Exploring Global Natural Disaster and Climate Migration Data: A Web GIS Application

by

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To Cecelia, Julia, my family, best friends, and Hannah: Thank you for everything.

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List of Abbreviations

GDACS	Global Disaster Alert and Coordination System
GIS	Geographic information system
SSI	Spatial Sciences Institute
USC	University of Southern California
IDMC	Internal Displacement Monitoring Centre
IDP	Internally Displaced Person/People
IOM	International Organization for Migration
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NRDC	National Resources Defense Council
USGS	United States Geologic Survey

Abstract

Natural disasters have always influenced migration, whether international or within one country's borders. However, as the effects of climate change continue to cause irregular weather patterns and stronger, more frequent natural disasters, the number of individuals at risk of being displaced from their home due to natural disasters is poised to substantially increase. Given the millions of people on the brink of needing to relocate due to natural disasters, as well as the potential billions of dollars needed to repair the resulting damages, there exists a need to better understand trends in weather and migration patterns. Such an understanding would allow for governments and emergency response teams to be more prepared to face sudden onset disasters. The Internal Displacement Monitoring Centre (IDMC) published a dataset detailing the number of internally displaced people (IDP) per country per year between 2008-2018, and the specific natural disaster event associated with each IDP. This project utilized the IDMC dataset to create a web map application using ArcGIS Online that will organizes and visualizes the data in a spatial context. The original IDMC dataset was broken down into smaller thematic datasets using the R programming language, which were subsequently visualized using the ESRI products ArcGIS Pro and ArcGIS Online. The application was designed for ease of use, thus allowing for new trends and potential patterns to be discovered far more easily. The resulting web application includes widgets and tools that allow users to manipulate the dataset in meaningful ways unique to their needs.

Chapter 1 Introduction

Historically, natural disasters have always played a role in human movement and where populations choose to live. Natural disasters have devastated entire cities and can demolish the homes of hundreds of thousands of people in a matter of minutes. We see disasters dramatized in summer blockbuster movies: giant waves crashing over New York City, volcanic eruptions wiping out entire villages, or an earthquake splitting California in half. Seemingly every few years, news networks dive into non-stop coverage about a major earthquake or tsunami, providing updates on the death toll every few hours. Pop culture may lead individuals to believe natural disasters are limited to large and deadly events. The reality is somewhere in between – while some natural disasters like the ones seen on the news are colossal in nature and carry high death tolls, natural disasters happen much more often than just once or twice a year and bear a multitude of different socioeconomic consequences in addition to injury and death (Coronese et al. 2019). Around the world, people and the economies they inhabit are affected by natural disasters of all scales and types multiple times a month. The resulting socioeconomic damages are not always covered in the news and are rarely ever seen in theaters. Nonetheless, millions of people all over the world feel the direct effects of these damages, and with the constantly increasing effects of climate change, countries are experiencing natural disasters at an even more frequent and costly rate (NOAA 2020).

In order to decrease damage caused by natural disasters and create better safeguards to protect vulnerable populations, there needs to be a better understanding of data surrounding natural disasters. Governments, international agencies, and scientific organizations have all been tracking the occurrence of natural disasters and their subsequent effects on society. When properly utilized, the datasets produced by these different entities can begin to provide insights into important questions. For example: which types of natural disasters are occurring the most frequently, and where? How many individuals are being displaced as a result? What patterns and trends are emerging from this data? Introducing an interactive and spatial representation of these otherwise dense, table-based datasets allows for these questions to be answered much more quickly and easily. This thesis introduces a web application aimed at providing a visual and spatial analysis of natural disaster events between 2008-2018, including which countries are experiencing the highest levels of population displacement (measured as internally displaced people, or IDP), and a ten-year historical analysis of which weather-related events are occurring in each country during this specific time period. The foundation of the web application is built upon data compiled by the Internal Displacement Monitoring Centre (IDMC). The web application is designed with a simplistic, accessible user interface to ensure a wide audience can interact with the extensive IDMC dataset – government agencies, international refugee and disaster relief organizations, emergency response teams, journalists, or even interested private citizens should all be able to utilize the application with little to no prior GIS experience.

1.1 Motivation

Since 2008, an annual average of 25.3 million people was displaced from their homes as a result of natural disasters such as flooding, earthquakes, storms, and volcanic activity (Internal Displacement Monitoring Center 2019). As the effects of climate change continue to worsen, the frequency of natural disasters continues to grow on a yearly basis, and on a global scale (Centre for Research on the Epidemiology of Disasters 2019). The increased severity of natural disasters such as heat waves, severe winter conditions, and drought have the potential to destroy billions of dollars' worth of infrastructure populations depend on for survival, including crops and livestock (Zagorsky 2017). Millions of people are therefore poised to be displaced from their homes as a result of these socioeconomic repercussions. While individuals being displaced by natural disasters is reason enough to explore the data further, there also exists an immense economic impact. In the United States, for example, the National Oceanic and Atmospheric Administration (NOAA) produced a report showing the number of natural disasters causing over $1 billion dollars in damages has steadily increased since 1980. For instance, any given year in the 1980s would typically experience an average of about 2.7 disasters resulting in over $1 billion dollars in damages (inflation adjusted). Conversely, the last five years in the US (2015-2019) saw an average of 13.8 events per year. Furthermore, since 1980 the US experienced 258 weather-related natural disaster events that caused over $1 billion in damages. The cumulative cost of these damages exceeds $1.75 trillion (Smith 2020). Without proper analysis of natural disaster and displacement data, the task of accurately allocating resources to mitigate the human and economic risks associated with natural disasters becomes increasingly difficult.

A cumulative, global economic cost resulting from natural disaster damages may not be as easily quantifiable globally as it was in the US. However, the effects of natural disasters on humans have been carefully studied and monitored by the IDMC, a Swiss agency that is part of the Norwegian Refugee Council. The IDMC partners with national governments, UN agencies, and other various international organizations to provide accurate data regarding the number of IDP on a global scale each year as a result of natural disasters (IDMC 2019). The data produced by the IDMC encapsulates the magnitude and scale of the humanitarian effects of natural disasters – millions of individuals are displaced each year in multiple countries throughout the world, and in certain countries, the number continues to increase. There is no simple solution that will reduce the number of IDP, as natural disasters are inevitable, and the causation behind each IDP is extremely complex. However, the approach and response to each natural disaster can be improved if each country prepared the necessary resources and infrastructure to vulnerable communities. This process starts at the statistical level – governments and emergency response organizations must first know which types of natural disasters are most likely to affect their communities, and how many individuals are at risk. The web application outlined in this thesis offers a tool that transforms a large Excel spreadsheet into an interactive, visual map. Such a map can help users decipher large amounts of information much easier than when presented in traditional spreadsheet formats.

1.2 IDMC Dataset

The foundation of the web application is a dataset created by the IDMC. The organization collected data for every country over a ten-year period (2008-2018) documenting each natural disaster event and the number of IDP associated with each event. Each row in the dataset represents a natural disaster event. The IDMC monitors and reports all natural disaster events by partnering with different sources and confirming the disaster event data with government agencies, UN agencies, news outlets, civil society organizations, and various other international organizations (IDMC 2019). By partnering with these various organizations, the IDMC is able to cross-check the disaster and IDP data among multiple sources in order to confirm the data's accuracy. The natural disaster events were collected on an event-by-event basis, with no specific criteria reported by the IDMC to constitute whether or not a disaster event should be added to the dataset. Given the IDMC's website did not specify the criteria for a disaster to be included in the dataset, there are disaster events documented in the dataset that did not result in any displacements. As a result, there are rows within the dataset detailing natural disaster events that have 0 associated IDP.

The IDMC's dataset is available as a downloadable spreadsheet containing over 6,400 unique records that lacks any type of spatial reference or tool that would allow for users to easily gain insights into any spatial or temporal patterns or trends within the data. The dataset can be downloaded from the IDMC's website in an Excel spreadsheet format. Table 1 in Section 3.1 contains a detailed breakdown of the 8 columns of information contained within the dataset. The IDMC does provide a data exploration tool allowing for users to generate their own charts based on the data held in the spreadsheet (Figure 1). This tool provides users no spatial reference, however, and can only generate two-dimensional charts on an x and y axis. Given that there are over 100 countries included in the dataset, the exploration tool is also difficult to interpret with multiple countries overlapping one another. As a result, the charts are challenging to read and do not provide a user-friendly experience when attempting to understand any one country within the group. Thus, there exists a need for an improved visual interface for the dataset.

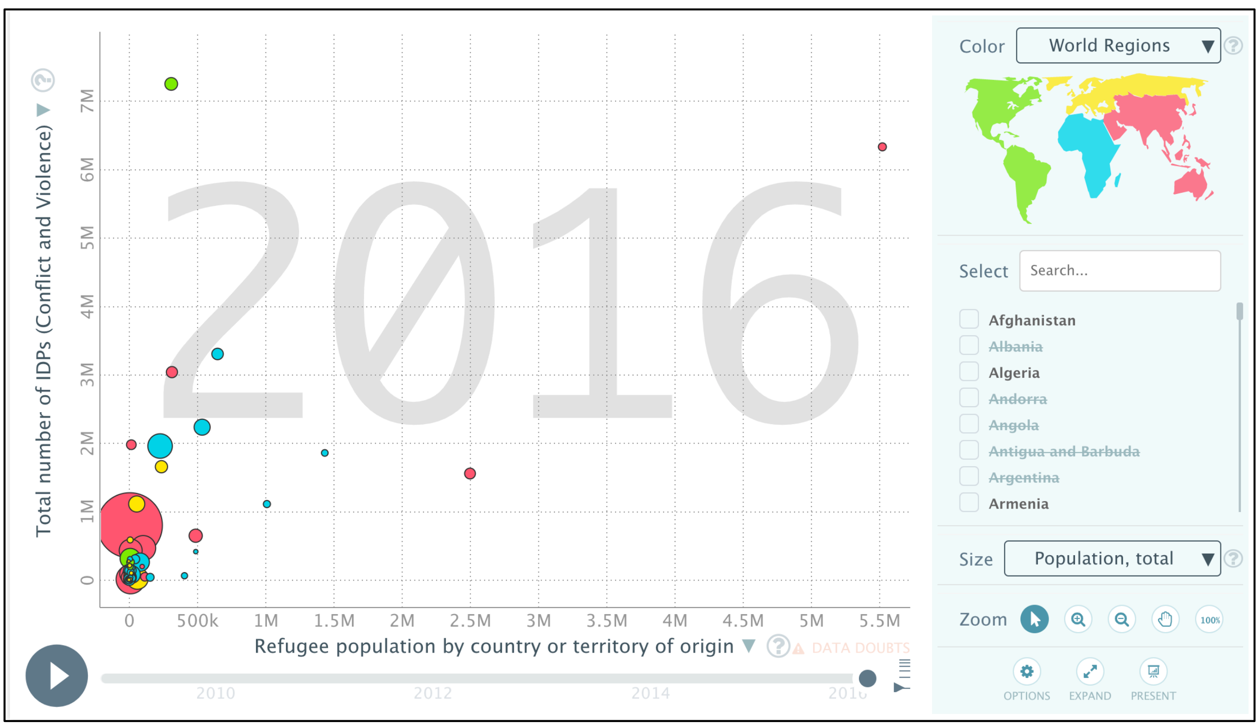

Figure 1. The IDMC's data exploration tool (Source: IDMC)

1.3 Project Goals

The IDMC dataset in its current form is difficult to filter and organize without breaking it up into separate, smaller datasets. The web application detailed in this thesis builds upon the dataset and created a web map offering a singular and more visual, intuitive, and interactive method of data exploration. The detailed methodological chronology can be beneficial for a broader audience, rather than just experts in the field of migration, disaster relief, or database administrators. The symbology, pop-up information, and widgets included on the web application provide an in-depth examination of the data. The web map will also allow for users with little to no knowledge of geographic information systems (GIS) to utilize one with relative ease due to the simple layout, symbology, and widgets.

This web application was built with multiple different audiences in mind. Potential end users can span from government officials, international agencies such as the IDMC or United Nations, emergency response teams, educators, students, journalists, or simply an interested private citizen. By utilizing GIS, the dataset is transformed into an interactive tool that allows users to explore and filter the data however they see fit. For example, governments can use the application to analyze trends in the number of IDP produced within their borders, as well as surrounding countries' borders. The ability to quickly decipher these types of trends will allow for government and international agencies to be more prepared to allocate resources when assisting IDP. Natural disaster trends can be discovered and analyzed to assist emergency response teams as well. Knowing the type, location, and frequency of natural disasters – as well as the number of people displaced as a result of each event – would allow for the managers of emergency response teams to better anticipate natural disaster events and which populations are at risk. Examining IDP totals throughout the ten-year time frame also allows for both government agencies and emergency response teams to prepare for adequate resource allocation to aid those affected by natural disasters.

When properly organized and visualized, the information in the IDMC dataset should be able to provide these types of organizations with the insights necessary to build or improve upon a robust disaster relief framework. The ability to quickly determine which types of disasters are having the most effects on a country's population can, in turn, ideally allow for the improvement of disaster response infrastructure. However, the design of the web application is not tailored towards government agencies or disaster relief organizations alone. Instead, the web application can be utilized as an educational tool for educators and journalists. The user interface allows for non-experts and otherwise inexperienced GIS users to have the same level of access and functionality in regard to data exploration. In an educational setting, the web application can provide students a unique tool to explore natural disaster and IDP data. Rather than approaching these two subjects from a more traditional perspective – a static, data-driven spreadsheet format focused on raw statistics – the web application acts a dynamic, interactive, and customizable tool in which students can discover trends and information based on their own inputs. Outside of the classroom, journalists can use the web application to supplement their articles about climate change or refugee crises. The software in which the web application was built (outlined in Section 1.4) is extremely easy to share – thus, the web application can be embedded into a variety of media, including online articles and websites. Rather than journalists citing statistics from the IDMC, they are instead able to offer readers hands-on access to the dataset itself via the web application. Ultimately, there is not one specific use-case for the web application. The web map was designed to encompass a wide variety of users, and to provide each user with a useful and intuitive new means to view an otherwise large, dense dataset.

The web application is able to filter the data in numerous different ways that would otherwise require a script or function when utilizing the original spreadsheet format. Each attribute within the dataset will be able to be combined or isolated from the other attributes. Below is a list of functionalities the web application offers the user:

- Time-lapse of natural disaster totals, 2008-2018
- Time-lapse of IDP totals per country, 2008-2018
- Remove categories that do not meet user-specified criteria
- Count the number of instances of natural disaster types in a given year per country
- Count the number of IDP of a given country or region in a given year
- Count the number of IDP per natural disaster of a given country, countries or region in a given year
- View the number of IDP produced by specific type(s) of natural disaster(s)
- View charts containing IDP per natural disaster and natural disaster frequency per country per year

1.4 Methods

In order to create a web map that included the majority of the IDMC dataset while still maintaining accessibility, separate custom data layers were created using the IDMC dataset. Each newly created data layer serves to enable the user to dive deeper into the attribute data within the IDMC dataset, including features like natural disaster category, type, and date. Each dataset was uploaded into ArcGIS Pro, where it was visualized and then published to ESRI's web platform, ArcGIS Online. Next, the data layers were imported into the web application itself, which was created using ESRI's Web AppBuilder tool. The Web AppBuilder tool was utilized for its built-in widgets that allow for users to customize the data layers as they see fit.

Lastly, the web application created in Web AppBuilder was embedded into ESRI's Story Map software, which contained a brief background on the topic of natural disasters and IDP, as well as instructions on how to use the web application.

In the web application, certain countries cannot display any information if they do not meet the user-specified criteria. For example, if users only want to examine natural disaster data, they are able to remove IDP data from the web map. As a result, countries that experienced natural disasters will populate the web map – if a country did not experience a natural disaster, it will not be represented with any symbology on the map.

The following chapter outlines similar research surrounding climate change, natural disasters, and IDPs, and outlines a more in-depth breakdown of the methodology used to create the resulting web application.

Chapter 2 Related Work

This chapter builds a case for the importance of mapping natural disasters and internally displaced people by examining previous work and data surrounding the two topics. The ensuing section will first demonstrate the need for a spatial context in regard to these subjects by detailing the benefits of data visualization. Section 2.2 details existing natural disaster maps and their use cases, and Section 2.3 outlines the importance of preparing for migrations as a result of natural disasters.

2.1 Benefits of Providing a Spatial Context

The IDMC's foundational dataset used in this thesis' web application contains rich attribute data, such as event name, date, hazard type, hazard category, and the resulting IDPs. By monitoring natural disasters as well as IDPs, this thesis explores which natural disasters are causing population displacement and visualizes these conclusions within an accessible spatial context. This is in contrast to a richly populated data table that may otherwise be difficult for non-experts in the field to uncover trends within the data. The following section examines past work focused on the phenomenon of climate migration, and how the increased effects of climate change can result in millions more displaced people throughout the world. As a result, the section concludes with a need for more research regarding the spatial context of climate migration.

The Migration Data Portal is a comprehensive resource for projects and case studies on migration. Funded primarily by Germany and Switzerland via the International Organization for Migration (IOM), the portal provides summaries on each theme driving immigration (human trafficking, family migration, gender and migration, labor migration, etc.). The portal contains a number of publications and case studies surrounding environmental migration since 1980. One major takeaway demonstrates that of the 522 case studies analyzed by the organization, only 11% of them include spatial analysis (IOM 2018). Given that only 11% of case studies include spatial analysis, the web application outlined in this thesis would provide a more unique approach to natural disaster and migration data. Thus, if the application were to be utilized by educators or journalists, the userbase would be exposed to a more distinct and engaging medium to interact with the large dataset.

The IOM's summary of environmental migration case studies was a key guide in determining the gaps in knowledge this application aimed to fill. The goal of this web application is to build upon the existing natural disaster and internal migration data provided by the IDMC by adding a visual and interactive spatial component. Overall, the web application as a whole has an equal emphasis on mapping both IDP and natural disaster trends. In order for a broad audience to comprehend the intersection of these two phenomena, the application will be in the form of an interactive web map.

ESRI's Story Maps team created a Story Map aimed to educate viewers as to the increased effects of climate change, resulting in increased vulnerability in populations throughout the world. However, the effects of climate change are exacerbated by a combination of non-climate related factors such as resource constraints, population growth, and unprepared governments. The results is that communities are forced to leave their homes in search for a safer place to live. ESRI's Story Map, entitled "Climate Migrants", details case studies of communities throughout the world at risk of displacement due to the impending destruction of their homes. Brought on by effects of climate change, this poses a risk to millions of people. The Story Map presents the data clearly so end users of all backgrounds are able to understand the issue. Presenting the data in a spatial format means end users without a technical, GIS-based background – such as government decision-makers, for example – can each access and comprehend the datasets and issues at hand. It is important for government officials in particular to be able to access and study the intersection of these phenomena as well, because the migration of millions of people places a burden on the governments accommodating the climate migrants; certain country's infrastructure and resources may not be able to handle such a dramatic influx. As such, this thesis aims to provide a tool that can allow for non-technical government officials to view an otherwise large and complex dataset, ideally allowing for easier comprehension and a better understanding of populations at risk.

2.2 Web Map User Interface and User Experience

An important component of any web application is the user interface (UI) and user experience (UX). As web maps increase in popularity due to convenience, scalability, and accessibility, it is paramount for the UI to be uniformly accessible from a variety of different devices and resolutions. However, there is not yet a uniform standard for any given web map's interface. The UI is therefore up to the map's designer, who is tasked with retaining as much simplicity as possible without sacrificing efficiency (You et al. 2007, 16).

One standard that has emerged in web applications is the grouping of similar tools in the same area. Users of web applications demonstrate higher accuracy when controls are grouped together (You et al. 2007, 17). Furthermore, in addition to accuracy, cartographers at a Polish university conducted an eye-tracking experiment that determined the grouping of similar tools on a web map increases user speed and overall efficiency. Based on their study's results, users tend to first examine the corners of a web map before finding their desired tool of choice (Cybulski and Horbiński 2020). Thus, in order to design an accessible and efficient UI/UX without sacrificing any access to the foundational data within the web map, the web map in this thesis was designed to have all tools and widgets grouped as close together as possible. The top right-hand corner of the web application contains a cluster of the Summary widgets, with each widget clearly marked with the corresponding year it calculates (as seen in Figure 16). This design element was done purposefully with the UX in mind. By keeping each widget grouped together, a non-technical user is able to quickly navigate through the map's tools and execute functions with the same efficiency as an experienced GIS-user.

2.3 Mapping Natural Disasters

Natural disasters can occur at any moment. According to the European Space Agency, earthquakes registering over a 5 on the Richter scale happen about 1,000 times in a year. Thus, it is important to track their frequency, type, scale, and residual effects. Government agencies and emergency response teams must be able to quickly sift through the data in order to determine which earthquakes had tangible effects on a population. The Global Disaster Alert and Coordination System (GDACS) produces a web map that tracks natural disaster alerts within a four-day time span (Figure 2). Each natural disaster within the last four days is categorized and placed in its respective location on the map and is provided a GDACS score in terms of the overall impact on the surrounding area. Some natural disasters have extremely detrimental effects to the surrounding area, while others are relatively harmless storms in the middle of the ocean. Web maps like those created via this project are efficient ways to demonstrate the frequency and general impact of natural disasters within a short time span and can be useful for emergency response teams to gauge the severity of such an event. While similar in scope – both the web application proposed in this thesis and the GDACS web map categorize and assess natural disaster events – the web map proposed in this thesis aims to provide a more historical look at the frequency and impact of each natural disaster between 2008-2018, while providing more specific data regarding the number of people displaced within a country's borders.

Figure 2. GDACS 4-day disaster alert map (Source: GDACS)

Historical natural disaster data can provide insights as to which areas are most at risk with respect to mortality. BestPlaces, a company focused on assessing and ranking metropolitan areas based on various indexes, published maps detailing which US cities are most at risk to experience a deadly natural disaster. Specifically, the maps utilized NOAA, USGS, and NCDC data to determine which US cities had the highest risk based on population and natural disaster frequency over the last 30 years (BestPlaces 2011). After analyzing 379 metropolitan areas, the study found that southern US cities were most at risk to experience natural disasters (Figure 3). Dallas, Texas was the city at highest risk, followed by Jonesboro, Arkansas, Corpus Christi, Texas, and Houston, Texas. While this type of map may be useful for citizens of the US, there are regions of the world at much higher risk due to population density and socioeconomic factors.

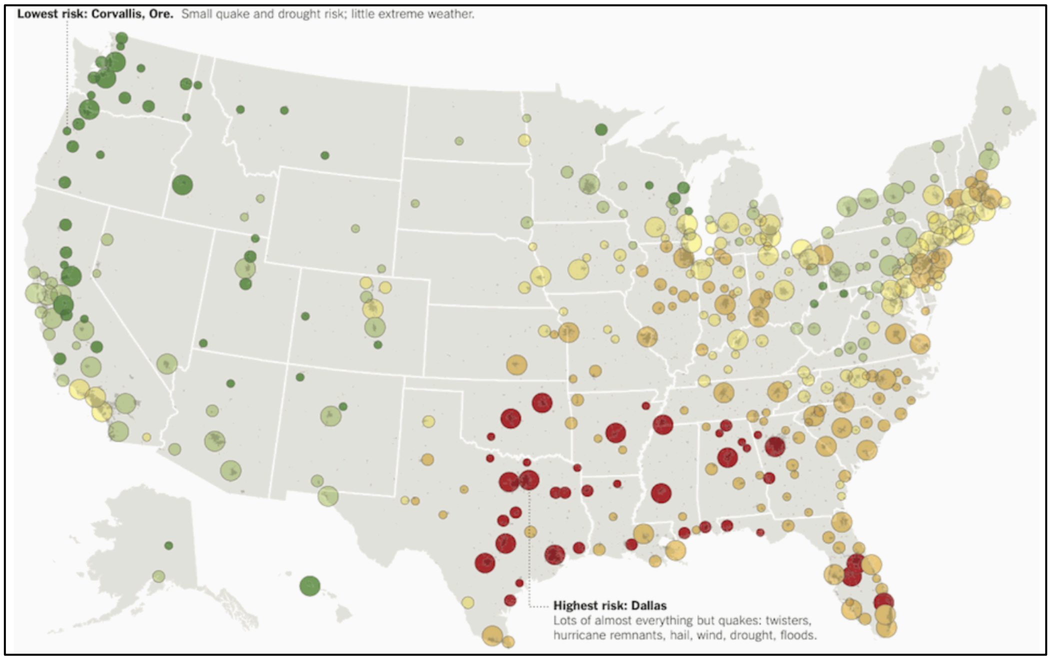

Figure 3. BestPlaces map showing US cities with highest risk to experience natural disasters

From a global perspective, IDMC data shows that average annual displacement – the average number of people expected to be displaced each year – is highest in South and East Asia, as well as the Pacific island countries such as Indonesia and the Philippines. According to the IDMC, these three regions account for two thirds of the world's population displacement risk (IDMC 2019, 85). Furthermore, an IDMC report finds that displacement risk associated with natural disasters will primarily affect developing countries. This means that countries with greater socioeconomic vulnerability are disproportionately at risk to experience population displacement compared to countries that, while highly vulnerable to natural disasters, do not have as vulnerable of a low-income socioeconomic population. As a result, many island countries such as the Bahamas, Antigua and Barbuda, and Dominica are disproportionately at risk compared to the rest of the world (Anzellini et al. 2017, 12). These findings demonstrate the need for a global perspective when measuring and analyzing natural disaster events and risk.

Thus, the web map presented in this thesis contains a global spatial extent that visualizes natural disaster type, frequency, and IDP as a result of each event.

2.4 The Importance of Preparing for Displacements

With the impending displacement of millions of people from various regions across the world due to climate change, there exists a need to protect the livelihood of the climate migrants while simultaneously strengthening the physical and societal infrastructure of the countries in which the migrants are relocating (Global Compact for Migration 2018). Climate migrants, and therefore IDP, should be legally protected – however, legal protection is currently a difficult and complicated work in progress, as there is not yet an official definition of what it means to be a climate migrant (Mateo 2019). As there is not yet a legal framework in place to protect climate migrants and IDP, the responsibility of accommodating individuals affected by natural disasters falls largely on the governments of countries with IDP. Dina Ionesco, the Head of the Migration Environment and Climate Change Division at the IOM, notes that climate migration is mostly internal anyway – that is, individuals displaced by natural disasters are usually moving within their home country's borders and are not seeking legal protection at an international level. Instead, the burden to ensure adequate accommodation for IDP falls on the IDP's home country. This thesis presents a GIS-based application that demonstrates the scale and location of each country's yearly IDP totals, as well as the natural disaster event associated with each IDP. As such, state governments can visualize their IDP and disaster totals between 2008-2018, a relatively recent timeframe, in order to prepare assistance for IDP within their own borders. If a country's IDP and natural disaster totals are increasing each year, its government should ideally organize disaster relief infrastructure and resources accordingly. The internal migration of potentially millions of people would otherwise result in various socioeconomic burdens within the country's borders.

The Nansen Initiative is a Swiss organization aimed at unifying countries in favor of protecting IDP in the context of natural disasters, including events spurred by climate change (Kälin 2015). One of the key conclusions detailed in the organization's Protection Agenda was that IDP are likely to continue increasing in the future, and that while many IDP are able to return to their original homes, tens of millions of IDP will need protection and assistance in order to successfully relocate. In 2015, the group published a consultation outlining the magnitude of issues IDP face, and how countries have an obligation to protect all those that are affected by natural disaster displacement. The authors of the Protection Agenda suggest that countries neighboring the regions heavily affected by climate change must create treaties and agreements to help absorb the millions of climate migrants and IDP that will otherwise place a strain on resources, jobs, and culture. Furthermore, the publication notes that between 2008 and 2013, an estimated 27.5 million people were displaced from their native country due to sudden-onset disasters annually (The Nansen Initiative 2015, 1). While many people are able to return to their original home, millions are forced to uproot and begin new lives in different parts of their home country. The Nansen Initiative strives to create an international support system for the latter group, especially given that climate change will likely drive these numbers up in the future. In their agenda, the group details a need for more scientific studies tracking IDP so that predictive models can created and set in place for countries with high amounts of IDP (The Nansen Initiative 2015, 3). While tracking IDP poses itself as a new and difficult problem, it is nonetheless possible to identify areas that are high-risk for natural disasters to occur, which can therefore identify populations at risk of displacement. Identifying these at-risk areas throughout the world aligns with one of the primary goals of this thesis. The web application outlined in this thesis can offer government organizations a perceptive method to discover trends and insights as to which countries are experiencing disproportionate numbers of climate-related disasters and the number of associated IDP. While the web application is more of a visualization tool than a decision-making tool, the web map is able to organize and present extensive IDP and natural disaster data in a more meaningful format, which in turn can ideally lead to more informed decision-making.

Climate-related migration will continue to increase globally unless the effects of climate change can be curbed. The National Resources Defense Council (NRDC) published an article summarizing sources that detail just how severely climate change is impacting global migration (Turrentine 2019). Scientists estimate that the three most densely populated developing areas of the world – Latin America, South Asia, and sub-Saharan Africa – will potentially see the internal migration of more than 140 million people before 2050 (Turrentine 2019). This means there is a need to focus on internal migration within largely populated continents such as Africa or Asia, rather than focusing only on international, multi-continental migration. The economic and social implications of 140 million people migrating within these continents are massive; if countries and cities do not have any predictive tools or an understanding of natural disaster and migration trends, their infrastructure is at risk to be unprepared to handle the influx of IDP. Countries that are already densely populated, or have existing socioeconomic issues of their own, will be on the brink of conflict should they experience sudden population surges within their cities. Specifically, population surges (especially in countries with existing resource scarcity and poor government management) can exacerbate the demand for natural resources and housing infrastructure. Countries and cities that are unequipped to handle such rapid population shifts are therefore risking conflict and violence within their borders (Acemonglu, Fergusson, and Johnson 2019). Thus, there exists a need for tools similar to the web application outlined in this thesis that examine which countries are experiencing rapid population shifts. GIS-based solutions can provide government leaders a visual and temporal blueprint for global weather-related disasters and migration patterns.

Chapter 3 Methods

The goal of this thesis was to create a web application that visualizes IDPs due to weather-related natural disasters over a ten-year period (2008-2018). The foundational dataset used in the web application, created by the IDMC, contains over 6,000 records of natural disaster events and the number of individuals displaced as a result; the spatial extent of these records is global – each country the IDMC collected data for is included in the dataset, and therefore the web application. This vast dataset contains useful information that, when presented spatially, can offer a better understanding of weather-related trends and their effects on human movement.

This chapter outlines the steps taken in order to organize the foundational dataset – as well as the sub-datasets created by breaking down the foundational dataset into three separate categories – and create a customizable web application that visualizes each of the attributes associated with the data. The following subsections – Data Cleanup, Data Parsing, Data Mapping, and Web Application & Story Map Creation – outline each stage of creating the web application. Each subsection will also discuss the rationale for the methodology used, including any potential benefits and shortcomings.

3.1 Data Cleanup

The web application was built upon a dataset created by the IDMC. The dataset contains detailed attribute data in addition to displacement numbers and natural disaster event categories; a snapshot of the master dataset can be found in Figure 4 below. With 6,432 rows of data, there was first a need to ensure the data quality was sound, with no gaps, duplicates, or other miscellaneous errors that would prevent an accurate spatio-temporal presentation of the data.

	A	B	C	D	E	F	G	H
1	ISO3	Name	Year	Start Date	Event Name	Hazard Category	Hazard Type	New Displacements
627	BRA	Brazil	2018	2018-01-01	Brazil - Droughts - 2018	Weather related	Drought	2358
628	BRA	Brazil	2018	2018-01-01	Brazil - Floods - 2018	Weather related	Flood	60316
629	BRA	Brazil	2018	2018-01-01	Brazil - Landslides - 2018	Weather related	Wet mass movement	639
630	BRA	Brazil	2018	2018-01-01	Brazil - Storms - 2018	Weather related	Storm	21042
631	BRA	Brazil	2018	2018-02-10	Brazil: heavy rainfall causing	Weather related	Flood	561
632	BRB	Barbados	2010	2010-01-01	Hurricane Tomas	Weather related	Storm	
633	BRB	Barbados	2016	2016-09-28	Hurricane Matthew	Weather related	Storm	90
634	BRN	Brunei Darussalam	2014	2014-01-23	Heavy flooding and landslide	Weather related	Flood	51
635	BRN	Brunei	2017	2017-12-19	Brunei : Brunei Darussalam,	Weather related	Flood	94
636	BTN	Bhutan	2009	2009-01-01		Geophysical	Earthquake	
637	BTN	Bhutan	2011	2011-01-01		Geophysical	Earthquake	20000
638	BTN	Bhutan	2015	2015-04-04	Nor'wester in Southern Bhut	Weather related	Storm	2851
639	BTN	Bhutan	2016	2016-06-17	Bajo town fires	Weather related	Wildfire	56
640	BTN	Bhutan	2016	2016-07-18	Sarpang River floods	Weather related	Flood	638
641	BWA	Botswana	2009	2009-01-01		Weather related	Storm	
642	BWA	Botswana	2009	2009-01-01		Weather related	Flood	
643	BWA	Botswana	2009	2009-01-01		Weather related	Flood	867
644	BWA	Botswana	2011	2011-01-01		Weather related	Flood	
645	BWA	Botswana	2013	2013-01-15	Francistown flood	Weather related	Flood	1241
646	BWA	Botswana	2014	2014-01-01	Northern districts hit by trop	Weather related	Storm	2000
647	BWA	Botswana	2015	2015-11-19	Bobonong storm	Weather related	Storm	250
648	BWA	Botswana	2017	2017-02-18	Botswana; Mozambique; Sou	Weather related	Storm	1950
649	BWA	Botswana	2018	2018-02-23	Botswana: floods - Central Di	Weather related	Flood	1634
650	CAF	Central African Republic	2008	2008-07-01		Weather related	Flood	14000
651	CAF	Central African Republic	2009	2009-01-01		Weather related	Storm	
652	CAF	Central African Republic	2009	2009-01-01		Weather related	Flood	11000

Figure 4. A snapshot of the master dataset compiled by the IDMC

As seen in Figure 4, the row dedicated to each country contains natural disaster attribute data associated with a specific year. Each disaster event was documented via an individual row, so if a country had multiple disasters it occupies multiple rows of data. For example, China contains 53 rows of information for the year of 2016 alone, meaning there were 53 natural disaster events in China during that specific year. If a country did not experience any natural disasters in a given year, it was not listed in the dataset. For example, Barbados is only listed in the master dataset twice, in 2010 and in 2016, corresponding with its natural disaster events in those years. A description of each field in the IDMC's dataset can be found in Table 1 below.

ISO3	Name	Year	Start Date	Event Name	Hazard Category	Hazard Type	New Displacements
Country code.	The name of the country.	The year in which the natural disaster event and displacements occurred, ranging between 2008-2018.	The date the specific natural disaster event started.	The name and/or description of each natural disaster event. Examples: Tropical Cyclone Zena, or Flash flood	There are two categories in which a natural disaster can fall into: weather related or geophysical.	The specific type of each natural disaster event. For example: flood, drought, earthquake.	The amount of IDPs produced as a result of each individual natural disaster event.

				in the French Riviera.			

Table 1. A description of each field within the master IDMC dataset

The IDMC dataset is comprehensive but not perfect, and thus needed to be cleaned before use. For instance, duplicate countries were found within the master dataset. “Viet Nam” contained natural disaster events for a given year, as did “Vietnam”. Some natural disasters that occurred in Russia were named as occurring in the country called “Russian Federation” – these types of errors needed to be fixed manually in order to create sub-datasets that contained accurate country names. In other cases, hazard events were removed because they were not considered natural disasters, and therefore did not fit into one of the 11 Natural Disaster Type categories. As an example, there was an oil spill listed in Colombia in 2018, and no Hazard Type was assigned to the event. The event was therefore deleted from the master dataset to ensure it was not included in any of the sub-datasets that would eventually be visualized on the web application.

3.2 R Script

In order to accurately and efficiently reorganize the master dataset and break apart the data into the aforementioned categories, an R script was created. Using R allowed for the sub-datasets to be created quickly and efficiently, rather than having to create new fields manually, enter the data row by row, and repeat the process for each year.

The R script takes the master dataset as an input file. To obtain yearly “slices” of the data from the master dataset, the first pre-processing step was to remove any redundant data, e.g. *Start Date, Event Name* and *Hazard Category*. Subsequently, the data was filtered from the master dataset for each particular year within the given 10-year timeframe (ensuring any empty cell has the value zero assigned to it). At this point, a data frame in the same format as the master dataset was created – however, only comprised of data for the year in consideration.

The next task of the R script was to create two additional data frames. The first data frame maintains the Total Natural Disaster category for each country for a given year, while the second data frame maintains the Total IDP per Natural Disaster Event category for each country for a given year. Once these sub-data frames were created, they were merged while maintaining the name of the country, the natural disaster types occurring for the country for a given year, the frequency of the hazard types for the country for the given year, and the total IDP produced by the natural disaster type for a country for a given year. After the merge, there were then several rows of data per country – each row type unique to a natural disaster type. To collapse the data even further, the R script needed to allocate one row per country per year. Therefore, a new data frame was created by adding a column each for a particular natural disaster type and the number of IDP displaced as a result. The initial values in the columns were then set to zero. From the previously merged data frame, the frequency of each natural disaster type and the number of IDPs as a result was recorded, and the values in the corresponding cells were updated in the new data frame. Thus, the data was successfully made available in separate Excel files. This process was repeated for all remaining years in the master dataset. Once the process was repeated, each sub-dataset for its corresponding category was created.

In summation, there were four categories created by the R script: IDP Total per Country (per year), IDP per Natural Disaster (per year), Natural Disaster Total per Country (per year) and Natural Disaster Event Count (per year). Section 3.3 summarizes how each resulting sub-dataset was organized within Excel, and eventually ArcGIS Pro.

3.3 Data Parsing

In order to decipher the thousands of rows contained in the master dataset's spreadsheet and to visualize the information in a valuable, distinct manner, the master dataset was re-categorized into sub-datasets, with the ultimate goal of symbolizing the resulting sub-datasets by category. Each of the four categories contains 11 sub-datasets corresponding with the ten-year timeframe of the master dataset. For example, there is a sub-dataset for each year between 2008-2018 that contains the total IDP per country for each specific year. Thus, there are 44 total sub-datasets used to create the web application – 11 for each of the four categories. Of the 44 sub-datasets, 22 were uploaded to ArcGIS Online for symbolization.

The figures below display the new fields created for each category's sub-datasets. Compared to the master dataset's fields in Table 1, the new sub-datasets allow for the data to be presented, and subsequently visualized, in a new and more meaningful way.

	A	B	C	D
1		**Name**	**Displacement Total**	**Date**
2	1	Afghanistan	3430	2008
3	2	Albania		2008
4	3	Algeria	25000	2008

Figure 5. Snapshot of the 2008 sub-dataset for the total IDP per country category

A primary goal of the web application was to symbolize the total number of IDP per country per year as a result of the IDMC's documented natural disaster events. The creation of this category requires separating the countries by each year between 2008-2018. Figure 5 displays the newly created sub-dataset that contains the total number of IDP in a given year per country. Note how countries with no displacements in a given year are left intentionally blank instead of a '0'. As such, these countries will not show up on the map for that specific year, which reduces visual clutter on the map. The R script was built to include this data category for the remaining years 2009-2018.

The next category contains sub-datasets detailing the number of IDP produced as a result of each natural disaster event type. These sub-datasets take the total IDP per country information in the first category (Figure 5) and break down the data by the specific natural disaster event that caused the displacements. This category offers a more detailed perspective on which of the 11 types of natural disasters found in the IDMC's dataset are affecting a country's population displacement. The column names in this category are as follows: Drought Displacements, Dry Mass Movement Displacements, Earthquake Displacements, Extreme Temperature Displacements, Flood Displacements, Mass Movement Displacements, Severe Winter Storms Displacements, Storm Displacements, Volcanic Displacements, Wet Mass Movement Displacements, and Wildfire Displacements. Each row represents a different country, and IDP are attributed to each natural disaster type column. The sum of each row will therefore equal the country's total IDP number as seen in Figure 5.

In this category's case, natural disaster types that did not produce displacements are represented with '0' rather than left intentionally blank. This is because the category is visualized on the web map using a pie chart, so whether a 0 or null value is in a certain field, it still will not be displayed in the pie chart. An important step taken with this category's sub-datasets was to merge each sub-dataset with the sub-datasets from the IDP total category as outlined in Figure 5 above. The resulting spreadsheets contained both categories' information: a country's total IDP for a specific year, and a breakdown of the IDP produced by each natural disaster. The categories were merged in order to symbolize both types of information in a single layer, which was achieved using pop-ups in ArcGIS Online (this process will be detailed in Section 3.3). Finally, the R code created each disaster type field and filled in the data associated with the specific years between 2008-2018.

	A	B	C	D
1		**Name**	**Total Natural Disasters**	**Date**
2	1	Afghanistan	3	2008
3	2	Albania		2008
4	3	Algeria	2	2008

Figure 6. Snapshot of the 2008 sub-dataset for the total natural disaster event category

The next category, as seen in Figure 6 above, contains the total number of natural disaster occurrences in a country each year. As was the case for the total IDP per country category detailed in Figure 5, countries that did not experience any natural disasters in a given year contain a blank field rather than a '0'. This category is visualized with graduated symbols and a time-slider similar to the total IDP category – countries with 0 natural disasters are therefore not relevant to the map and are not displayed as a result.

Finally, the last category is composed of sub-datasets detailing the amount of natural disaster types a country experienced in a given year. This category breaks down the total natural disaster category as seen in Figure 6 and provides a more detailed look at the types of natural disasters that affected a country in a given year. Each column name in these sub-datasets represents one of the 11 types of natural disasters included in the IDMC dataset. Each row represents a country, and the sum of each row will equal the total amount of natural disasters in a given year for that country. Similar to the second category (number of IDP produced per natural disaster), this category is displayed as a pop-up when a user clicks on a country's total natural disaster symbol on the web map. In order to achieve the pop-up functionality, this category's sub-datasets were also merged with another's – this time, with the natural disaster total category detailed in Figure 6. Both merges occurred in Excel before the sub-datasets were uploaded into ArcGIS Online. The symbolization of each subcategory will be discussed in more detail in Section 3.4.

In summation, as seen in the column names in Table 1, the original IDMC dataset contains detailed information regarding event dates, event names, hazard category, and hazard type. In order to present this information in a way that is both insightful and accessible, while still retaining as much of the original detail as possible, the dataset needed to be broken up into separate categories using R. The R script helped neatly organize the wealth of information into 4 distinct groups. As a result, trends and patterns that are otherwise not easily discernible within the master dataset's numerous rows were brought to the forefront of the web map. Section 3.4 delves deeper into the logic and methodology behind the symbolization of each categories' sub-datasets.

3.4 Data Mapping

The web application aims to provide users an interactive, visual, and seamless tool in which they can manipulate the extensive master dataset. In order to achieve this goal, the ESRI software suite was utilized. Specifically, the software utilized to build the final web application included ArcGIS Pro, ArcGIS Online, Web AppBuilder, and Story Map. After the total IDP category was merged with the IDP per event category, the resulting 11 sub-datasets were uploaded to ArcGIS Pro. The Total Natural Disaster category was merged with the Natural Disaster Event Count category, and the 11 merged sub-datasets were also uploaded to ArcGIS Pro. Thus, 22 sub-datasets representing the four categories were uploaded to ArcGIS Pro to begin the symbolization process. The sub-datasets were imported into ArcGIS Pro as a .csv file, and subsequently visualized using the Geocode Table tool. The Geocode Table tool produced point data associated with each countries' location based on the "Name" field in the .csv file. The "Name" column included every single country documented in the IDMC's master dataset, including countries that may not have experienced any natural disaster events. ArcGIS Pro was utilized for the quickness and accuracy of the Geocode Table tool, as well as the ability to easily add a temporal component to the dataset by adding a time aspect within each layers' properties later on in the symbolization process. After a sub-dataset was geocoded, the results were reviewed to ensure accuracy. Ten countries required a manual edit to confirm the country's accurate location on the map. Figure 7 is a snippet of the ArcGIS Pro basemap displaying the point data that was produced after using the Geocode Table tool.

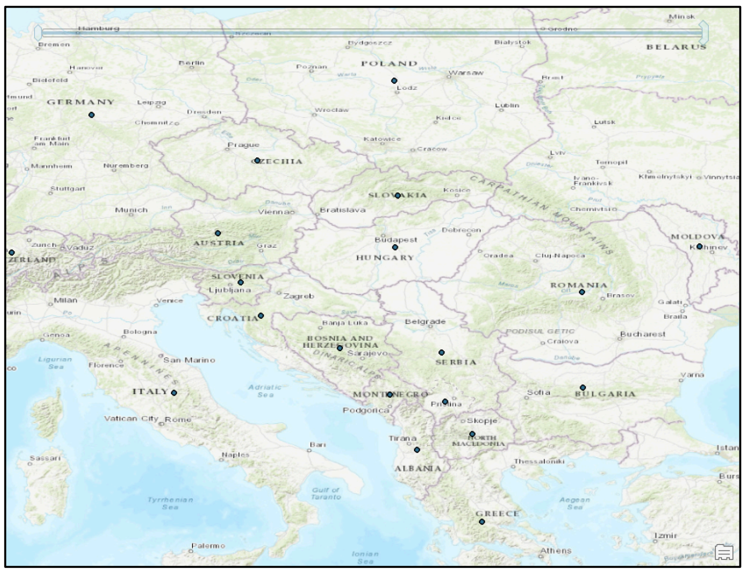

Figure 7. An example of the point data produced from geocoding the sub-datasets

Once the sub-datasets were geocoded, each individual layer was assigned a time property based on the year of the data. No further symbolization was completed in ArcGIS Pro, because ArcGIS Pro does not allow layers to be shared to ArcGIS Online if they contain any chart symbolization, including pop-ups. Therefore, once each layer was geocoded and given a time property, they were immediately shared to ArcGIS Online to complete the majority of the symbolization.

The web map in ArcGIS Online contains 22 layers: 11 for IDP Totals and 11 for Natural Disaster Totals. The IDP Total layers were symbolized with six classes of red graduated symbols, ranging from ≤ 500 IDP to ≤ 20,000,000 IDP. Because the IDMC's master dataset contains such a large amount of detailed information, it is nearly impossible to display all the information at once on the web application. If all four categories were displayed on the web map, the result would be difficult to interpret, and the user would be tasked with interacting with 44 different layers. Therefore, in order to ensure all of the IDMC data is displayed as neatly as possible, pop-ups were configured in order to display the IDP per Natural Disaster and Natural Disaster Event Count categories. The pop-up feature eliminates the need for these categories to be displayed as their own separate layers, effectively reducing the overall clutter of the web map. Thus, each of the IDP Total symbols contain a pop-up displaying a pie chart of the IDP per Natural Disaster category's data. The pop-up was configured by using the attribute data from the IDP per Natural Disaster sub-datasets that were previously merged with the IDP Total sub-datasets. Figure 8 provides an example of the IDP Total symbology displaying the IDP per Natural Disaster data in its pop-up.

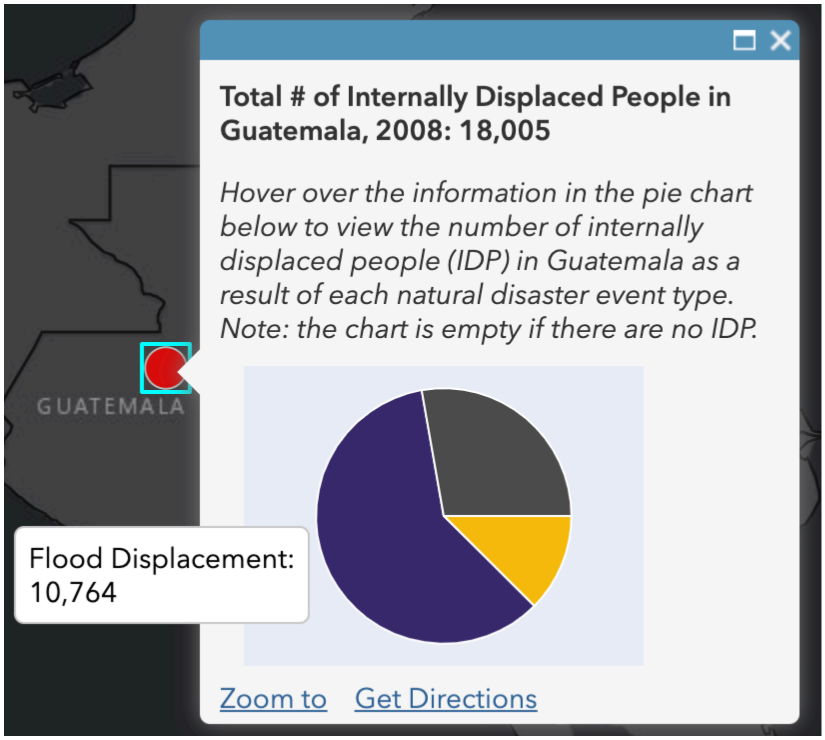

Figure 8. Pop-up for Guatemala's IDP Total symbol for the year 2008

When a user hovers the mouse over a portion of the pie chart, the type of natural disaster and the exact number of IDP associated with the disaster are displayed. In Figure 8, the pointer was hovering over the purple portion of the pie chart, which represents the flood displacement attribute. Figure 9 outlines the configuration of the pop-up title, which displays the exact number of total IDP for the country selected. Displaying the exact total provides users a more detailed look at the data, rather than relying on the graduated symbols. Instead, the graduated symbols are utilized to provide a more general view of the data when the time-slider is activated.

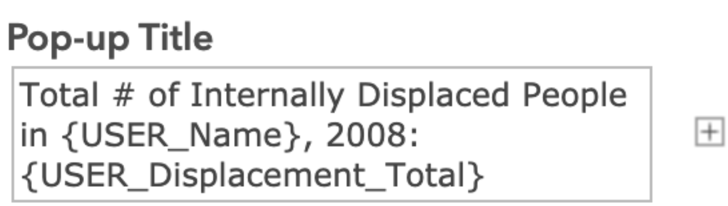

Figure 9. The configuration of the pop-up title for the IDP Total layers

Next, the Natural Disaster Total category's layers were symbolized. By separating the natural disaster data from the displacement data, the web map is able to neatly display two different, yet equally in-depth data categories from the master dataset. Without separating the sub-datasets, the resulting web map would be entirely too cluttered, difficult to read, and nearly impossible to glean any useful information. In order to avoid a map with too much data and various different types of symbolization, the Natural Disaster Total layers were symbolized using the same graduated symbols as the IDP Total layers, providing the map with a consistent visualization of the categories. Many countries experienced less than five recorded natural disasters, according to the IDMC's data – several countries had only one instance in a given year. Conversely, a handful of countries experienced over 150 natural disasters in a single year, such as Indonesia or the United States in 2018. Six classes were created ranging from 1 - 50 and above to account for the large variance of natural disaster occurrences. Next, a pop-up was configured that broke down the number and type of a country's total recorded natural disasters by using the Natural Disaster Event Count category's data found in the attribute data of the Natural Disaster Total layers. Figure 10 details an example of the Natural Disaster Total's pop-up information.

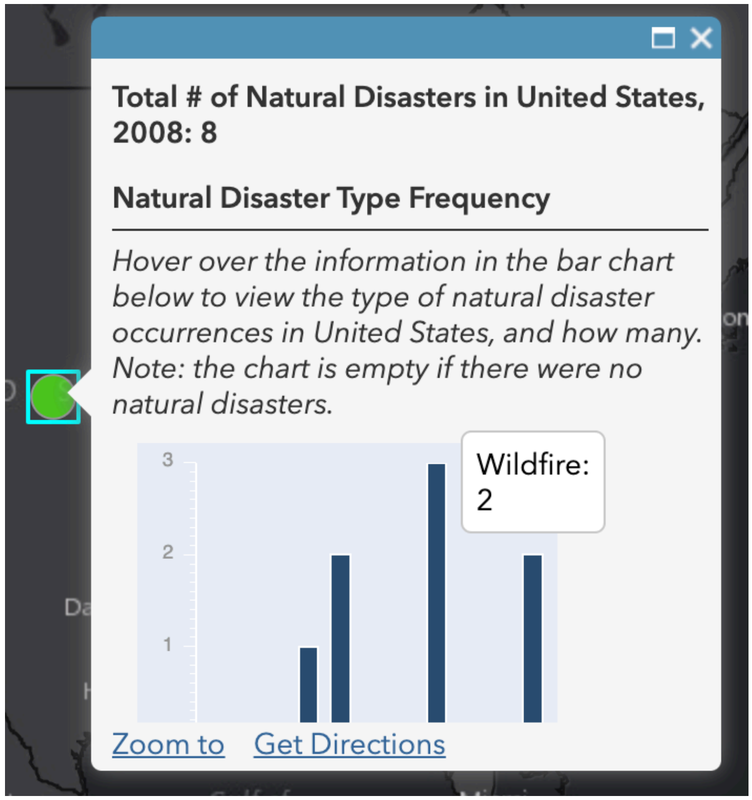

Figure 10. Pop-up for the United States Natural Disaster Total symbol for the year 2008

In this category's case, the information was displayed as a column chart instead of a pie chart. This is because the data for the Natural Disaster Event Count category contains much lower numbers than the IDP per Natural Disaster category, and the disparity between each number is also much lower than the IDP per Natural Disaster numbers. For example, if the IDP per Natural Disaster data was displayed with a column chart, countries with over 1,000,000 IDP as a result of floods would sky-rocket the y-axis – if that same country had 100 IDP as a result of wildfires, the column would be barely visible. The Natural Disaster Event Count data is dispersed more evenly, and contains lower numbers overall, which make the category a sensible candidate to be displayed with a column chart. The title of the pop-up was configured the same way as the title for the IDP Total pop-up – the only difference is the total number was pulled from the natural disaster total column in the Total Natural Disasters layer's attribute table, using "{USER_Total_Natural_Disasters}".

Once the symbology and pop-ups for each of the 22 layers were configured, the web map was complete. The web map and each of its layers' sharing level was set to "Everyone (public)", which allowed for users to access the web application without requiring ESRI credentials. The last step to complete the web application at this stage was to import the web map into ESRI's Web AppBuilder software. Section 3.5 details the creation of the web application itself using this tool.

3.5 Web Application & Story Map Creation

The steps taken leading into the web application and Story Map creation stage are as follows: each sub-dataset was created using the R script, then uploaded to ArcGIS Pro where they were geocoded. Once the sub-datasets were geocoded, they were published and shared to ArcGIS Online. Each individual layer was imported into a blank web map on ArcGIS Online, and symbolized accordingly. The final step involved creating the interface for the user, which was built using ESRI's Web AppBuilder. Web AppBuilder was selected because it provides a user interface that is clean and easy to use with little to no prior GIS experience. Web AppBuilder also offers users the option to use widgets that further filter the data to match their preference, rather than a static map. Lastly, the finalized web application was then embedded in ESRI's Story Map tool, which provided context for the web map's theme as well as basic user instructions on how to interact with the data.

First, the web map built in ArcGIS Online was imported into Web AppBuilder. After the web map was imported into Web AppBuilder, various different widgets were configured and added to the web application, giving the application an extra layer of customization for the users that would otherwise be missing from a static map created in ArcGIS Pro. Widgets can be powerful tools that can perform mathematical functions on layers' attributes and return values that are otherwise not listed in the layers. The theme chosen for the web application was the Foldable Theme, due to the fact that it allows for an unlimited number of widgets while still offering users a simple and clean layout (Figure 11).

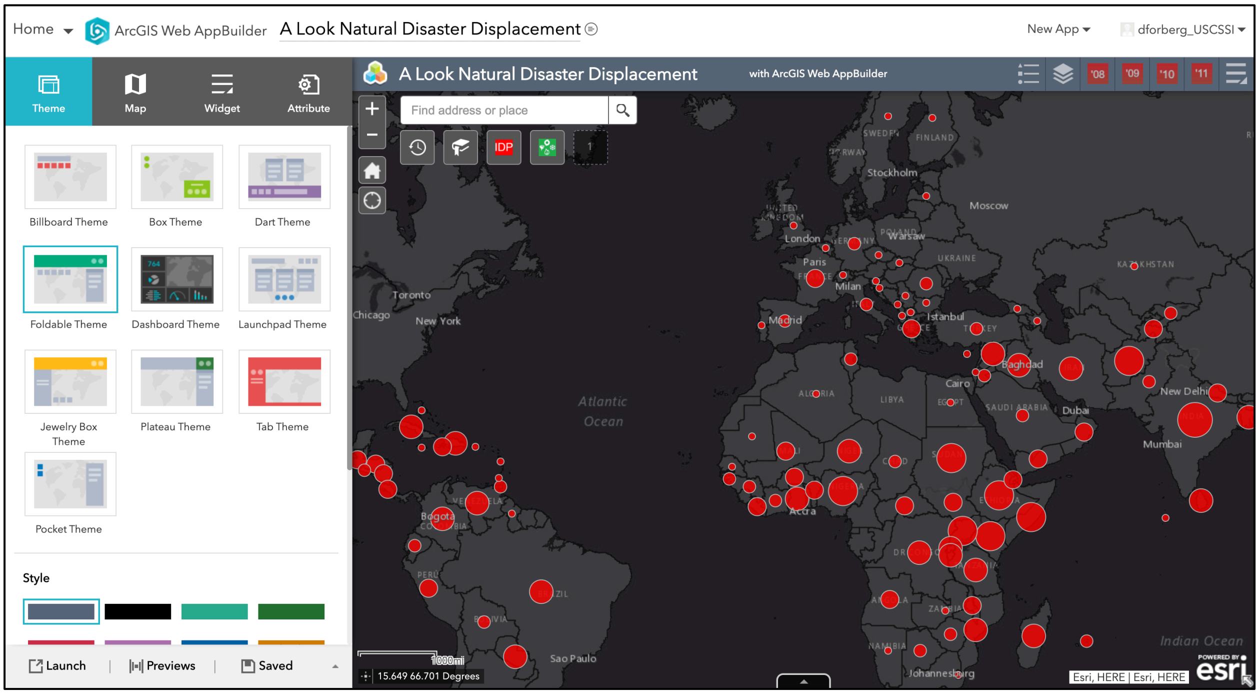

Figure 11. The Web AppBuilder displaying the theme, web map, and widget options

The first widget added to the map was the Time Slider widget. Because the time properties were already configured on the layers in ArcGIS Pro, there was little need for any customization of the Time Slider widget. The time parameters of each layer were already configured before they were imported to Web AppBuilder, so when the Time Slider is activated, the layers respond accordingly.

The second widget added to the application was the Layer List widget. The Layer List widget is used as an organizational tool for users to easily toggle layers' visibility on the map. There are two Layer List widgets on the web application: one for the IDP Total category's layers, and another for the Natural Disaster Total category's layers. The IDP Total Layer List widget contains the 11 layers for the IDP Total category. Users can turn them on or off to match their preference, and can also turn them all on at once, click the Time Slider widget, and view the data change over time. This functionality is the exact same for the Natural Disaster Total category as well. Users can toggle the 11 Natural Disaster Total layers and view each year individually if they choose.

The third widget added to the web application is the Summary widget. There are 22 instances of the Summary widget on the web application, as each instance corresponds with a specific layer's year. The Summary widget presents the sum of each attribute of the corresponding layer depending on the web map's extent. To ensure this tool's functionality is made clear to the user, the Summary tool's icon is the year and color of the layer it summarizes (example: the Summary widget for IDP Totals in 2015 is a red box with a "15" inside the box, as the IDP Totals layer is symbolized using the color red). The Results section provides an in-depth examination of the web application and delves into the details of each aforementioned widget.

Chapter 4 Results

This chapter explores the web application and its functionality in detail, as well as the development process leading up to the final application. Additionally, Figure 19 displays the Story Map template, which was added to provide users additional context regarding climate change, natural disasters, and IDP. The Story Map also details instructions for users on how to interact with the web application and outlines the use and purpose of the various widgets.

The web application's foundation is built upon the 22 layers imported from the map built on ArcGIS Online. One of the challenges facing an application containing 22 layers is ensuring the layers are organized and displayed in a manner that does not distract the user or become too complicated for interaction. If a user wishes to see all layers in a single list, they have the option to do so by utilizing a Layer List widget in the top right tool bar. However, in order to avoid a cluttered map with overlapping layers and easier navigation between layers, a Layer List widget was created for both data categories (Figure 12). The Layer List widget separates the categories into two different widgets, allowing for users to toggle and interact with each group of layers separately.

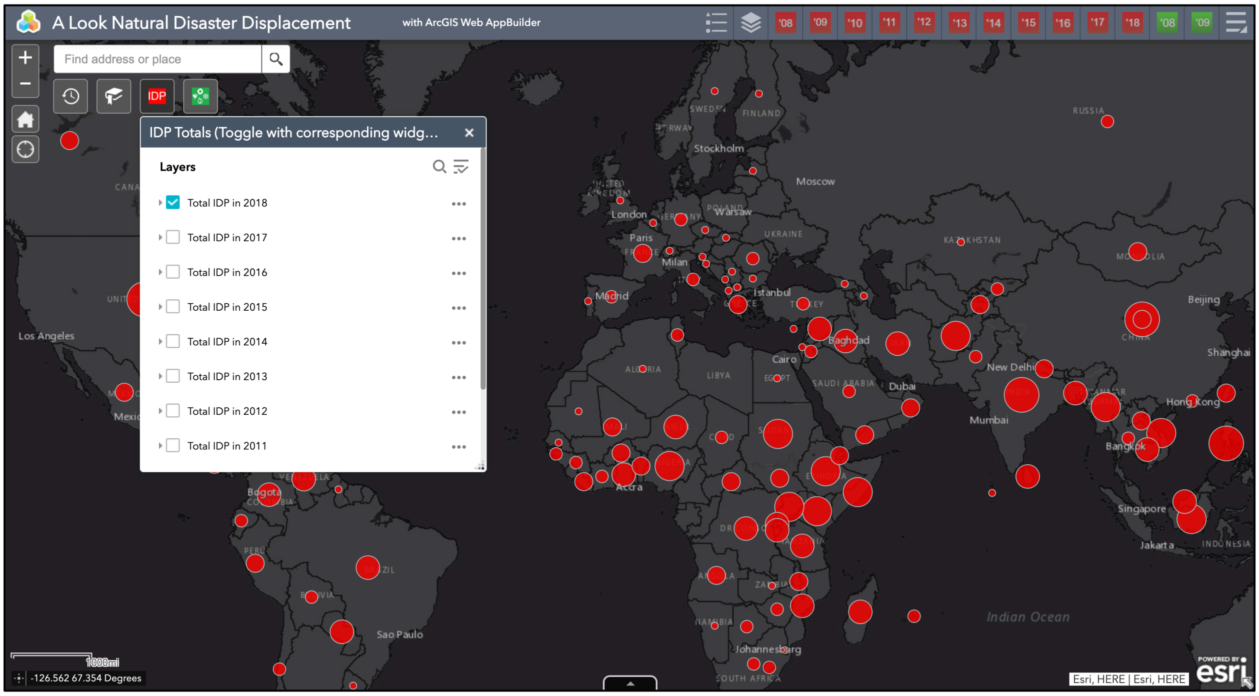

Figure 12. View of the web application with the IDP Total Layer List widget activated

Separating the two categories allows for users to interact with each category seamlessly, and the connection between the layers and the Summary widget is made clearer using color coding. As seen in Figure 12, users have the ability to turn all layers on or off at the same time. If users turn all layers on, they are then able to utilize the Time Slider widget to the left of the Layer List widgets.

The Time Slider widget is designed to work when all layers of a single category are turned on. After a user turns on all the layers of a category, they can click the Time Slider to view the individual data totals change year over year (Figure 13). Users can also take advantage of the search bar located above the Time Slider widget to view a specific country's totals over time, and pause the Time Slider tool at the bottom of the application in order to focus on a single year. When a single layer is activated, users can click on the layer's symbology to view a graph of the layer's attributes that are otherwise not shown on the web map. This functionality was outlined in Chapter 3.3 – Figures 8 and 10 demonstrate the pop-ups that display whenever a graduated symbol is selected by a user.

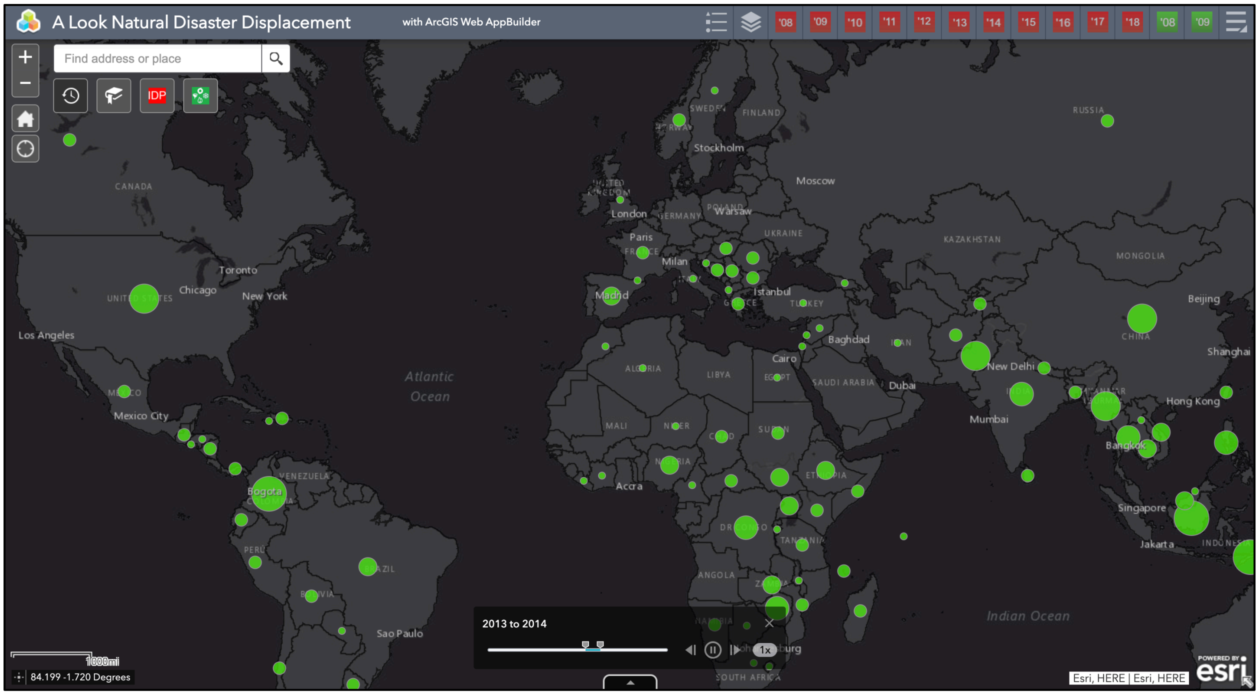

Figure 13. The web application's time slider activated for Total Natural Disasters layer

The Summary widget provides a deeper look into the attribute data for both IDP and Natural Disaster categories. When a data layer's year is turned on in the Layer List, users can select the corresponding Summary widget in the widget controller in the top right portion of the application. The Summary widgets are color-coded and labeled with a year to correspond with their respective category's layer. For the IDP Total category, users can zoom to an extent of the web map to view the total number of displacements per natural disaster type in that specific extent of the map (Figure 14).

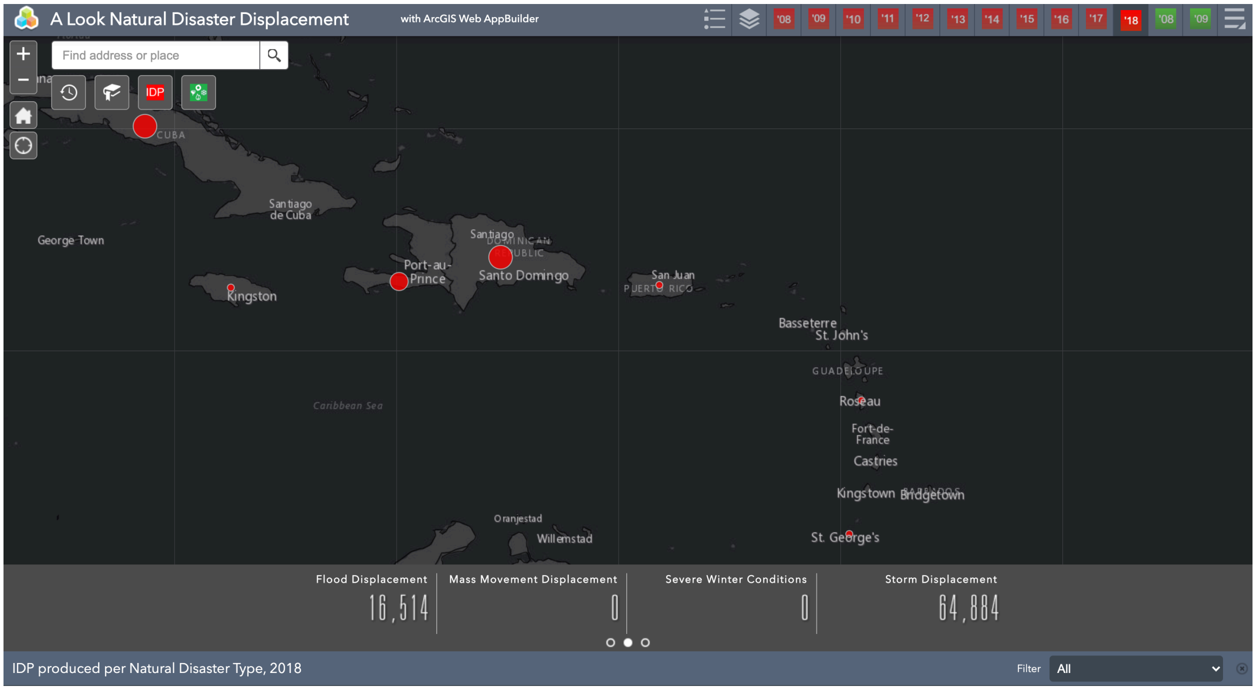

Figure 14. View of the Caribbean islands' total IDP per natural disaster type in 2018

Figure 14 displays the web map zoomed to the extent of the Caribbean islands with the 2018 Summary widget activated, as well as the Total IDP in 2018 layer turned on. The result is a sum of the IDP produced by each natural disaster type in the region. The three dots at the bottom of the tool allow for users to toggle through each page of the Summary widget to show all of the natural disaster types. Note that the country's symbology must be displayed on the web map's extent in order for the country to be included in the Summary widget's count. Furthermore, a filter feature is built-in to the Summary widget. Figure 15 is an example of the filter feature's utilization. Users can click the "All" drop-down arrow to select a specific country. In Figure 15, Sri Lanka was selected. The web map responds by zooming to the extent of Sri Lanka and displays the IDP per Natural Disaster totals. However, this information can also be found by clicking the symbology of a country, so the Summary tool is best utilized for multiple countries. Nonetheless, the filter feature is an easy shortcut to move from country to country without having to scroll and zoom throughout the map.

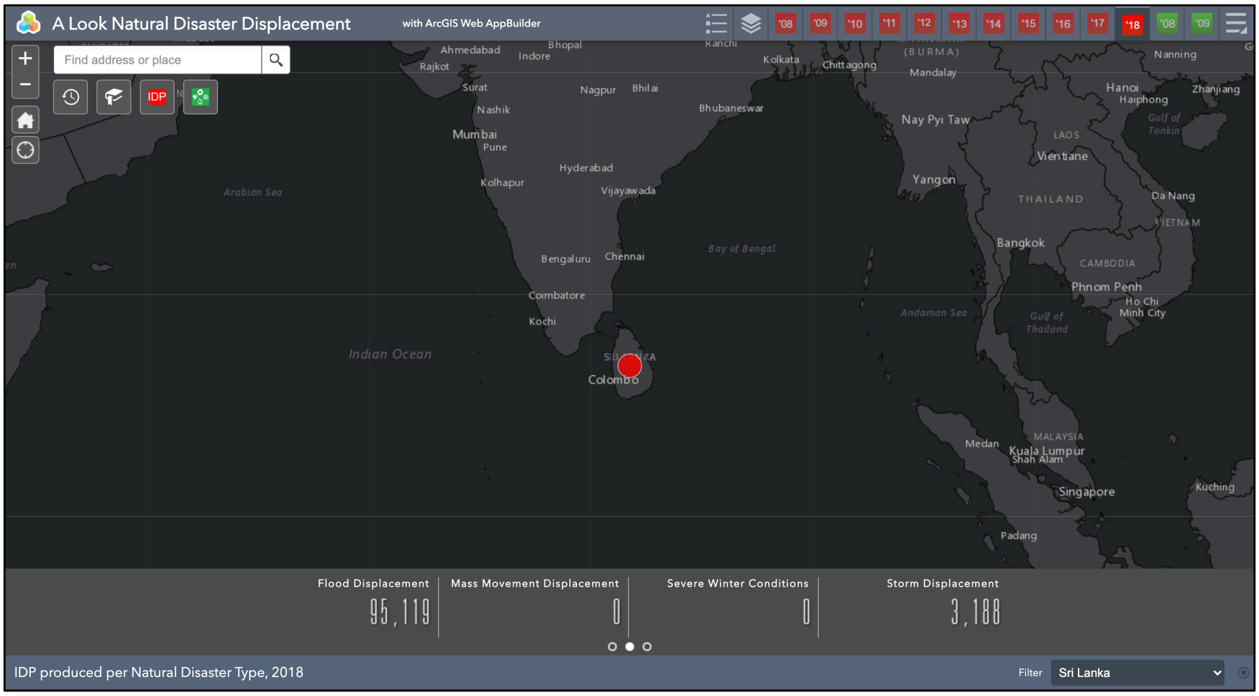

Figure 15. View of the Summary widget while utilizing the filter feature

The Summary widget works similarly when activating the Natural Disaster Total layers. Only 13 widgets can be displayed in the top right widget controller, however, so the rest of the green-labeled Natural Disaster Total Summary widgets are housed in the "more" tab at the end of the widget controller (Figure 16).

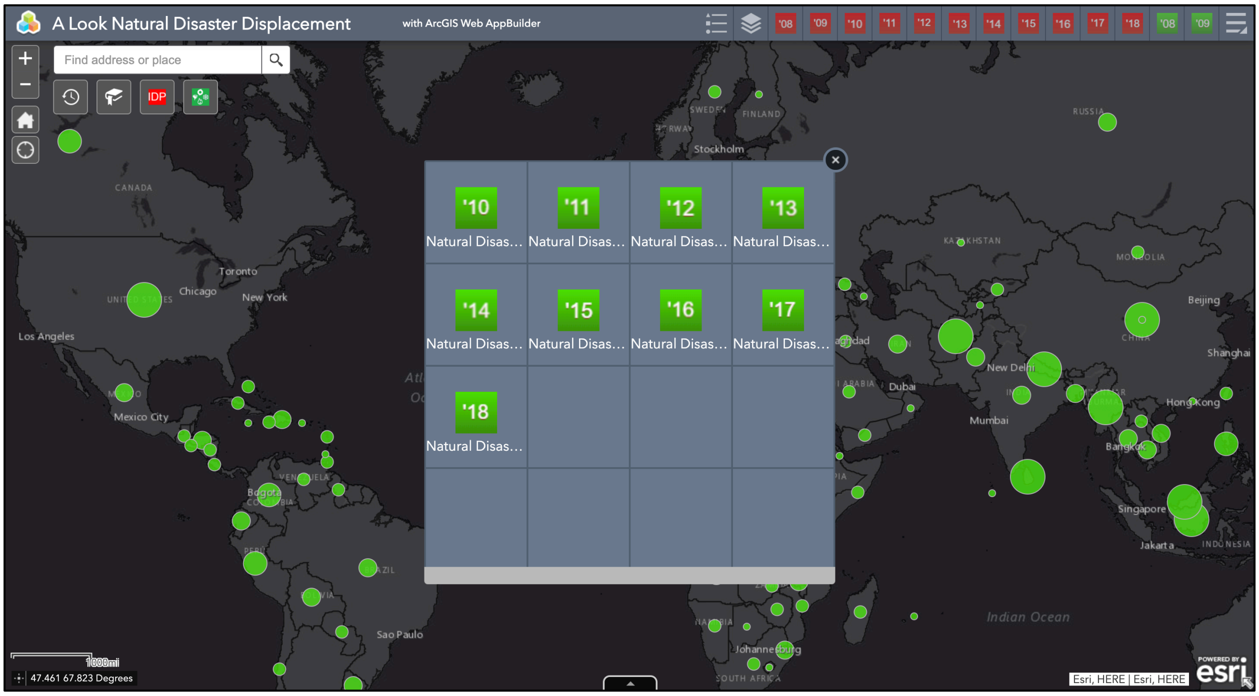

Figure 16. The Natural Disaster Total Summary widgets found in the "more" tab

When the Summary widget is activated for a Natural Disaster Total layer, the widget displays the sum of all the types of natural disaster occurrences within the map's extent. Figure 17 is an example of the Summary widget focused on a group of South East Asian islands. According to the Summary widget, 159 floods occurred in that area in 2018. Note that the year of the Summary widget will always be highlighted in the top right widget controller, as seen in Figure 17.

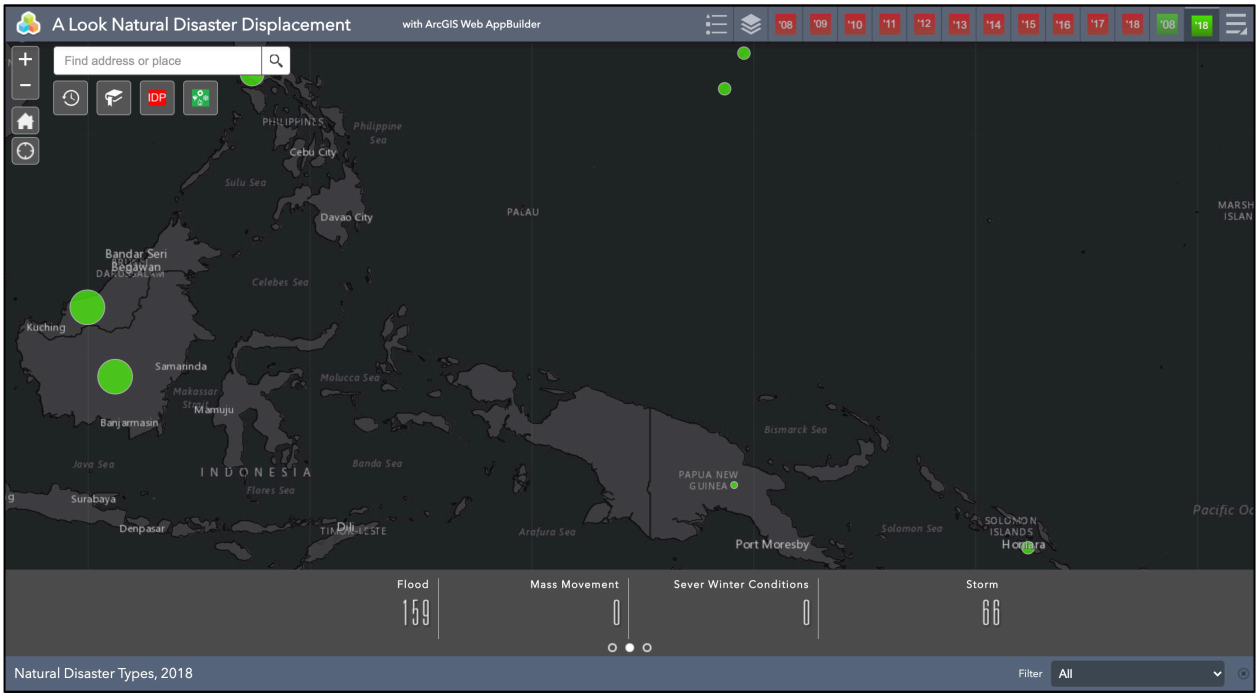

Figure 17. Summary widget used in Pacific Island countries for the 2018 dataset

Finally, if a user has been zooming and scrolling throughout the map and wants to return to the original extent of the web map, a Bookmark widget was added next to the Time Slider widget. This simple tool allows for users to quickly zoom back to the original extent of the map with just two clicks (Figure 18). The widget also allows for users to create their own bookmark's if they are focusing on a specific area of the map.

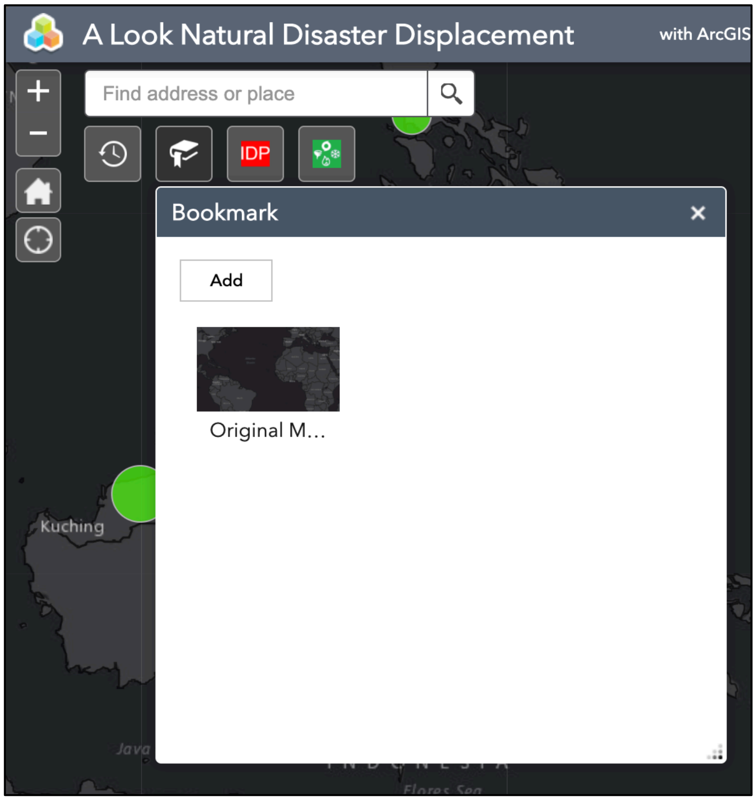

Figure 18. View of the Bookmark widget and the original extent shortcut

The web application's purpose was to provide users an intuitive tool to view IDP and natural disaster data over a ten-year time span, and on a global scale. The widgets and their functionalities outlined in this chapter helped achieve this purpose, while still providing a clean and practical interface. While 22 layers may initially be difficult to organize, the widgets offered in ESRI's Web AppBuilder were able to manage them as seamlessly as possible.

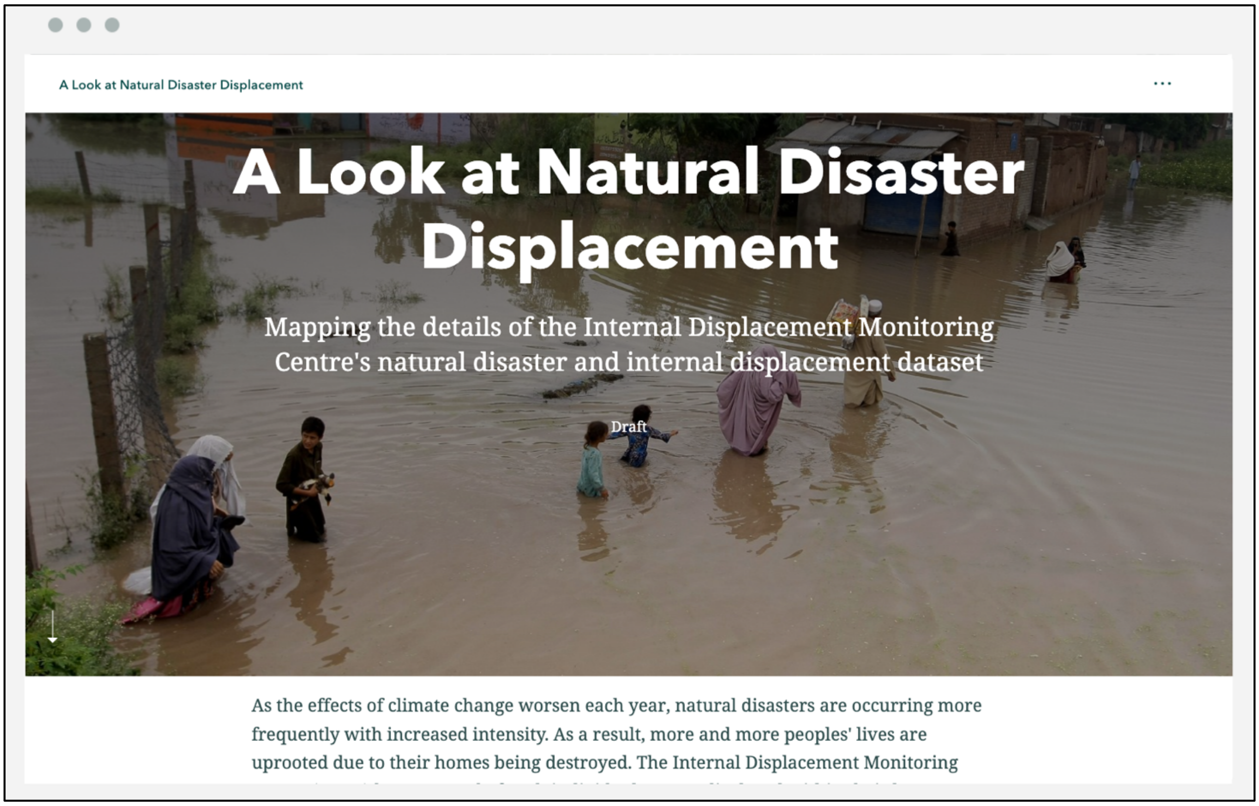

Figure 19. The landing page for the web application on ESRI's Story Map

Finally, ESRI's Story Map tool was utilized as a landing page for the web application (Figure 19). In embedding the web application into the Story Map website, the site also provides users a summary of the web application's theme and an explanation of IDP in relation to natural disasters. This added context will allow for users to better understand the data with which they are interacting. Instructions on how to navigate and interact with the web application, as well as a description of the Summary widgets, are also included above the web application.

Chapter 5 Conclusion

This chapter discusses the web application as a whole, including a summary of the web map design and application creation process, difficulties that arose throughout the data parsing and web map development process, application limitations, and finally, the opportunity for future development, improvement, user testing, and expansions.

5.1 Summary of Web Application Development

The web application's foundation is built entirely on the single master dataset compiled by the IDMC. The various widgets, layers, and symbolization would not have been possible without the R code created to count various attributes found throughout the master dataset, such as natural disaster frequency per country and IDP produced per natural disaster. The R code successfully created four separate categories, which were then combined into the two main categories displayed on the final web map: Total IDP and Total Natural Disasters.

ArcGIS Pro served as the foundational application used to visualize the sub-datasets. Once the sub-datasets were accurately geocoded and visualized on a static map, they were given a time property in each layer's properties. After each sub-dataset's attributes contained an accurate location and time property, they were shared to ArcGIS Online. The bulk of the symbolization, including the creation of the graduated symbols for both categories and the configuration of their respective pop-ups, took place in ArcGIS Online. After the web map was finalized, it was imported into ESRI's Web AppBuilder. Web AppBuilder bolstered the functionality of the web map with the addition of its built-in widgets, including the Layer List, Time Slider, Bookmark, and Summary widgets. Lastly, the finalized web application was imported into ESRI's Story Map application. The Story Map provided context for the web application's theme by including information about climate change, natural disasters, and an overview of the definition of IDP. Additionally, the Story Map contained a set of instructions for users regarding widget functionality, and information about the layer categories. Overall, the utilization of the Story Map helped prepare users to better comprehend the data with which they are interacting, and provided additional information and instruction regarding the functionality and tools built into the application.

5.2 Difficulties Encountered During Development

Once the web map was imported into Web AppBuilder, there were few difficulties encountered aside from briefly troubleshooting the sums found in the Summary widget. This was quickly resolved by deleting and re-adding the widget, then refreshing the application, which likely means the issue was a bug in the widget.

Most of the issues encountered throughout the project occurred in the early stages of development. The R code needed to be re-ran multiple times on the master dataset to eliminate random errors or unnecessary information that existed in the IDMC's original data. For instance, when the R code was running a count on each natural disaster type, the IDMC data contained an "oil spill" midway through their spreadsheet. This caused the R script to stop counting all natural disaster types after the oil spill record, resulting in the latter half of the Natural Disaster Event Count sub-dataset for that specific year to have 0's in every single row. Finding the error meant manually checking each record in the IDMC dataset until the anomaly record was found. Once the record was deleted from the IDMC dataset, the R script ran as initially planned.

There were also numerous errors when attempting to share the sub-datasets' layers from ArcGIS Pro to ArcGIS Online. If any chart symbology was applied to any of the layers in ArcGIS Pro, they could not be shared to ArcGIS Online – ultimately, layers with certain types of symbology cannot be shared. As a result, the layers shared from ArcGIS Pro to ArcGIS Online were extremely rudimentary – each layer contained simple location point data, which is why the majority of symbolization and pop-up configuration was completed in ArcGIS Online. Furthermore, when attempting to merge the 4 categories' sub-datasets into 2, the resulting layers also could not be shared. This is because layers that underwent a join are unable to be shared to ArcGIS Online. Therefore, the merging of the Natural Disaster Event Count category with the Natural Disaster Total category, as well as the merging of the Total IDP category with the IDP per Natural Disaster category, was done manually in Excel. After these steps were completed, each layer was successfully shared to ArcGIS Online.

Lastly, layers cannot be grouped in ArcGIS Online, which is why each layer needs to be turned on and off individually in the Web AppBuilder. The layers could have been grouped in ArcGIS Pro – however, once layers are grouped in ArcGIS Pro and published to ArcGIS Online, the editing and symbolization is far more limited and would have inhibited the functionality of the web application.

5.3 Future Development

Currently as it stands, the web application is hosted on USC SSCI servers. In order for the web application to continue existing long-term, either the Dornsife Spatial Sciences Institute would agree to continue hosting the application, or the application would need to be recreated on a personal or different organization's server that has access to each of the ESRI software programs used to create the application.

One long-term goal of the application is to be able to implement future IDMC data. Just recently, the IDMC published the data for the year 2019. A workflow needs to be created so that new data for future years can be seamlessly added to the web application. Once the workflow is established, the goal would be for future users to be able to quickly add new IDMC data to the map. For example, the IDMC compiles displacement data for conflict and violence formatted similarly to their natural disaster dataset. It is entirely possible to add this non-weather related data to the web application, but would require various changes to the web application's widgets depending on the attribute data found in the conflict and violence dataset. However, the scope of this web application focused solely on weather-related displacements.

Furthermore, the web application's theme can be enriched with the addition of supplemental data for each country. For instance, each country's total population can be added to the web map to provide context for the country's IDP total. The visualization of countries with smaller populations that contain a large amount of IDP in a given year can demonstrate the scale of natural disaster displacement. Population data would be able to determine the ratio of IDP per population in each country. Other supplemental data types that would further enrich the application include a country's wealth and poverty statistics, urbanization, cultural diversity, or land use. Such information would help determine whether poorer countries are disproportionately affected by natural disasters compared to wealthier countries with stronger emergency infrastructure in place, for example. Demographic data would provide a glimpse into which groups are affected as well – however, the IDMC does not include the demographics of each IDP. Rather, demographic data would instead provide more detailed context for each country affected by natural disasters.

The web application could also benefit from user testing. User testing would allow for multiple groups of individuals from various different backgrounds and GIS experience to interact with the application, and ultimately provide feedback regarding the user interface and functionality. While the user interface of the web application was designed for both technical and non-technical users, user feedback would help determine whether the application's interface meets its design goal. Feedback from technical users with GIS experience would also be beneficial, as these types of users could provide recommendations regarding widget functionality, symbolization, and the potential addition of new widgets, features and supplemental data. The feedback garnered from user testing would ideally be compiled and evaluated, with the end goal of implementing relevant suggestions to the web application.

Overall, the primary goal of the project was met, which was to provide users with a dynamic user interface that is simple enough to use with no prior GIS experience, yet powerful enough to transform a large spreadsheet into an interactive, visual tool that can provide new trends and information to the user. The web application serves as a data visualization tool that can be utilized by a wide variety of users. It can be applied as an educational tool in a classroom, journalists can use it to present large amounts of data to their audience, and government organizations and disaster relief agencies can discover trends in the data to make more informed decisions to protect IDP. Rather than depending on headlines presented by the news, attempting to decipher information on a spreadsheet with over 6,000 rows, users instead have the ability to directly access, customize, and filter natural disaster and IDP data to match their preference in a dynamic, visual web application.

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