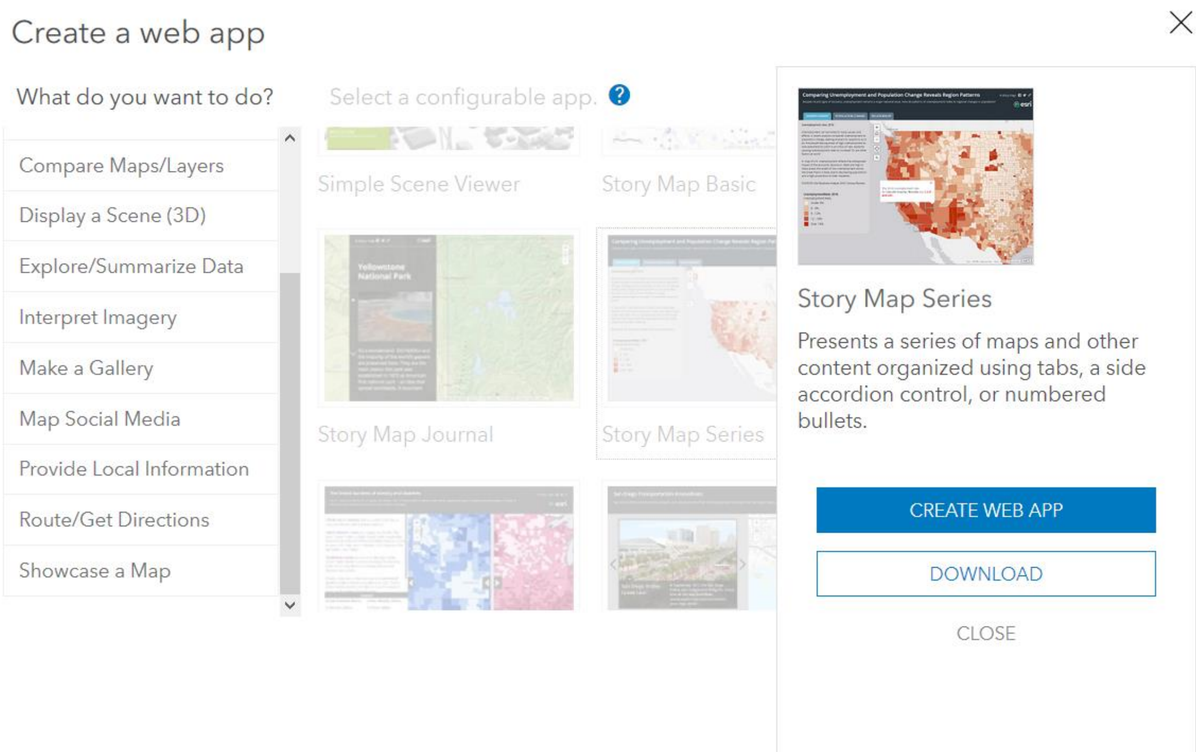


Figure 14. Web application template gallery with Story Map Series option highlighted.

Another element of design was a survey tab that enabled a small group of in-house industry professionals to provide immediate feedback on the web application. The tab contained an embedded page from SurveyMonkey.com with a specialized survey designed specifically for this web mapping application (Figure 15). The survey provided immediate feedback on the user interface and any issues the survey participants faced in real time. Given that those surveyed were a small group of industry professionals, USC’s Institutional Review Board (IRB) approval was not required. If the survey were turned into a long-term feature of the website, IRB approval would be pursued.

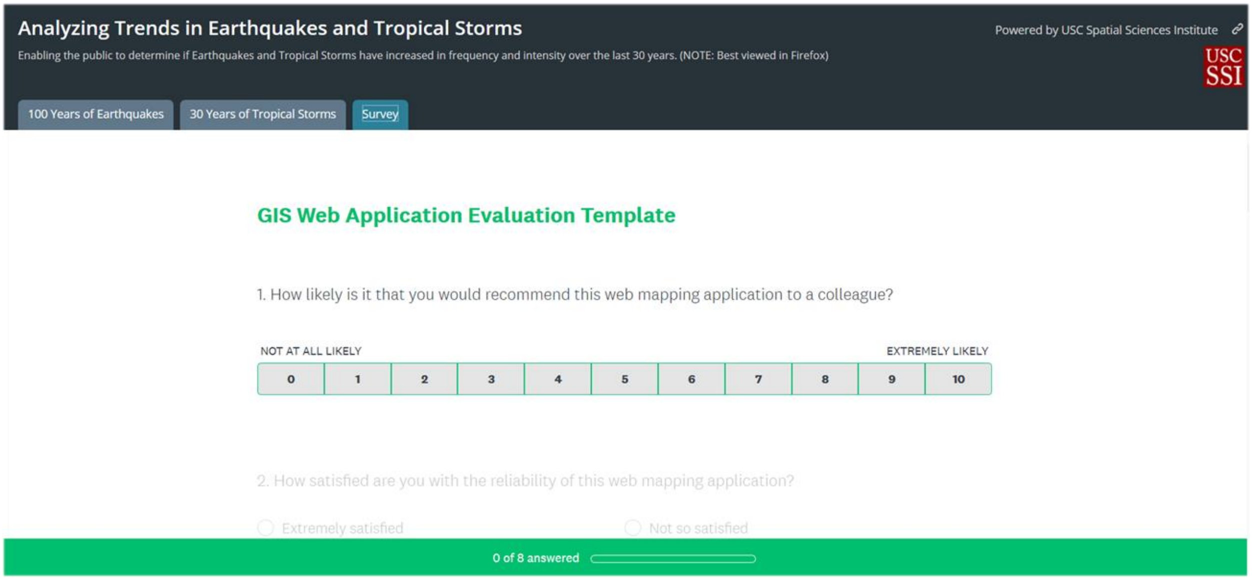


Figure 15. Third tab with customized survey embedded in the application

Another feature included in the application design was a hidden tab, visible only to the site administrator. This tab provided the survey results in real time (Figure 16). This tab allowed the administrator to view the survey submissions on the fly. The survey results are discussed further below in Chapter 6. The survey results allowed for UCD principles to quickly implement user – feedback. For example, at one point a participant requested more information about earthquake and hurricane science and proposed that the USGS and NOAA websites could provide that. Two more tabs were then quickly added to the web mapping application with links to specific USGS and NOAA pages. Unfortunately, both USGS and NOAA web sites blocked the ability to load their actual pages in an iFrame and initially threw an error (Figure 17).

Figure 16. Fourth "hidden" tab displaying survey results only visible to site administrator

Figure 17. Error displayed when trying to embed USGS page to web application tab

The problem was easily overcome by typing text in body of the tab directing the user to "Click here for more information on....", then right clicking on the text, clicking "add hyperlink" and pasting the USGS and NOAA page urls into the add hyperlink box.

Chapter 5 Results

This chapter explores the results of the web application development designed to provide users the ability to explore earthquake and tropical storm events and analyze trends in frequency and intensity. It outlines the individual web applications and the nested web applications into the tabbed story map series.

The web application consists of two separate individual web applications each focused on earthquakes and tropical storms, respectively. They both contain time-enabled maps along with accompanying charts displaying the global statistics in earthquake and storm frequency and intensity for the 1988-2018 time period. Each of the individual web mapping applications allow the user to visualize the data, create custom maps by toggling on and off data feeds, share resulting maps, charts, and infographics, and link to informational sites and data sources for further research.

Each individual web application was designed with a main mapping window in the right of the frame (Figure 18). They contain user controls on the top left of the map such as zoom in/out buttons, a home button (to return map to initial display/zoom), a time slider widget, a USC SSI title and logo that launches a link to the USC SSI academic program site, a basemap selection widget, a layer widget, and a legend widget. The map frame also contains a scale bar, and a full screen toggle button on the bottom left and right sides of the map, respectively. The time slider widget is on by default, displaying a continuous cycle of the data feeds in 2-year increments, starting with 1989 and ending in 2019. All these widgets were enabled by working through the template’s tabbed GUI and choosing each widget to display and applying various settings for layout, color and other variables. Some of those variables enable users to click on each earthquake event in the mapping window to launch an information popup window. The window displays attribute information and allows the user to zoom to the event or display the event in the attribute table at the bottom of the application. Users are also able to pan and scroll within the map window to control the map display.

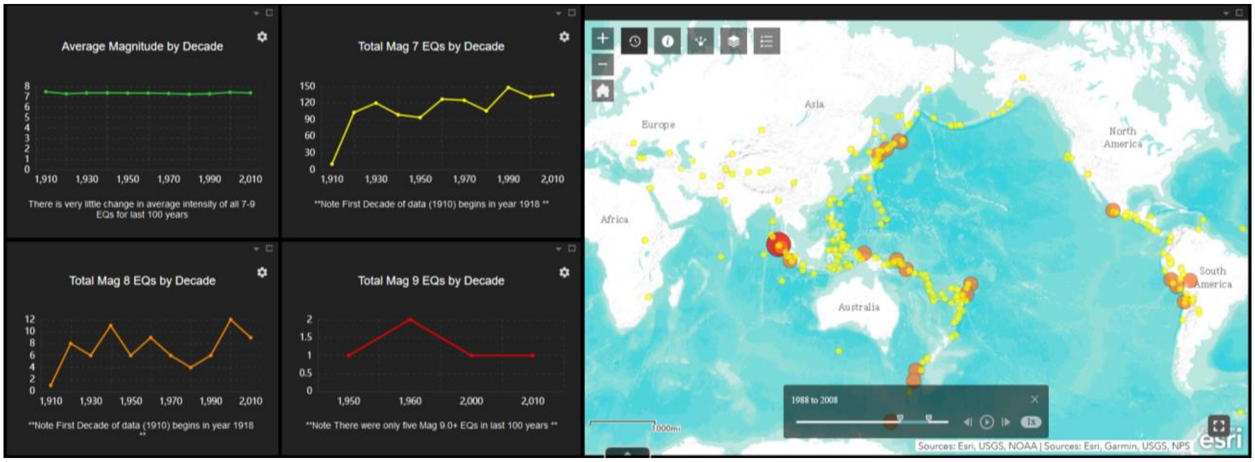


Figure 18. Earthquake web application with a main mapping window and infographic widgets displayed.

In addition to the above settings implemented, on the bottom of the web application is a small up arrow tab that launches an attribute table widget. The widget displays tabs for each layer in the map services currently displayed in the map window. It allows the user to select earthquake or hurricane events, ranges of events, or geographically related events. There is a zoom-to-selected button, clear selection button, refresh button, and filter by map extent button. The widget also has several options for the user to manipulate and show selected records, hide selected records, filter, and show/hide columns.

On the left side of the web application, there are several charting widgets depicting the earthquake data feeds in different ways. The first chart is called, “Average Magnitude by Decade”, and takes all the earthquake data feeds and averages out the magnitude by every ten years. There is a note at the bottom of each of the graphics giving the user pertinent information about each graph. The successive graphs are called “Total Mag 7 EQs by Decade”, “Total Mag 8 EQs by Decade”, and “Total Mag 9 EQs by Decade”, respectively.

All the chart widgets have a slider bar, allowing the user to zoom in to parts of the timeline. The bar stretches or compresses the graph as desired by the user to investigate smaller or larger time frames. The user is also able hover their mouse over the charts and click to pan or use the scroll wheel to manipulate the graph display.

Lastly, all the chart widgets and the main map frame have a maximize button to allow the user to enlarge that portion of the web application and interact with it alone in the browser window. To return to the initial web application, the user can click the minimize button. This is a useful feature if the user has multiple screens and wants to view the map or infographic on a larger screen and enable them to save a screenshot to view later or print the larger version of the map or graphic if needed.

The first tab calls the initial earthquake interface discussed above. The second tab displays the similarly designed second interface devoted to the tropical storms data encompassing the last thirty years with time slider enabled (Figure 19).

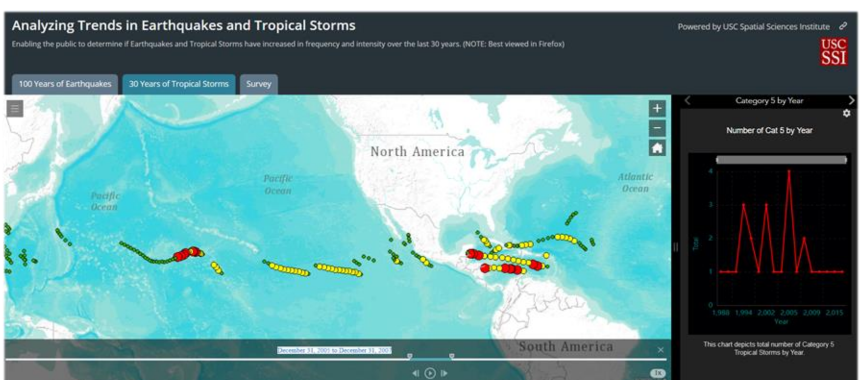


Figure 19. Web application with multiple tabs added and functional time slider.

This tab contains the full web map interface designed for tropical storms as described in Section 4.2.3.1. It includes the entire map and same suite of map tools including the time slider, basemap gallery, layer list, measurement tool, zoom in/out, attribute table popup, and latitude/longitude hover tool. It also contains three charting widgets that either load on the right side of the map one by one, with a slider option, or load all three at once on the left side of the page, depending on the screen size of the user's device (Figure 20). The three charting widgets are called "Number of Cat 5 by Year", "Number of Cat 4 by Year", and "Number of Cat 3 by Year", respectively and each graph reflects the color of their respective map symbols (red for category 5, yellow for category 4, green for category 3). While this had to be done manually, it provided a visual connect for the user to quickly understand which data set the graphs were referencing.

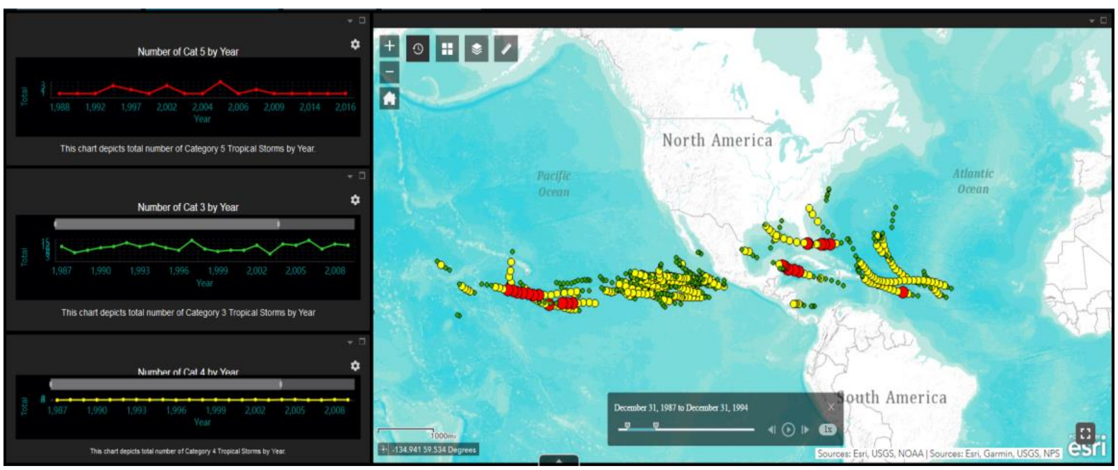


Figure 20. Tropical storm application with charting widgets loaded simultaneously.

In order to allow the users access to more earthquake and tropical storm information, two more tabs were made available linking the user to NOAA’s National Ocean Service which discusses hurricane science, hurricane prediction and hurricane preparedness (Figure 22) and USGS’ Earthquakes Hazards program page and which discusses the science behind earthquake events, shows earthquake animations, and has background information on well-known earthquake events throughout history (Figure 21).

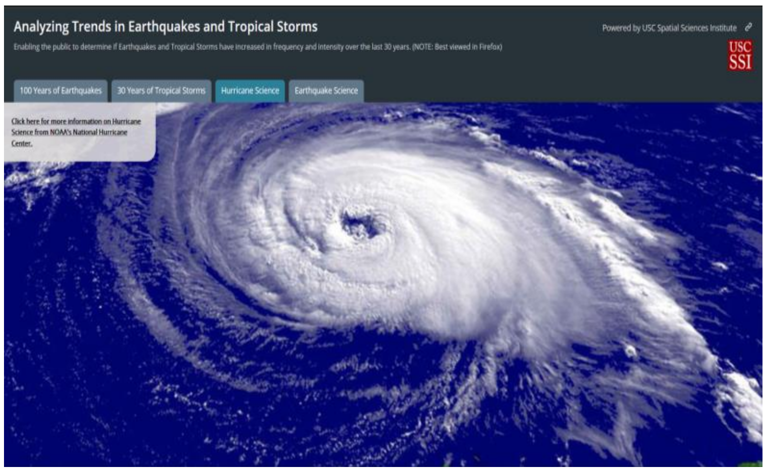


Figure 22. Additional hurricane science tab added as a result of UCD feedback.

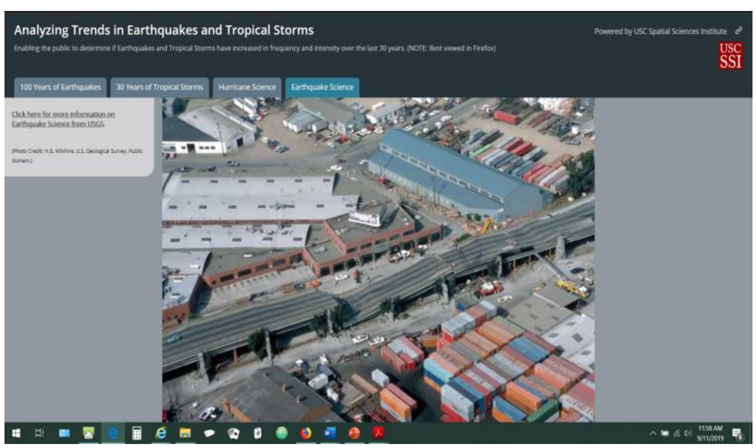


Figure 21. Additional earthquake science tab added as a result of UCD feedback.

One last feature included in the web mapping application’s design is for the interface to automatically adjust based on what type of device the user uses while visiting the application.

While the interface was originally designed for a larger computer screen (laptop or desktop style screens), it does technically work on smart phones and tablets (Figure 23). It is touch screen enabled so that users merely need to swipe across the bottom to switch between what appears as tabs in a larger computer screen. Users can drag the map to pan, pinch to zoom in/out, and touch a drop down a menu to enable the other mapping tools.

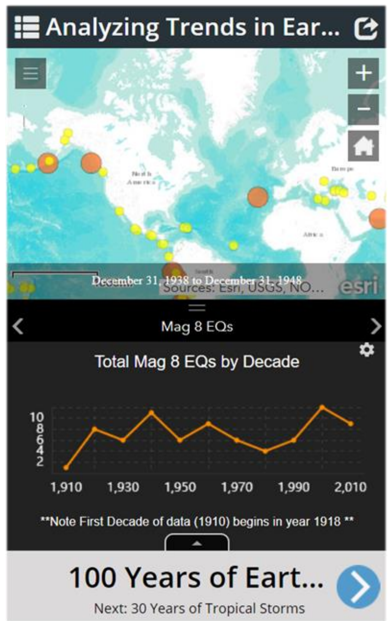


Figure 23.Web mapping application layout when viewed from a smartphone.

The web mapping application meets the initial application purpose of giving users the opportunity to determine increasing and decreasing trends in the earthquake and tropical storm events throughout the thirty-year time frame. It is accessible through a variety of devices, including desktop and laptop computers, as well as tablet and smart-phone type mobile devices. It also allows the user to view the earthquake and tropical storm events spatially on a map and temporally with a time slider that cycles the events across the map by years.

Chapter 6 Application Assessment

This chapter discusses the application assessment process, disclosing participants in the survey and how they were contacted, evaluation of the results with some discussion regarding the potential reasons for some of the responses, and finally, a summary of the overall assessment.

6.1. Application Assessment Process

Ten industry professionals were invited to participate in the survey process based on their professional associations and previous experience with web mapping interfaces. None of the assessors had any knowledge of the Earthquake and Tropical Storm application or were involved in any way with the development process. The week of July 1st, 2019 the participants were contacted in person and requested to survey the web application. They were provided instructions on accessing the website, and details on the background of the website. Eight of the ten professionals responded by July 13th with their survey responses. The survey tab was then removed from the web map application.

The survey was designed using SurveyMonkey.com and embedded into the actual web mapping application as a separate tab. In order to ensure the survey questions were appropriate for the web mapping application, SurveyMonkey's web application survey template was used, focusing on eight of the top recommended questions. Several questions had to be reworded slightly to reflect the web mapping application theme but did not alter the questions' intent.

6.2. Evaluation Results

The eight survey questions are available in Appendix B – Web Mapping Application Survey Questions. The first question, "How likely is it that you would recommend this web mapping application to a colleague?" had interesting results. The question was designed to be answered on a scale of 0 – 10, with zero being "Not at all likely", and 10 being "Extremely likely". Half of the respondents (4 of the 8) fell within what SurveyMonkey labeled "Promotors", that is, those that scored the question either a 9 or a 10. The other half (4 of 8) scored what SurveyMonkey labeled as "Passives", that is a score of 7-8. There were zero respondents in the "Detractors" category encompassing a score of 0 – 6 (Figure 24)

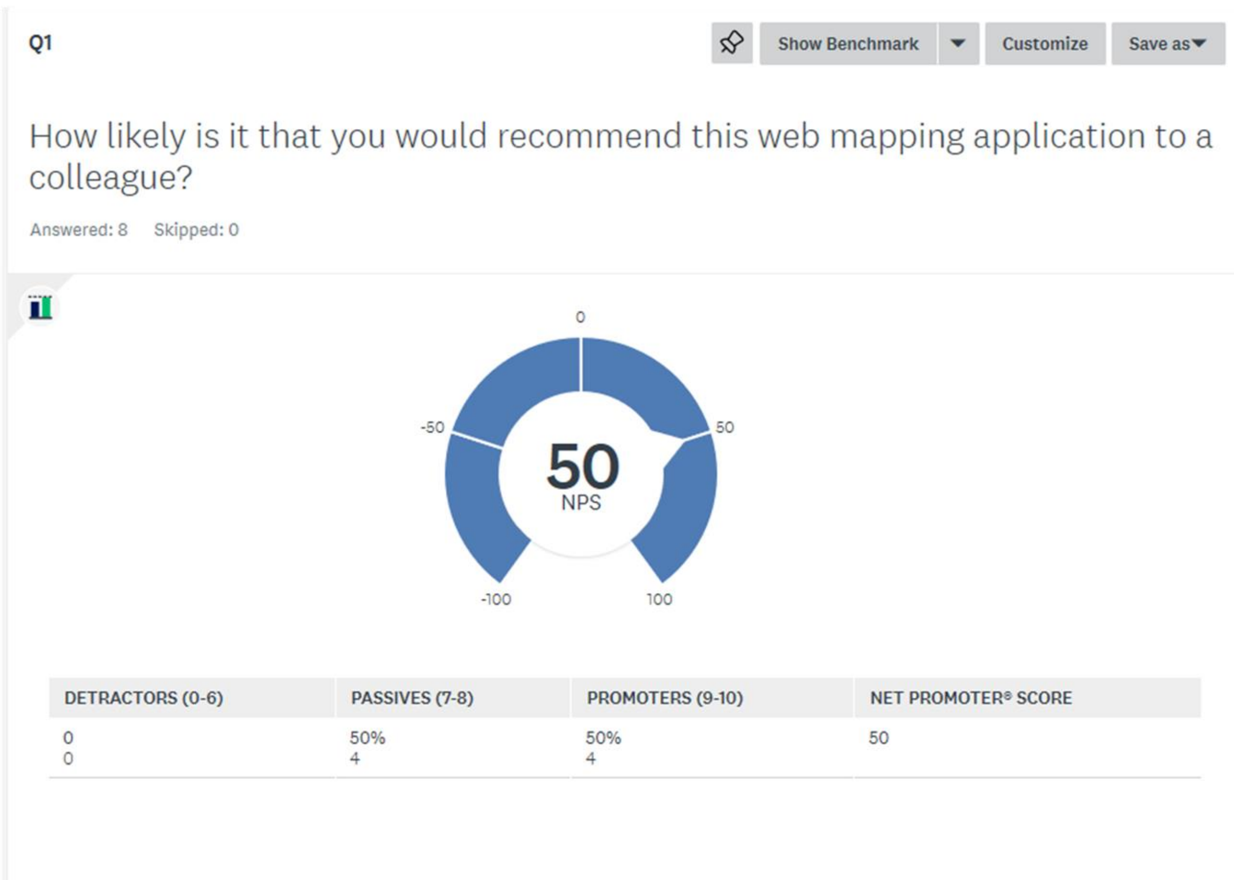
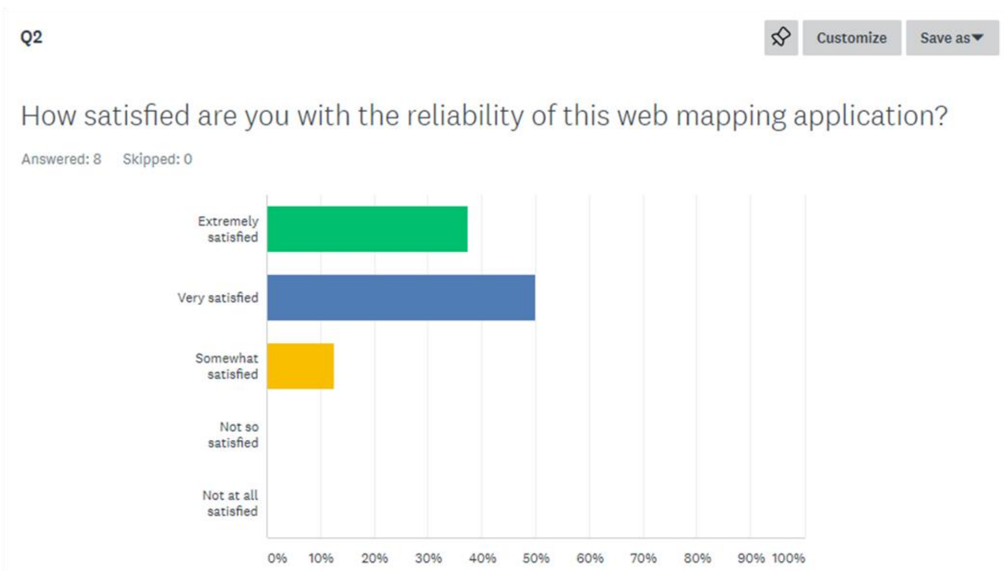


Figure 24. Survey question 1 responses

The second question, "How satisfied are you with the reliability of this web mapping application?" was answered by all eight respondents (Figure 25). Their answers ranged from a "somewhat satisfied" (1 respondent) to "very satisfied" (4 respondents) and "extremely satisfied"

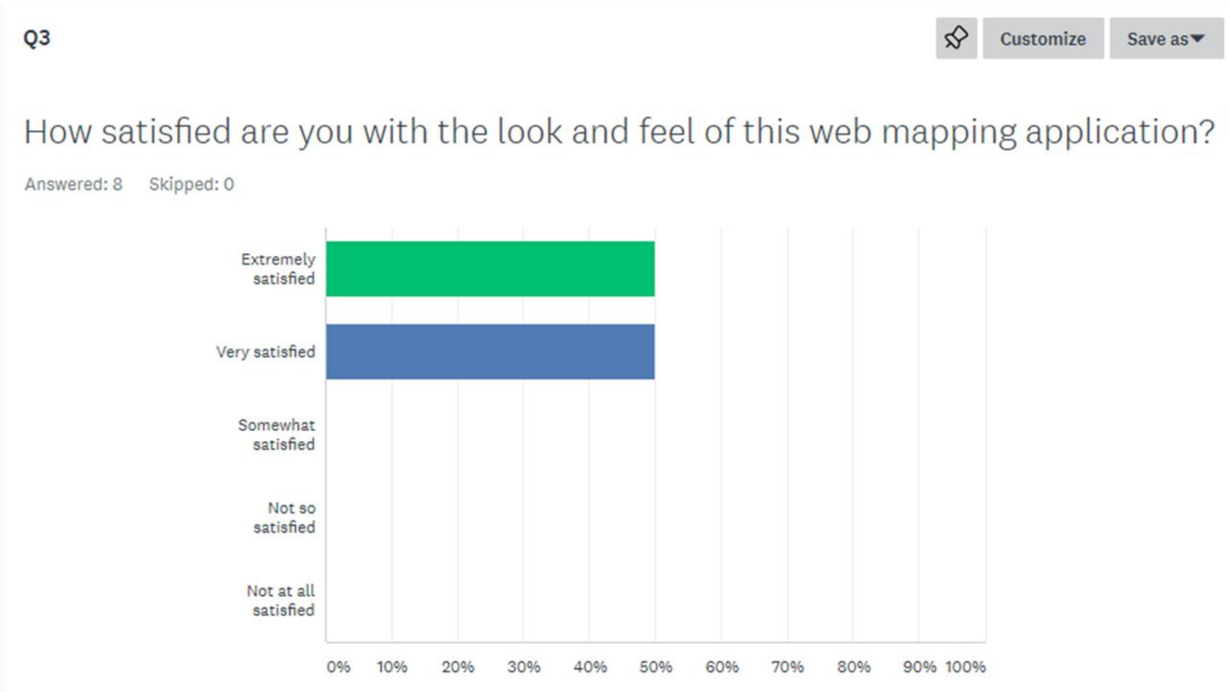
(3 respondents). Upon looking further at the respondent that answered “somewhat satisfied”, their open ended response to Question 8 “Do you have any other comments, questions, or concerns?” was “charts were a little slow to load on my work computer...might have been a work network thing?”. Their slow work network could have had some impact on their answer to Question 2. Upon verbal trouble shooting with this respondent, it was discovered that his work IT department slows their access to the internet over the lunch hour to discourage audio and video streaming of non-work-related subjects. When the respondent re-accessed the website from his work computer later in the day and from his home office, he had no difficulties with access or load times for any portion of the website.



ANSWER CHOICES	RESPONSES	
Extremely satisfied	37.50%	3
Very satisfied	50.00%	4
Somewhat satisfied	12.50%	1
Not so satisfied	0.00%	0
Not at all satisfied	0.00%	0
TOTAL		8

Figure 25. Survey question 2 responses

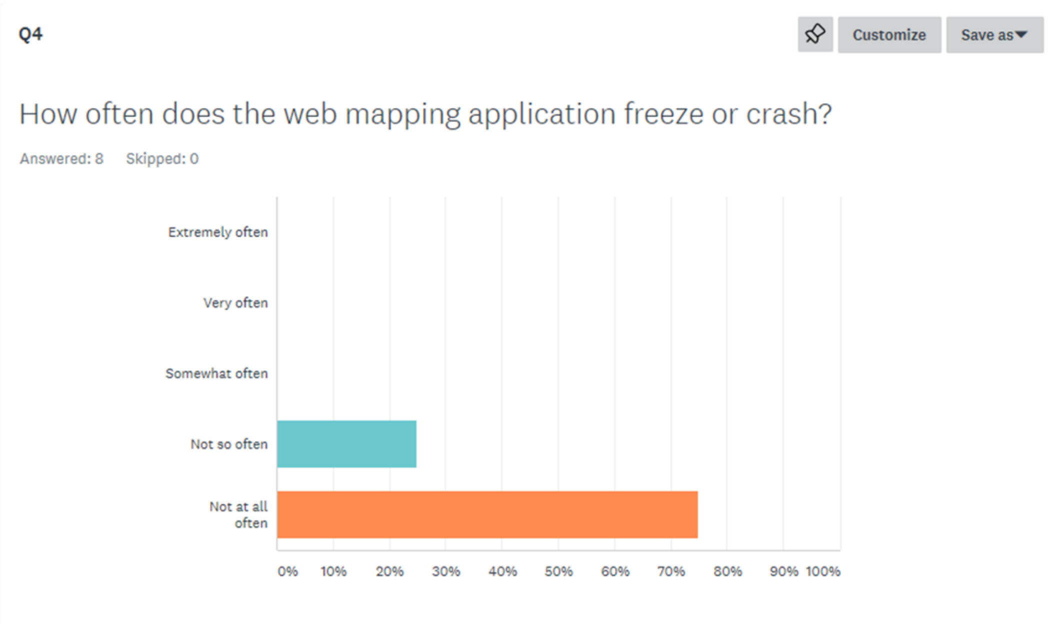
The third question, “How satisfied are you with the look and feel of this web mapping application?” was answered by all eight respondents (Figure 26). Half (4 of the 8) responded with a “Very Satisfied” and the other half responded with an “Extremely Satisfied.



ANSWER CHOICES	RESPONSES	
Extremely satisfied	50.00%	4
Very satisfied	50.00%	4
Somewhat satisfied	0.00%	0
Not so satisfied	0.00%	0
Not at all satisfied	0.00%	0
TOTAL		8

Figure 26. Survey question 3 responses

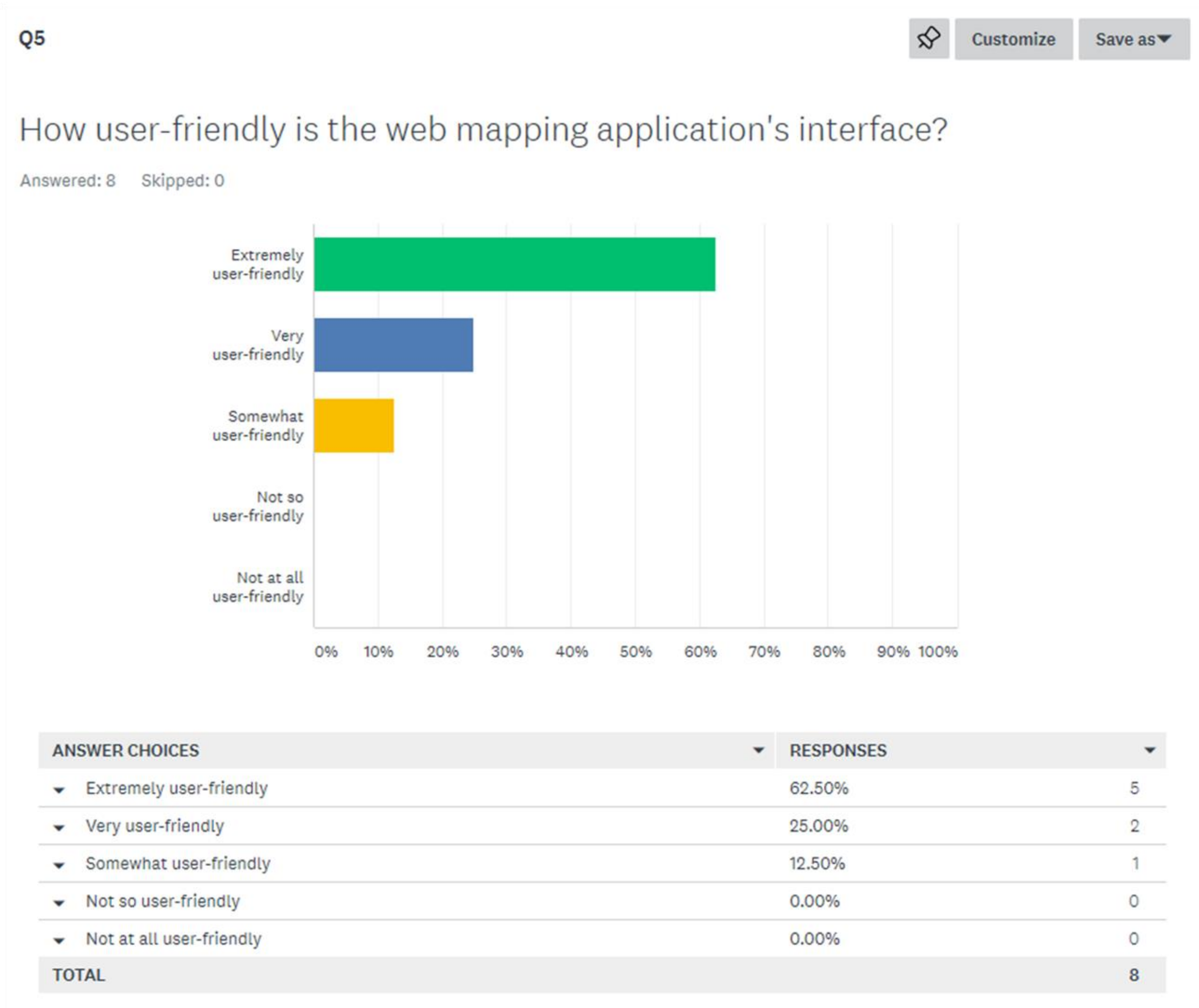
The fourth survey question “How often does the web mapping application freeze or crash?” was also answered by all the respondents (Figure 27). Two of the respondents chose “Not so often”, while six chose “Not often at all”. Of the two who chose “not so often” , one did not fill out the open-ended questions (# 7 and 8) at all, but the other respondent did have a comment in Question #7 (“Do you have any thoughts on how to improve this software?”). He or she stated, “I am thinking it may have been a network problem, but I had to manually turn on the layers.” It is possible that their network slowness could have impacted their choice for Question #4. Given that no respondents had “somewhat often”, “very often” or “extremely often” as their response to Question #4, the initial data curation and map service optimization namely using SQL queries to limit the data feeds to only what was required for the web maps) was successful in preventing sluggish map service loads.



ANSWER CHOICES	RESPONSES	
Extremely often	0.00%	0
Very often	0.00%	0
Somewhat often	0.00%	0
Not so often	25.00%	2
Not at all often	75.00%	6
TOTAL		8

Figure 27. Survey question 4 responses

The fifth question “How user-friendly is the web mapping application's interface?” was also answered by all eight respondents (Figure 28). This question had two “Very user-friendly” and five “Extremely user-friendly” responses. The only concerning result was the one “Somewhat user-friendly” response. Upon further research, it was the same respondent who stated, “I am thinking it may have been a network problem, but I had to manually turn on the layers.”

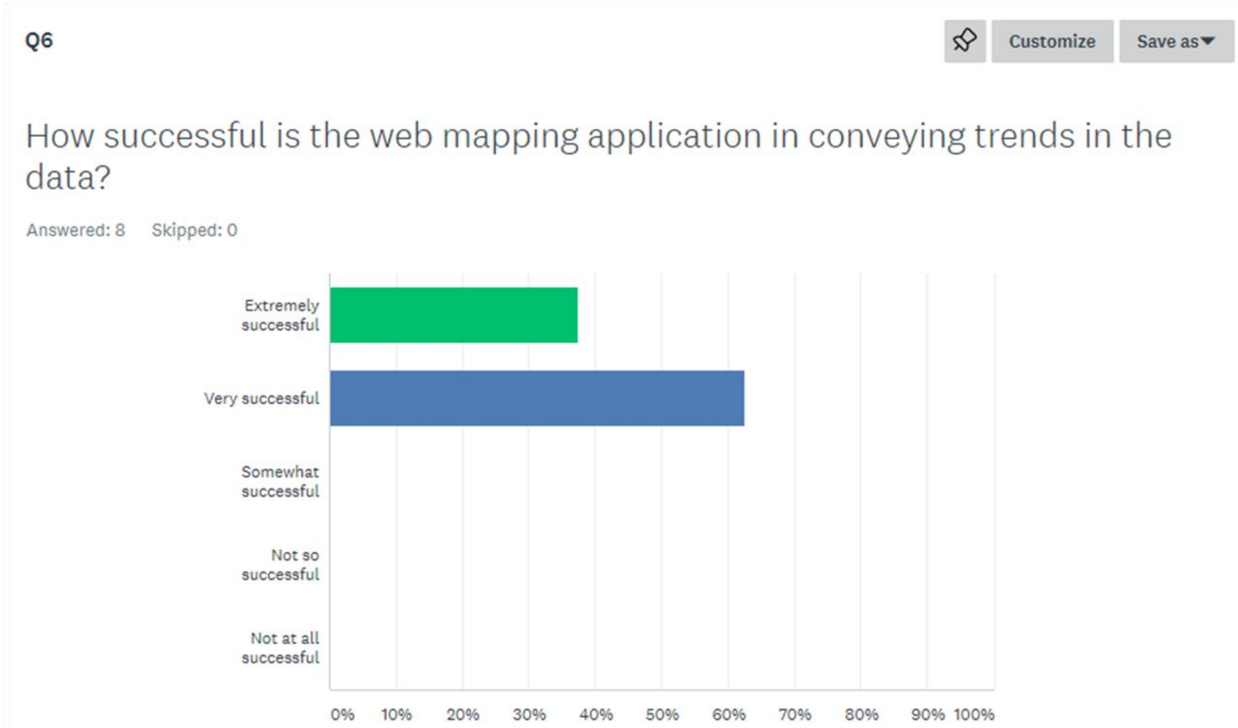


ANSWER CHOICES	RESPONSES	
Extremely user-friendly	62.50%	5
Very user-friendly	25.00%	2
Somewhat user-friendly	12.50%	1
Not so user-friendly	0.00%	0
Not at all user-friendly	0.00%	0
TOTAL		8

Figure 28. Survey question 5 responses

The sixth question “How successful is the web mapping application in conveying trends in the data?” was also answered by all the respondents (Figure 29). This question was answered positively by all the respondents with five choosing “Very successful” and three choosing

“Extremely successful” as their answers.



ANSWER CHOICES	RESPONSES	
Extremely successful	37.50%	3
Very successful	62.50%	5
Somewhat successful	0.00%	0
Not so successful	0.00%	0
Not at all successful	0.00%	0
TOTAL		8

Figure 29. Survey question 6 responses

Lastly, the two open ended questions, Questions 7 and 8, “Do you have any thoughts on how to improve this software?” and “Do you have any other comments, questions, or concerns?” respectively were both answered by only six of the respondents (two respondents did not give any response to either Question 7 or Question 8). Question 7 was answered with the following six responses:

- It would be nice to have links to more information on hurricanes and earthquakes...USGS or NOAA maybe have good sites to link to?
- I would have like to see more earthquake magnitudes besides the 7s, 8s, and 9s. 5s and 6s would have been nice as well, though prob way too much data for the feeds to handle.
- I'd like to see more tabs with other data sets like tsunamis/floods/landslides etc.
- None. Looks beautiful!!!!
- I am thinking it may have been a network problem, but I had to manually turn on the layers.
- N/A

The first response of “It would be nice to have links to more information on hurricanes and earthquakes.... USGS of NOAA maybe have good sites to link to?” is a good example of a UCD feedback loop. Given that this response occurred just before the end of website development this suggestion was incorporated by adding two more tabs into the web mapping application with links to USGS and NOAA informative pages on Earthquake Science and Tropical Storm Science, respectively.

Question 8 responses had more positive feedback and had fewer suggestions:

- I used Explorer to open the webpage and everything looked wonderful.
- The web page looks great.
- Great site; look forward to using it more.
- great interface.... loved the time slider feature and the graph colors matching the map symbol colors.

- charts were a little slow to load on my work computer...might have been a work network thing?
- N/A

6.3. Assessment Summary

Overall, the survey was successful in doing what it was intended. Interestingly, some respondents, regardless of their interest, simply were not interested in writing out more detailed feedback in the open-ended questions. Primarily, the issues that a few respondents seemed to run into were not specifically reflective of poor design, data management, or map service optimization, but merely (according to their assessment) sluggishness on their own work network access. While troubleshooting their unique work networks' capacity, firewalls, security infrastructure is beyond the scope of this thesis, it is something to consider in future development on this or other web mapping interfaces. While all network protocols are impossible to plan for, in the future, the UCD feedback loop should include more scheduled time for trouble-shooting unique network bottlenecks in order to mitigate some of the slowness for users with slow network access.

Chapter 7 Conclusion

This chapter discusses the overall web application, summarizing the design, disclosing some of the difficulties encountered during development, limitations in the source data and application, and ends with potential areas for future development and improvements.

7.1. Summary of Web Application

The web application was designed using a nested concept. The initial data sets from USGS and NOAA were fed to web maps using OGC map services published using Esri's ArcServer software. The map services were fed to themed web maps on USC SSI web GIS portal located at https://uscssi.maps.arcgis.com.

Those web maps were then used as the basis for web map applications that were combined with charting widgets to display trends of the individual data sets across time. The final nesting occurred by feeding the two individual web map applications (earthquakes and tropical storms) into a tabbed story map that enables the user to toggle between the different web map applications and link to more earthquake and tropical storms information for further research.

7.2. Difficulties in Development

There were few difficulties encountered throughout the development process. Initially, the first issue was making the data look and behave the way it should before attempting to publish as a map service. That meant fixing attribute field names and querying very large datasets down to a manageable size in order to optimize the map service interaction speeds. Once the most efficient queries were determined to subset the data, there were not many issues with publishing the map services or building the web maps.

The next difficulty came with designing the charting widgets to accurately display the trends in the data over time. The chart widget templates did not interact well with the map services, so after much testing, the datasets had to be loaded to the web application as extra data sources. This enabled the chart widgets to “see” the data and interact with them more efficiently.

The only other difficulty came with fully understanding how to nest the different elements of the design. Once it became clear that it was possible to embed web maps into web applications and then embed multiple web applications into a tabbed story map, there were no further major issues with the actual design or development.

7.3. Future Development

In order to turn the web mapping application into a long-term hosted web site several events would need to occur. First, arrangements would need to be made with the USC SSI program to continue hosting the data and map services on their server or recreate them on a private web server that has Esri’s ArcServer software installed. The actual web applications and tabbed story map application would have to be moved to a private portal account on arcgis.com, as only USC students are allowed access to those accounts.

A few future developments would improve the website design. The primary improvement would be to turn the earthquake and tropical storm map services into live services that are updated in real-time as earthquake or tropical storm events occur. As it is now, the map services must be manually updated with data downloaded from the USGS and NOAA websites. With live updated map services, to the charting widgets and SQL queries would have to be redesigned. As live data feeds were beyond the extent of the initial web application design, the queries or chart widgets were not designed to account for changes in dates, e.g. starting and ending dates change when “today’s date” changes every day. “Today” introduces a level of complexity in SQL and charting that is outside the scope of this thesis.

Another thing to consider in future development is the users’ individual network issues. Some users may be accessing the web application from a disadvantaged network, as slow network connections still exist in many parts of the world, as well as the fact that some network providers or employers intentionally throttle back network speeds or streaming capabilities during high traffic periods like the lunch hour. While a web application developer cannot control network provider choices, there could be potential to develop a “lite” version of the application where a user could be presented with an option to launch a different version of the web application when they experience slow network speeds.

Lastly, the full web mapping application could be improved with other natural disaster data sets beyond the initial earthquake and tropical storm data sets. Some of the survey participants asked about tsunamis, floods, landslides, and fires and if they could easily be added to the application. If the data were readily available and curated into easy to publish map services, the rest of the design could go smoothly. The difficulty lies in acquiring and curating those types of datasets, particularly on a global scale. For the purposes of this thesis, the workload to acquire, curate, manage, and publish that volume of data would be daunting.

Overall, this project served to provide users the ability to explore earthquake and tropical storm events over the last 30 years and analyze trends in frequency and intensity of the events. Members of the general public can now determine for themselves whether earthquakes and tropical storms are increasing in frequency and intensity. By providing reliable data, statistics, maps and online tools, users have a more empirical approach to trend analysis in earthquakes and tropical storms other than dramatic headlines and pictures in the news.

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Appendix A – CRED EM-DAT Database License Agreement

From: https://www.emdat.be/emdat_db/

DATABASE LICENSE AGREEMENT

(UCL2019)

This Database License Agreement (the Agreement) is made between yourself (**the Licensee**) and Université Catholique de Louvain (UCLouvain), a Belgian University with its registered office located Place de l'Université, 1, B-1348 Louvain-la-Neuve, Belgium, acting through its Research Group "Center for Research on the Epidemiology of Disasters" or CRED (**the Licensor**).

WHEREAS Licensor has developed the EM-DAT database (hereinafter the "Database") made available on the internet for Authorized Use on the one hand and, upon payment of a fee, for Extended Authorized and commercial uses on the other hand;

WHEREAS the Database aims at providing an objective basis for vulnerability assessment and rational decision-making in disaster situations, by collecting, organizing and giving access to validated data on the human impact of disasters (such as the number of people killed, injured or affected), and the disaster-related economic damage estimates;

Licensor wishes to lay down the conditions enabling Licensee to use said Database.

ARTICLE 1: OWNERSHIP OF THE DATABASE

Licensor guarantees to be the owner of all intellectual property rights related to the Database, including all copyrights and determines the content of the Database. Licensor shall at all times, have the right, without any prior notice or motivation, to –amongst other decisions-: (i) modify the data disclosed, (ii) disclose other data, (iii) suspend the availability of the Database for maintenance or any other purposes, (iv) decide to cease making available such Database. Licensor shall notify Licensee of any amendment that might have a consequence on the access rights of Licensee by email at the Licensee's email address.

ARTICLE 2: SUBSCRIPTION AND LICENSE OF THE DATABASE

2.1. Subject to the terms set forth in this Agreement, Licensor agrees to make available to the Licensee the data contained in the Database:

- free of charge for **Authorized Use,** as detailed in article 2.3 of this Agreement;
- upon payment fee for **Extended Authorized Use,** as detailed in article 2.4. of this Agreement
- upon payment fee for **Commercial Use,** as detailed in article 2.5. of this Agreement.

Licensee acknowledges that, except for the use rights granted in article 2 of this Agreement, no intellectual or any other proprietary rights are transferred or assigned through the Agreement. All intellectual property rights, including but not limited to copyrights, trademark rights and database rights, used or embodied in or in connection with the Database are and remain entirely with the Licensor.

2.2. Access to the Database. Upon completion of the registration information on www.emdat.be and acceptation of the present Database License Agreement, Licensor shall provide Licensee with a password for internet access of the Database.. Data transmission and computer link to the Database through the internet shall be the sole and exclusive responsibility of the Licensee.

2.3. Authorized Use. Licensor grants Licensee, who accepts, a royalty-free, worldwide, non-exclusive, non-transferable and non-sublicensable license with **Limited Access** to use the Database for **Authorized Use** , counting as from the date of acceptance of the present Agreement and automatically expiring as from the moment the Limited Access is reached. *Authorized Use* refers to using and accessing the Database, searching within the Database, viewing the search results displayed in an excel sheet or csv file, downloading the search results files (texts, images or else) and printing these search results for research, teaching or information purposes, excluding, without limitations, any Commercial Use. ***Limited Access*** means that Licensor shall put at the disposal for academic organisations and students an amount of maximum 8000 data contained in the Database, for international organisations and private companies' access shall be granted up to 1000 data contained in the Database.

2.4. Extended Authorized Use. Licensor grants Licensee, who accepts, a royalty-free, worldwide, non-exclusive, non-transferable and non-sublicensable license with **Limited Access** to use the Database for **Extended Authorized Use,** for a duration of one (1) year counting as from the date of acceptance of the present Agreement. Extended Authorized Use refers to using and accessing the Database, searching within the Database, viewing the search results displayed in an excel sheet or csv file, downloading the search results files (texts, images or else) and printing these search results for research, teaching or information purposes, excluding, without limitations, any Commercial Use, exceeding the Limited Access (for perfect understanding: for academic organisations and students assessing more than 8000 data contained in the Database and for international organisations and private companies accessing more than 1000 data contained in the Database). Licensee shall be invoiced for such Extended Authorized Use in conformity with article 4 of this Agreement.

2.5. Commercial Use. In case the Licensee needs a Commercial Use license on the Database, Licensee shall send a prior written request to Ms. Regina BELOW, EMDAT data manager – regina.below@uclouvain.be . (hereinafter "the Database Manager") describing the aim of such Commercial Use and the amount of users needing access to such data subject to article 7.1. Upon the Database Manager's sole discretion to consent to such project, which shall not be unreasonably withheld, the terms and conditions of the present Agreement relating to such Commercial Use and more precisely article 4 of this Agreement shall apply.

Parties agree that shall be considered *Commercial Use* , all use of the Database for a commercial interest rather than a public, not for profit, or educational interest and may include a corporation, partnership, limited liability company, law firm or other business, organization, that wishes to access the Database. Commercial interest means the sale, lease, license or other transfer of the Database to a for-profit organisation or the use of the Database to perform contract research, to produce or to manufacture products for sale purposes, or to conduct research activities that result in any sale, lease, license or transfer of the Database to any organisation. It is understood by the Licensee that the Unauthorized use as defined in article 2.6. of this Agreement shall not be considered to be included in the Commercial Use.

2.6. Unauthorized use. Licensee undertakes not to:

- Reproduce, copy, communicate, lend, or otherwise distribute a substantial part of the Database or in whole;
- Make a direct commercial use of the Database, such as selling, renting or leasing a substantial part of the Database or in whole
- Reverse assemble, de-compile, de-compose, or disassemble the Database;
- Create substitute or derivative databases of the Database;
- Attempt to unlock or bypass any initialization or security systems used by the Database;
- Share, use and/or transmit any portion of the Database via the Internet to unauthorized users;
- Divulge the password to unauthorized users that have not agreed to the Database License Agreement;
- Remove, alter or obscure any proprietary legend, copyright, trademark or other intellectual property right notice, logo and image in or on the Database; or
- database via the Internet to unauthorized users;
- Divulge the password to unauthorized users that have not agreed to the Database License Agreement;
- Remove, alter or obscure any proprietary legend, copyright, trademark or other intellectual property right notice, logo and image in or on the Database; or
- Perform acts that conflict with the normal exploit

Perform acts that conflict with the normal exploitation of the Database or unreasonably prejudice the interest of Licensor;

ARTICLE 3: PERSONAL DATA

Licensee agrees that certain personal data may be collected and processed via our site, for example through the registration form to be completed, in order to provide access to the Database. The collected personal data shall be used exclusively for the purpose indicated above. Licensor undertakes to process such data in accordance with the Belgian Law of 8 December 1992 on the protection of privacy in relation to the processing of personal data, as amended and the General Data Protection Regulation, Regulation (EU) 2016/679 of April 27, 2016 of the European Parliament and the Council Concerning the protection of individuals with regard to the processing of personal data and the free movement of such data and repealing Directive 95/46 / EC (General

Data Protection Regulation) The legal texts can be consulted on the website of the Commission for the Protection of Privacy (http://www.privacy.fgov.be/).

The data collected is neither transferred nor transmitted to any other organization. However, Licensor reserves the right to disclose information and / or personal data at the request of a legal authority in accordance with the laws and regulations in force.

ARTICLE 4: FEES

In exchange for the **Extended Authorized Use** of the Database, Licensee shall pay an annual fee equal to the amount of:

- 600,00€ (TVA not included) for academic, universities and non-profit research institutions
- 6.000,00€ (TVA not included) for international organisations (UN agencies, multi-lateral banks and institutions and national government) and private firms, consultancies companies and other profit organizations

The financial considerations for a **Commercial Use** shall be agreed upon in a separate agreement.

The Database shall be available upon proof of payment of the corresponding fee.

ARTICLE 5: WARRANTY AND LIABILITY

5.1. Warranty. The data contained in the Database are given for information purposes only and do not constitute any form of advice, recommendation, representation or endorsement. Licensor disclaims all warranties and/or conditions of any kind, express or implied, in respect of the functions, performances, completeness or accuracy of the Database. Licensor does not guarantee that the functions or performances of the Database will meet Licensee's requirements or that the operation of the Database will be uninterrupted or error free, or that any defects in the Database will be corrected. Licensor shall have no obligation to repair or replace the Database under any circumstances.

5.2. Liability. Licensor shall in no event be liable for any business decision taken by Licensee based on the data made available through the Database. The entire risk arising out of the use of the Database remains with the Licensee. Under no circumstances, including claims of negligence, shall Licensor be liable for any damages whatsoever (including, without limitation, damages for loss of business profits, interruption of business activity, loss of business information, or other monetary loss) arising out of the use or inability to use the Database. More in particular since use of and access to the Database depends, in part, on third parties (e.g. telecommunications carriers) whose performance is outside Licensor's control, Licensor disclaims all liability for damages arising from the failure of the transmission or receipt of data.

The entire risk arising out of the possible reproduction and distribution of the Database remains with the Licensee.

ARICLE 6: CITATION

Licensee agrees to use Proper Citation of the Database in all public use of the Database or its data. All published papers and technical reports from the Licensor related to the Database may be used free of charge by the Licensee, provided the Licensee uses Proper Citation. Proper Citation of both the Database and data obtained through the Database is the responsibility of the Licensee alone. "*Proper Citation* " of the Database means: "EM-DAT, CRED / UCLouvain, Brussels, Belgium – www.emdat.be (D. Guha-Sapir)"

ARTICLE 7: DURATION OF THE AGREEMENT

7.1. Term. This Agreement shall become effective as of the moment Licensee agrees to it by clicking on the "I agree' button (hereinafter "the Effective Date") and shall continue in full force and effect:

- For Authorized Use: for an indefinite term until reaching the granted Limited Access counting as from the Effective Date.
- For Extended Authorized Use and Commercial Use: for a definite term of one year counting as from the Effective Date.

7.2. Termination. The Agreement shall automatically terminate at its termination date.

The Agreement shall automatically terminate, without any compensation due, in case Licensor does no longer provide access to the Database or ceases its activities. Licensor shall notify the Licensee of such termination with no undue delay at the Licensee's email address.

Without prejudice to the rights and remedies Licensor may have under this Agreement or at law, in particular to claim compensation for damages incurred, Licensor shall have the right to terminate immediately and without any prior notification the Agreement in case of breach of use by Licensee. In such case, Licensee shall have no longer access to the Database and shall be notified hereof at the moment of first login after termination.

7.3. Consequences of termination. Upon termination of this Agreement, Licensee will cease and desist from all use of the Database and will uninstall, remove and destroy all copies of the Database in Licensee's possession or control, including any modified or merged portions thereof, in any form, and execute and deliver evidence of such actions to the Licensor. Licensee shall remain bound by those provisions of the Agreement which by their terms extend beyond the date of termination.

ARTICLE 8: MISCELLANEOUS

8.1. Assignment. Neither this Agreement nor any of Licensee's rights hereunder shall be assigned, sublicensed or transferred (in insolvency proceedings, by mergers, acquisitions or otherwise) by Licensee without the previous written consent of the Licensor. Any assignment or other transfer which is inconsistent with the foregoing shall be null and void ab initio.

8.2. Entire Agreement. This Agreement constitutes the entire agreement between the parties with respect to the subject matter of this Agreement and supersedes all previous agreements, arrangements or undertakings between Licensor and Licensee relating to its subject matter and any representations or warranties previously given or made to it, if any.

8.3. Failure or neglect of the Licensor to enforce any provision of this Agreement at any time shall not be construed or deemed to be a waiver of its rights and shall not in any way affect the validity of this Agreement or any of its provisions nor prejudice the Licensor‘s right to take subsequent action.

8.4. In the event that any provision of this Agreement is deemed by any competent authority having jurisdiction to be invalid, unlawful or unenforceable to any extent, that provision shall to that extent only be severed from the remaining provisions which shall continue to be valid.

8.5. Jurisdiction venue. In the event of any dispute arising out of or in connection with the subject matter of this Agreement, the Parties shall first endeavor to resolve such dispute amicably within thirty (30) days after the date of the notification by one Party of such dispute to the other Party. Should the Parties fail to do so, then such dispute shall be subject to Belgian law except its conflicts of law rules and the competent courts of Brussels.

Appendix B – Web Mapping Application Survey Questions

GIS Web Application Evaluation Template

1. How likely is it that you would recommend this web mapping application to a colleague?

NOT AT ALL LIKELY — EXTREMELY LIKELY

0	1	2	3	4	5	6	7	8	9	10

2. How satisfied are you with the reliability of this web mapping application?

- ◯ Extremely satisfied
- ◯ Very satisfied
- ◯ Somewhat satisfied
- ◯ Not so satisfied
- ◯ Not at all satisfied

3. How satisfied are you with the look and feel of this web mapping application?

- ◯ Extremely satisfied
- ◯ Very satisfied
- ◯ Somewhat satisfied
- ◯ Not so satisfied
- ◯ Not at all satisfied

4. How often does the web mapping application freeze or crash?

- ◯ Extremely often
- ◯ Very often
- ◯ Somewhat often
- ◯ Not so often
- ◯ Not at all often

5. How user-friendly is the web mapping application's interface?

- ◯ Extremely user-friendly
- ◯ Very user-friendly
- ◯ Somewhat user-friendly
- ◯ Not so user-friendly
- ◯ Not at all user-friendly

6. How successful is the web mapping application in conveying trends in the data?

- ◯ Extremely successful
- ◯ Very successful
- ◯ Somewhat successful
- ◯ Not so successful
- ◯ Not at all successful

7. Do you have any thoughts on how to improve this software?

8. Do you have any other comments, questions, or concerns?

DONE