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Evaluating CYGNSS Wind Data to Assess Tropical Storm Impacts in the Gulf of Mexico

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Evaluating CYGNSS Wind Data to Assess Tropical Storm Impacts in the Gulf of México

by

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1. Abstract
Covering approximately 600,000 square miles, the Gulf of México (GoM) houses the Outer Continental Shelf (OCS). The OCS consists of submerged coastal land that borders the continent before reaching the deep ocean (Encyclopedia Britannica, 2018). Tropical storms that occur within the GoM can impact the US states of Texas, Louisiana, Mississippi, Alabama, and Florida. To assess the impact of tropical storms on this area, this project analyzed the dynamics of wind intensity and precipitation levels during tropical storm events. Wind condition maps were created using data collected by the Cyclone Global Navigation Satellite System (CYGNSS) constellation. Precipitation maps were created using data from the Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm, which estimates the daily accumulated precipitation. Combining the wind speed maps with the precipitation maps can help scientists understand the correlation between wind speed and precipitation on other factors, such as the flooding extent, during tropical storms.

This project is a continuation of the Fall 2018 DEVELOP project, "Gulf of México Transportation and Infrastructure," which focused on how wind speeds and wave heights affect infrastructure, such as oil rigs, in the GoM. The GoM provides a significant amount of oil for the US; it accounts for 17% of all US oil production. As the warming climate brings higher intensity tropical storms, the production and availability of such oil resources are threatened. Energy infrastructure, such as oil and natural gas rigs, transportation pipelines, and processing plants, caught in the path of these storms must shut down, effectively halting production. The additional wind condition maps can be used to find potential impacts on energy infrastructure during tropical storms as well as providing guidance for future infrastructure placement sites.

Keywords
oil, oil rigs, tropical cyclone, tropical storm, hurricane, Outer Continental Shelf, flood, precipitation

2. Introduction

2.1 Background Information
Playing a notable part in the US energy industry, The Gulf of México (GoM) houses around 4,000 offshore oil and natural gas platforms along with over 50,000 km of pipeline (Cruz & Krausmann, 2008). The GoM is a partially landlocked body of water which is mostly bordered by the US and México (Figure 1). With energy resources that contribute 17% of US offshore crude oil production and 5% of offshore dry natural gas, studying the conditions of the GoM is important to keep production consistent and efficient (US Energy Information Administration, n.d.).

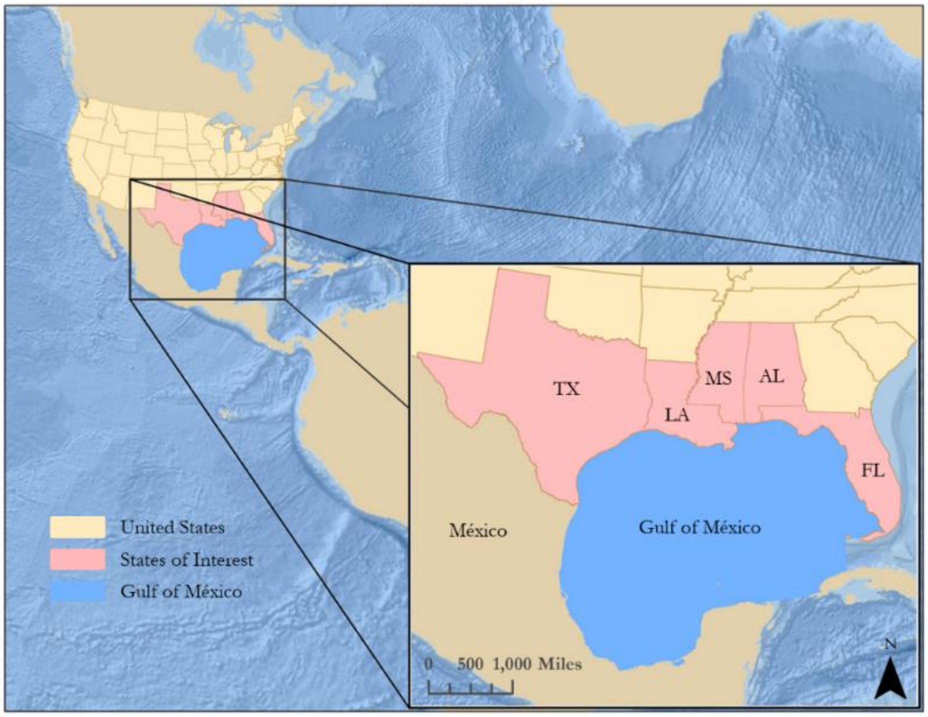

Figure 1. The study area of the GoM bordered by AL, FL, LA, MS, & TX
Created by Michelle De Luna for NASA Develop

Inside the GoM, the warm Loop Current strengthens tropical systems by fueling the warm ocean waters (Oey, Ezer, & Lee, 2005). As a result of tropical storms, structures can endure "catastrophic failure," like 2-4% of damaged structures have suffered in the past few years (Kaiser, 2014). During these storms, waves can hit the platform's deck, leading to damage to the braces, legs, joints, conductors, and risers (Kaiser, 2014). Since this damage is expensive to repair and dangerous to the environment, when a storm is predicted to occur in the GoM, oil companies and drilling contractors must decide whether to shut-in well production and evacuate the personnel. While the decision to shut-in production can protect structures, it can also disrupt the energy industry by delaying fuel supply times and cause an increase in fuel prices (Dismukes, 2010). There can be an even higher price to pay when pipelines are damaged, as this greatly increases the risk of leaking oil or natural gas into the ocean. Hurricanes Katrina and Rita in 2005 caused hundreds of oil-drilling platforms to shut down. As a result, there were many changes to infrastructure regulation in The American Petroleum Institute's update to guidance materials and industry recommendations (Cruz & Krausmann, 2008).

GoM wind speeds from June 2017 to November 2017 were assessed using data obtained from the Cyclone Global Navigation Satellite System (CYGNSS). This satellite receiver system uses Global Positioning System (GPS) signals to gauge surface roughness and wind speeds. Attenuation of the signal in traditional scatterometers causes them to inaccurately measure the wind speed in the inner core of tropical systems. CYGNSS, however, operates at 1.575 Ghz, which is not significantly affected by cloud and precipitation attenuation (Ruf et al., 2018; Paola Clarizia & Ruf, 2016). CYGNSS' higher temporal resolution and more complete coverage of the tropics allows it to view each storm more frequently and get a better overall picture of the changes the storm goes through (Ruf, et al., 2013).

2.2 Project Objectives

This project's main objective was to assess wind conditions in the GoM. The case study was focused on combining the wind conditions and precipitation levels in the GoM and Texas during Hurricane Harvey. For this project, data was taken from Hurricane Harvey in 2017 as well as a random day from each month in the 2017 hurricane season. The precipitation levels were analyzed for August 25 – August 29, which were the days when Hurricane Harvey made landfall. Looking at data from 2017 will give additional insight into any changes that are occurring within the GoM in recent years. The data from Hurricane Harvey can be compared to other studies on other factors, such as flooding, to help researchers recognize patterns in wind speeds and flooding.

3. Methodology

3.1 Data Acquisition

Data from NASA Earth observation datasets (Table 1) were used to identify the varying wind speeds in the GoM during the 2017 hurricane season. This project focused on a random day of each month (appendix A.2), as well as a case study: Hurricane Harvey. Each random day was selected by using Microsoft Excel random number generator. Instrumentation aboard the CYGNSS constellation acquires wind data. CYGNSS is a series of eight micro-satellites (i.e. observatories) that records discrepancies between the direct and reflected signals that reach an individual observatory's zenith-pointing and nadir-facing antennas, respectively (Ruf et al. 2016). Delay Doppler Maps (DDMs) are visualizations of these discrepancies (Ruf et al, 2016). Ocean-surface measurements such as wind speed can be extracted from DDMs. CYGNSS and level three data files formatted to the standards of the latest 2.1 version from NASA's Earthdata portal.

The dataset used for the daily precipitation was the GPM Level 3 IMERG Final Daily 10 x 10 km (GPM_3IMERGDF), which was downloaded from NASA's Earthdata portal. The IMERG algorithm estimates the daily accumulated precipitation from various precipitation-relevant satellite passive microwave (PMW) sensors. This Final Level 3 product is finished about 3.5 months after observation with monthly gauge analysis as well as forward and backward morphing being considered.

Table 1

Information on the CYGNSS dataset which was used to assess wind conditions and precipitation levels in the GoM

Dataset	**Parameter**	**Spatial Resolution**	**Data Availability as of 11/5/2019**	**Info source**
CYGNSS DDMI	Wind speed	0.2° x 0.2°	03/18/17 to Present	**JPL site NASA CYGNSS handbook**
IMERG Final Precipitation L3	Precipitation	0.1° x 0.1°	06/01/2000 to Present	**NASA GES DISC**

3.2 Data Processing

The wind speed data from CYGNESS was averaged in MATLAB, which produced individual data files. These data files were then were exported as GeoTIFF's and imported into ArcMap 10.7.1. After converting the data points from the raster layers to vector point features with individual wind speed values, an Inverse Distance Weighted (IDW) interpolation was done on the data. IDW interpolation is a spatial method of analysis that determines the value of unknown points based on how close they are to points with known values. Predicted points are more heavily influenced by the value of points closest to them. The influence a known point has decreases as the distance increases (ArcGIS Pro, n.d.). Because of CYGNSS satellites take a sinusoidal path over the tropics, there are gaps in the data, which were estimated using IDW interpolation.

Precipitation data was downloaded as NetCDF-4 files and entered into MATLAB with the "Make CDF Raster Layer" tool in ArcMap. The "natural breaks" from the day with the area with the highest level of precipitation were used to determine the different precipitation levels, shown in Table A.2. The breaks were reclassified for each day with the new values to standardize the values across the days.

4. Conclusions

The maps produced from this project show wind speeds over the GoM during the 2017 hurricane season and wind speeds and precipitation levels for the Hurricane Harvey case study. Continuing the DEVLEOP project from fall 2018 further shows the CYGNSS' potential to asses wind data and its tropical storm impacts on energy infrastructure in the GoM. Precipitation maps for when Hurricane Harvey made landfall can be used with the wind speed maps to find correlations between wind speeds and precipitation levels with other factors. The project also demonstrates applications for NASA Earth observations to address community concerns such as transportation and infrastructure.

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6. Glossary

BOEM – Bureau of Ocean Energy Managements
CYGNSS – Cyclone Global Navigation Satellite System
DDM – Delay Doppler Map; a gridded map produced using data collected by Delay Doppler Mapping Instruments found aboard each of the eight CYGNSS observatories; DDM graphs the delay time and shift in frequency (i.e. the extent of scattering) between the direct and reflected signals received by a CYGNSS observatory
DDMI – Delay Doppler Mapping Instrument
Earth observations – Satellites and sensors that collect information about the Earth's physical, chemical, and biological systems over space and time
EIA – Energy Information Administration
FTP – File Transfer Protocol
GFS – Global Forecasting System
GoM – Gulf of México
GPS – Global Positioning System
GRIB – Gridded Binary
hs – the significant height of combined wind waves and swell
M2T1NXOCN – MERRA-2 tavg1_2d_ocn_Nx: 2d,1-Hourly, Time-Averaged, Single-Level, Assimilation, Ocean Surface Diagnostics V5.12.4
MERRA-2 – Modern-Era Retrospective Analysis for Research and Applications, Version 2
NCEI – NOAA National Centers for Environmental Information
NEPA – National Environmental Policy Act
NetCDF – Network Common Data Form
NOAA – National Oceanic and Atmospheric Administration
OCS – Outer Continental Shelf
OGDR – Operational Geophysical Data Record
PMW –Passive Microwave
Shut-in – To close off a well so that production comes to a halt or slows down

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8. Appendices

8.1 Appendix A

Table A.1

Douglas Sea Scale classifications for wave height and the typical associated wind speeds

Douglas Sea Scale	**Wind Speed (m/s)**	**Description**
0	0 – 0.77	Calm (Glassy)
1	0.77 – 2.57	Calm (Rippled)
2	2.75 – 4.37	Smooth
3	4.37 – 6.97	Slight
4	6.95 – 9.77	Moderate
5	9.77 – 12.6	Rough
6	12.6 – 19.29	Very Rough
7	19.29 – 26.49	High
8	26.49 – 30.61	Very Rough
9	30.61 – 32.92	Phenomenal

Table A.2

Levels of Precipitation used in the precipitation maps

Level of Precipitation	Precipitation (mm)
1	0 – 0.93
2	0.93 – 3.235
3	3.235 – 6.825
4	6.825 – 12.03
5	12.03 – 19.455
6	19.455 – 30.775
7	30.775 – 50.295
8	50.295 – 86.51
9	86.51 – 211.14

Table A.3

Randomized days studied for June 2017 to November 2017

June	3
July	14
August	24
September	19
October	31
November	9

9.1 Appendix B

Level 3 CYGNSS Data Product
Hurricane Harvey

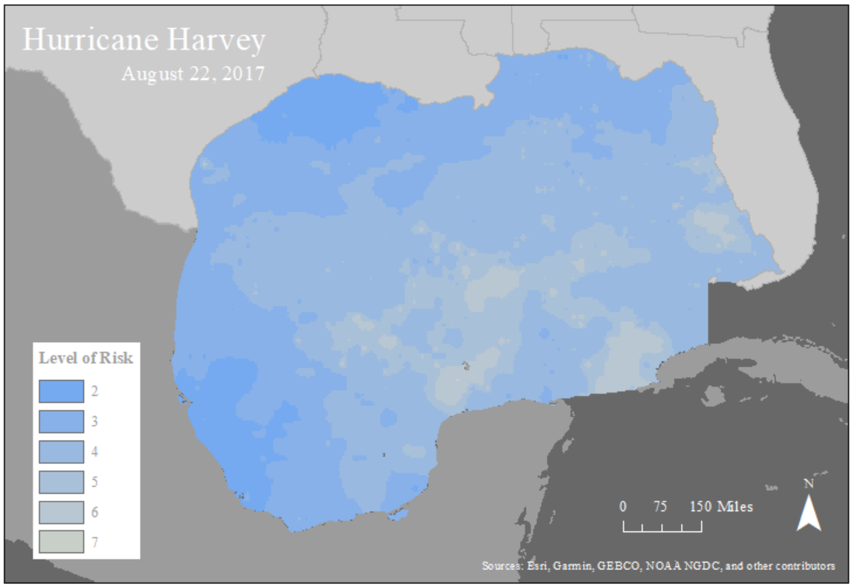

Figure B1.1: Average Windspeeds for August 22, 2017

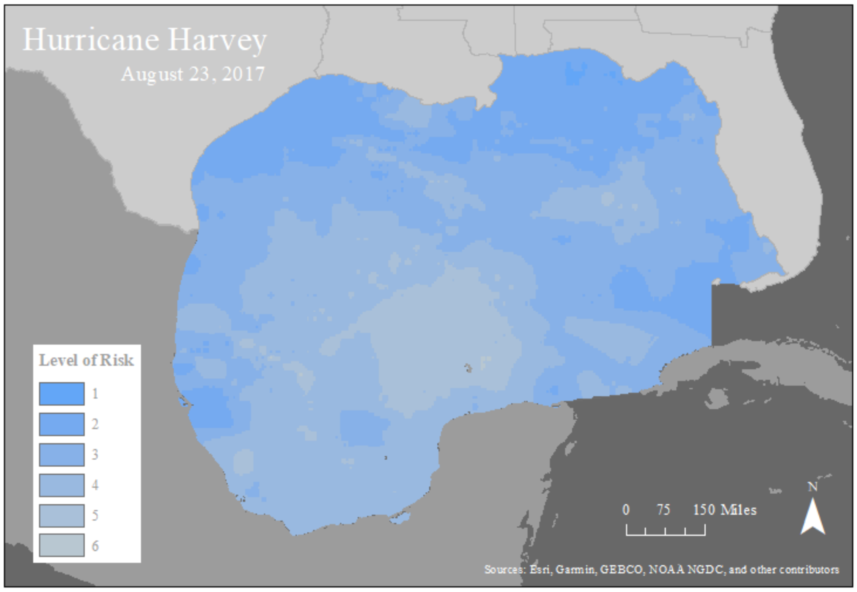

Figure B1.2: Average Windspeeds for August 23, 2017

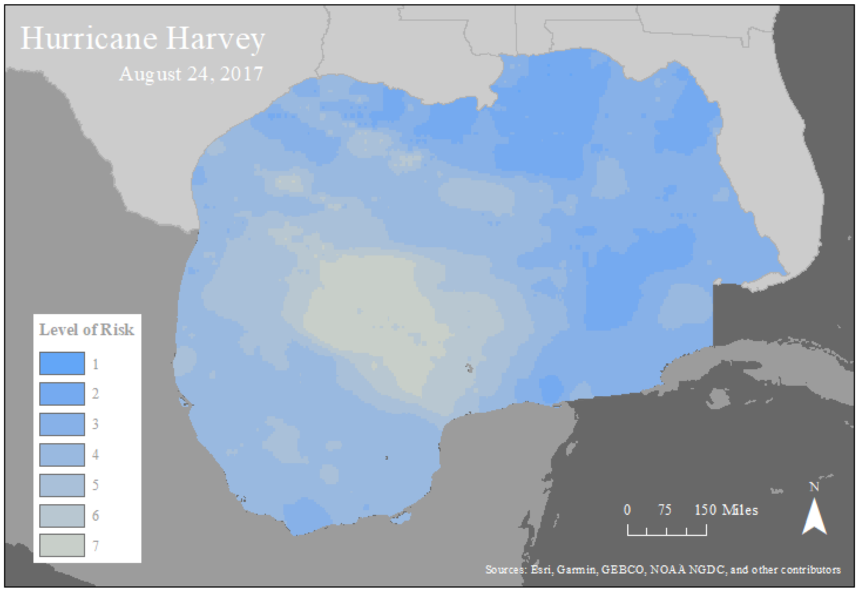

Figure B1.3: Average Windspeeds for August 24, 2017

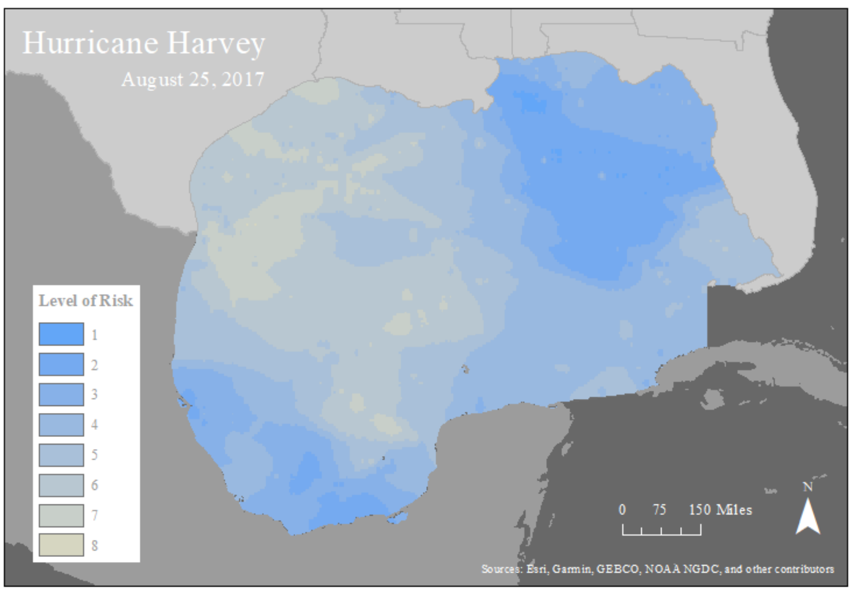

Figure B1.4: Average Windspeeds for August 25, 2017

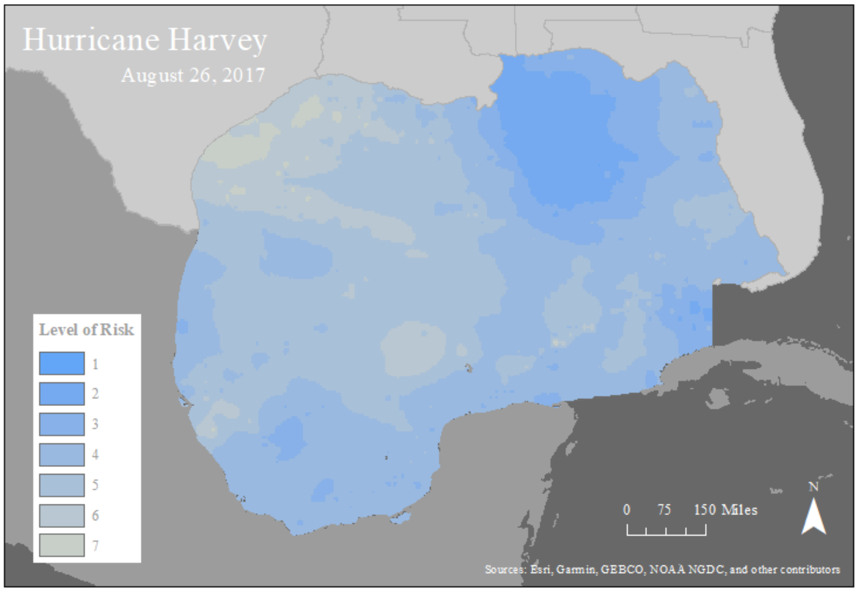

Figure B1.5: Average Windspeeds for August 26, 2017

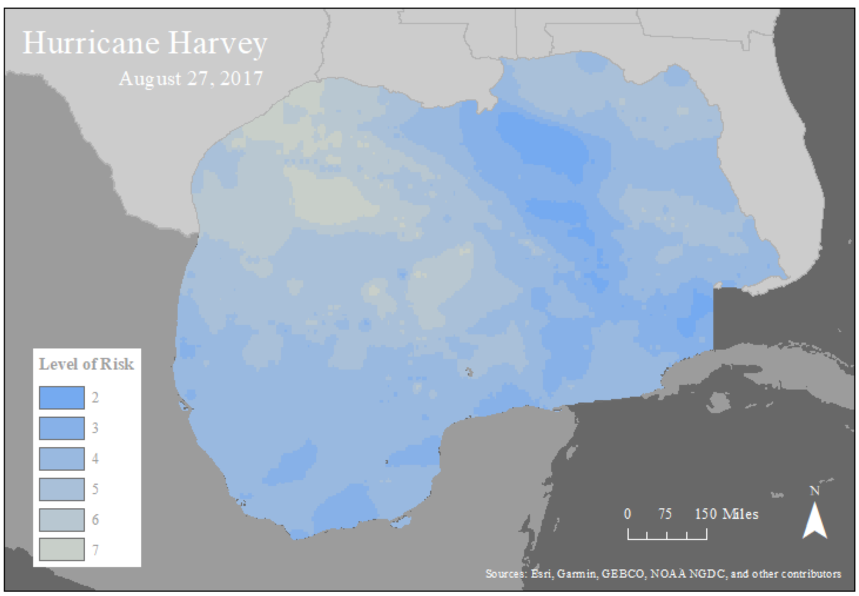

Figure B1.6: Average Windspeeds for August 27, 2017

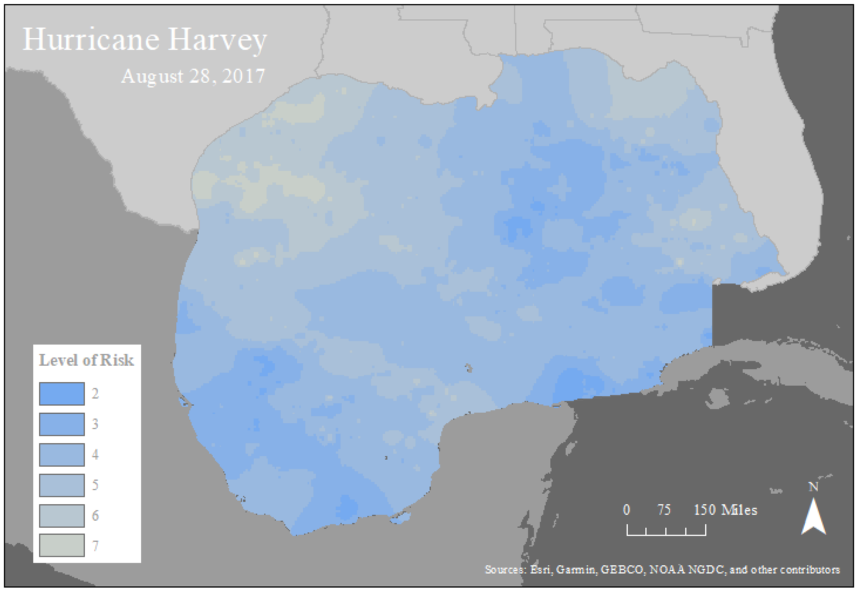

Figure B1.7: Average Windspeeds for August 28, 2017

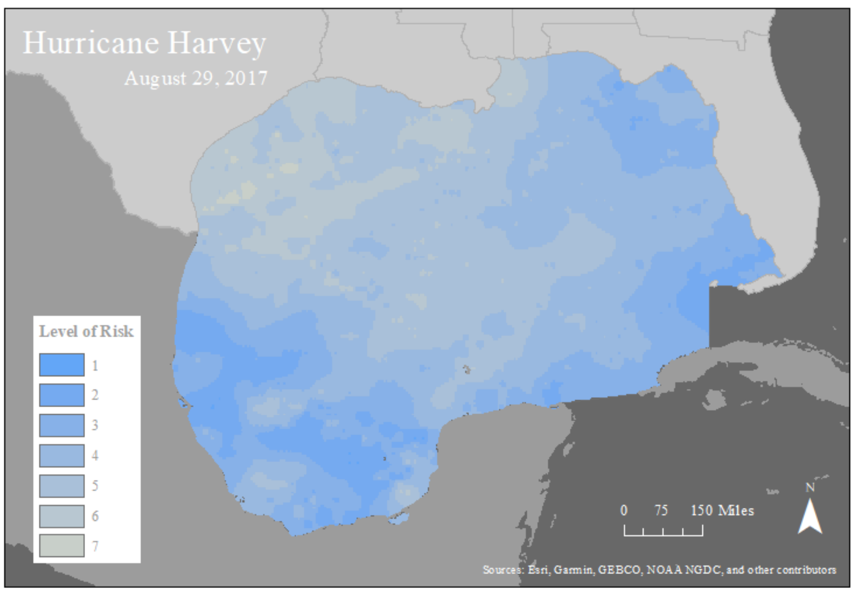

Figure B1.8: Average Windspeeds for August 29, 2017

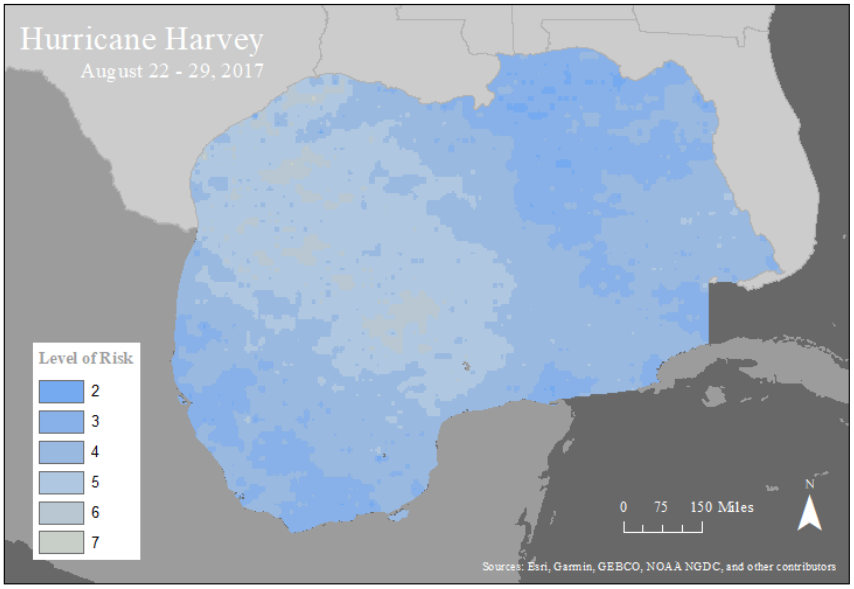

Figure B1.9: Average Windspeeds for Hurricane Harvey: August 22 - 29, 2017

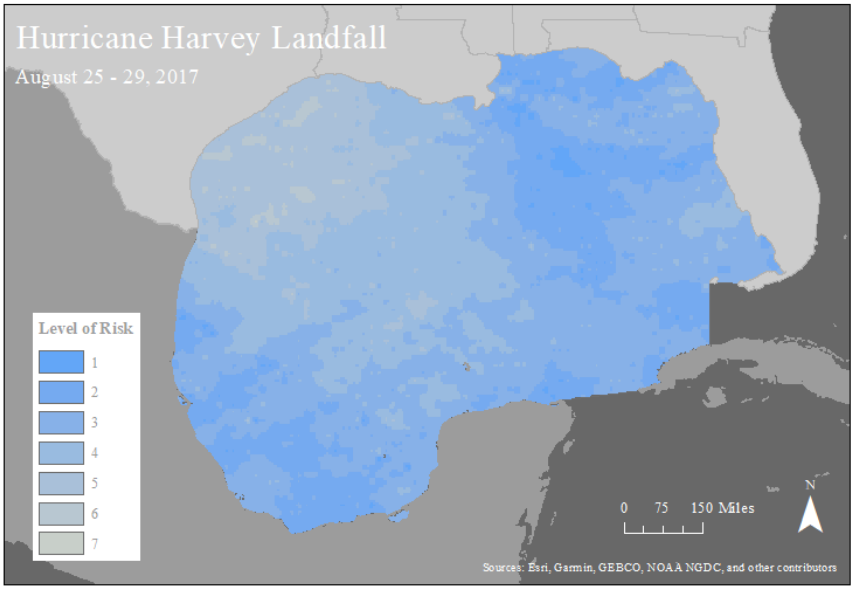

Figure B1.10: Average Windspeeds for Hurricane Harvey during landfall: August 25 - 29, 2017

Level 3 CYGNSS Data Product
2017 Hurricane Season

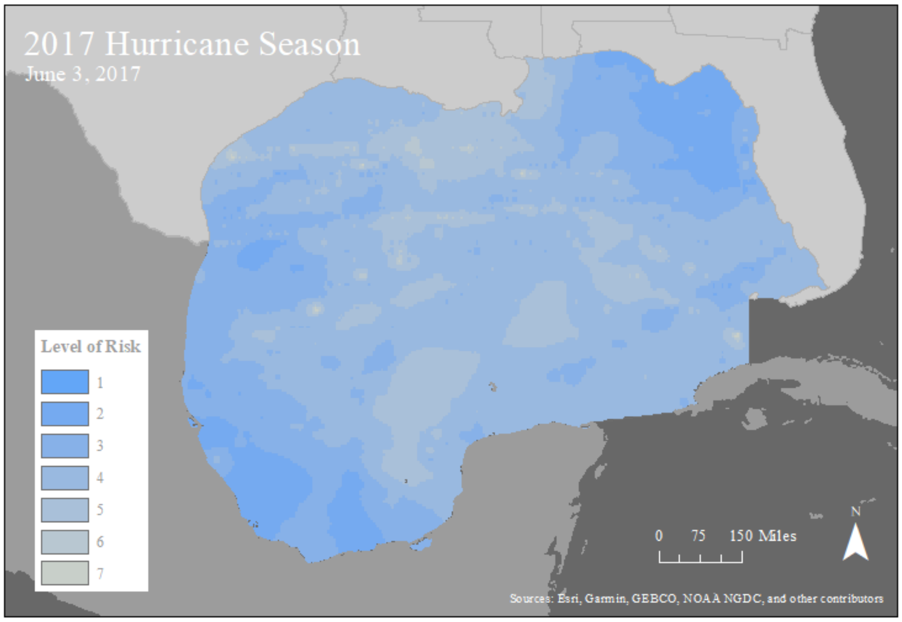

Figure B2.1: Average Windspeeds for June 3, 2017

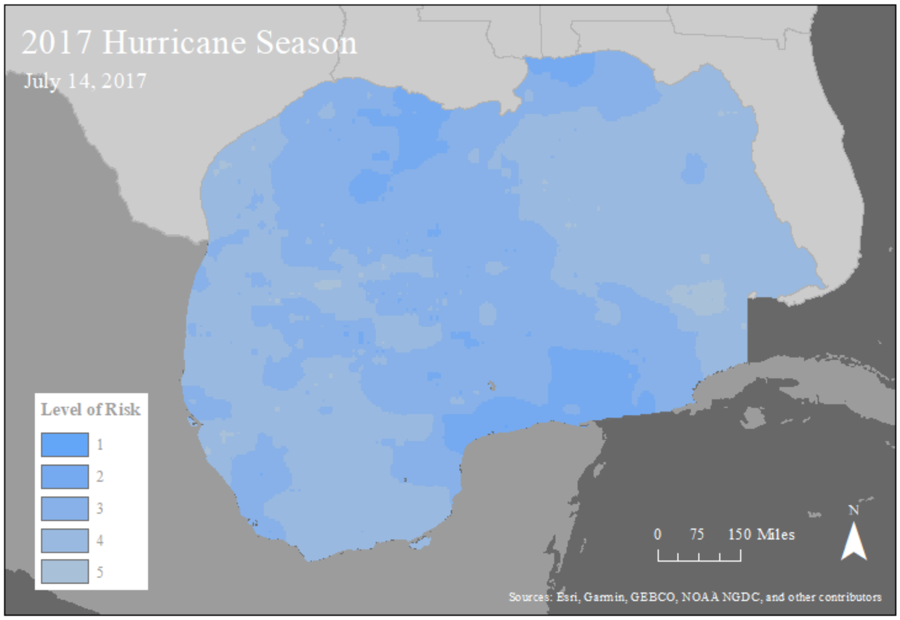

Figure B2.2: Average Windspeeds for July 14, 2017

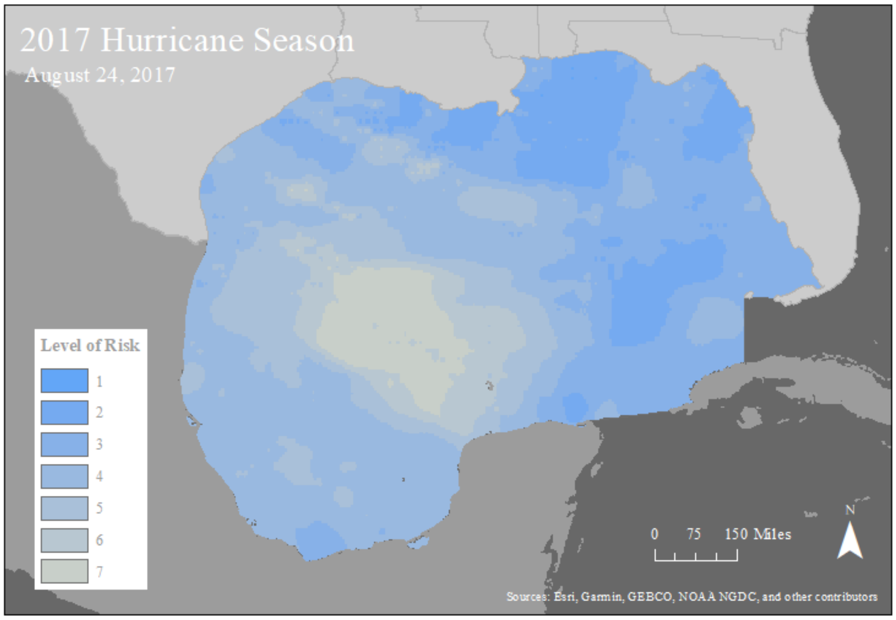

Figure B2.3: Average Windspeeds for August 24, 2017

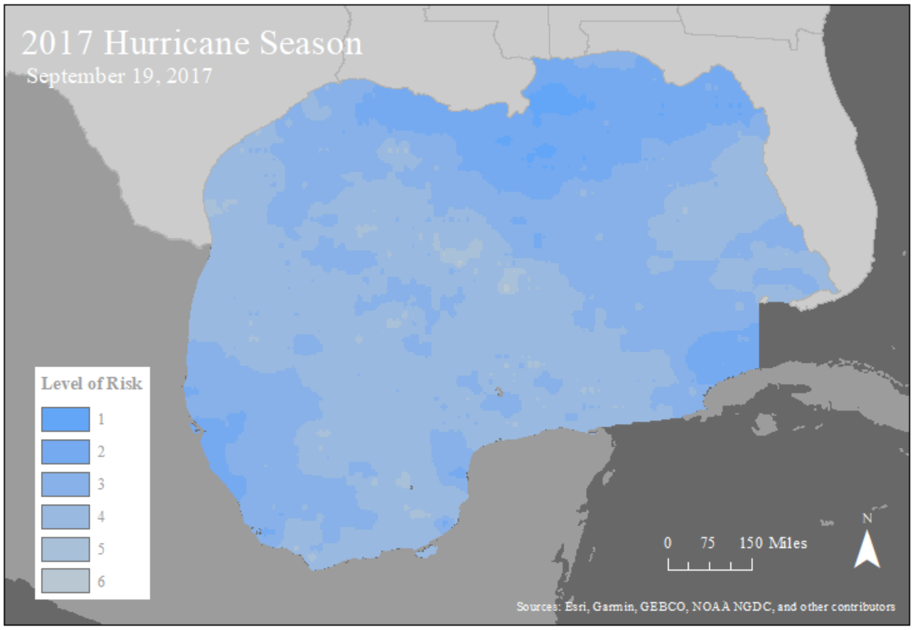

Figure B2.4: Average Windspeeds for September 19, 2017

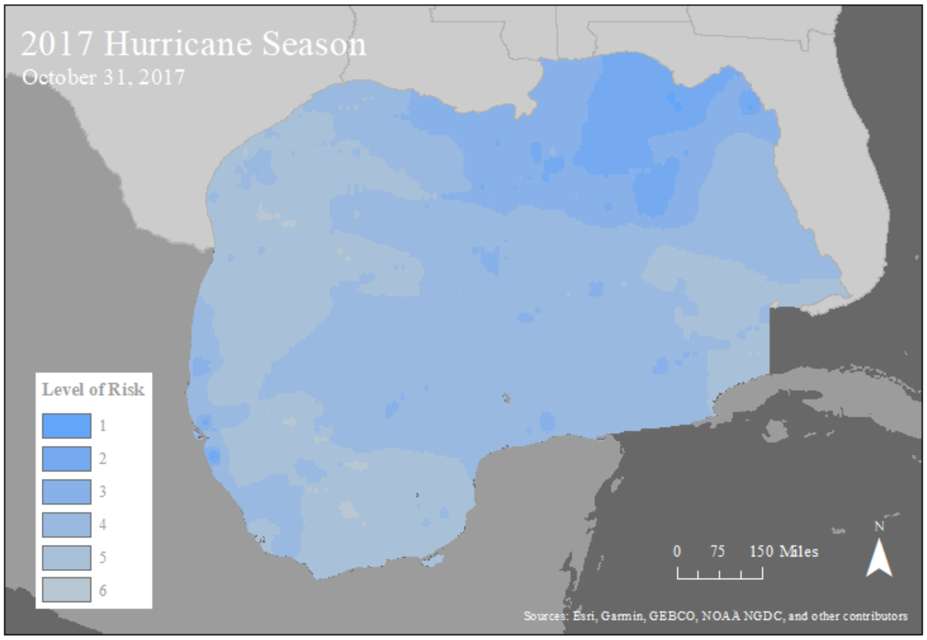

Figure B2.5: Average Windspeeds for October 31, 2017

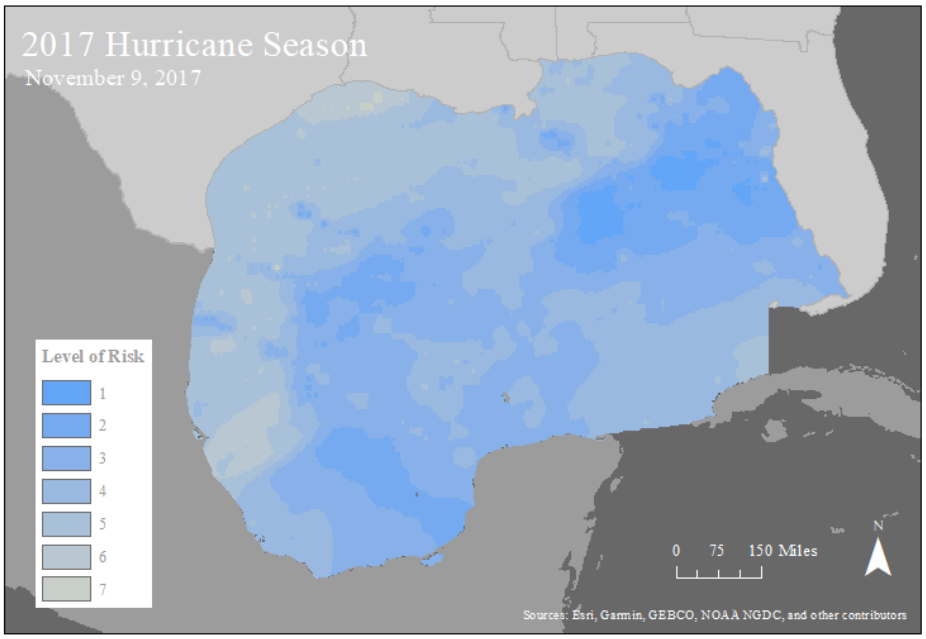

Figure B2.6: Average Windspeeds for November 9, 2017

GPM IMERG Final Precipitation L3
Hurricane Harvey

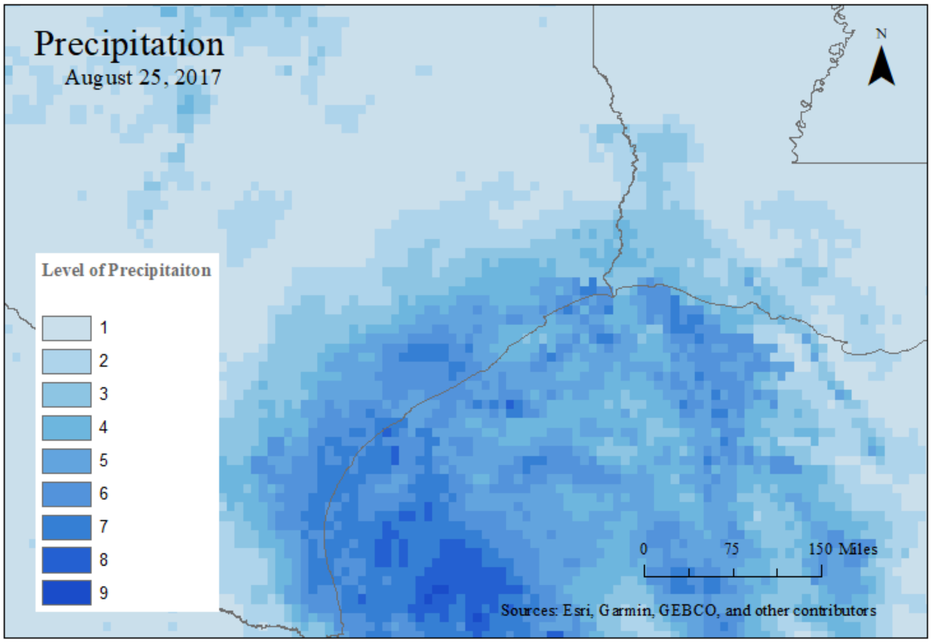

Figure B3.1: Precipitation Map for August 25, 2017

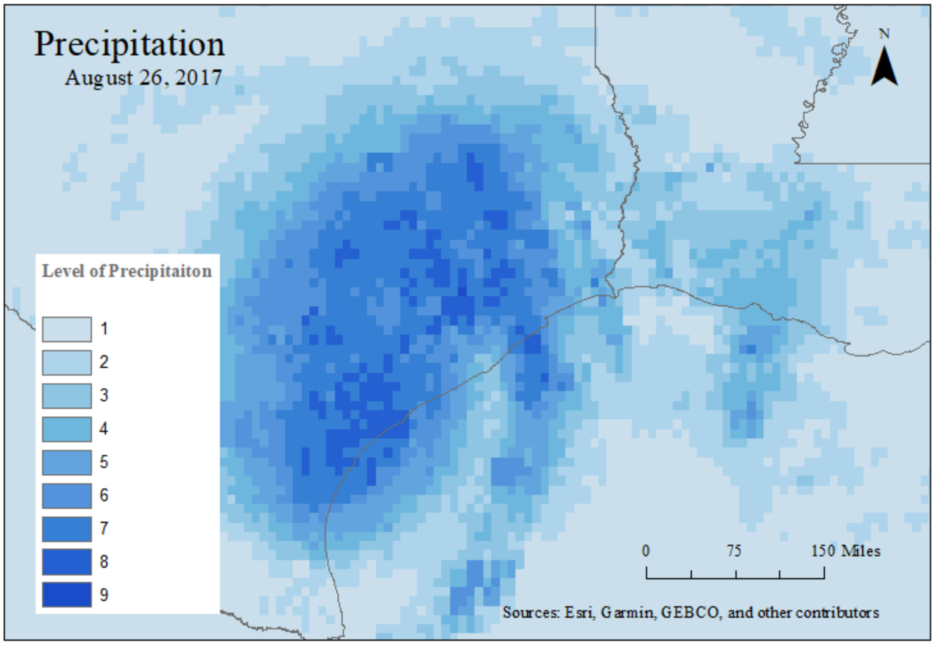

Figure B3.2: Precipitation Map for August 26, 2017

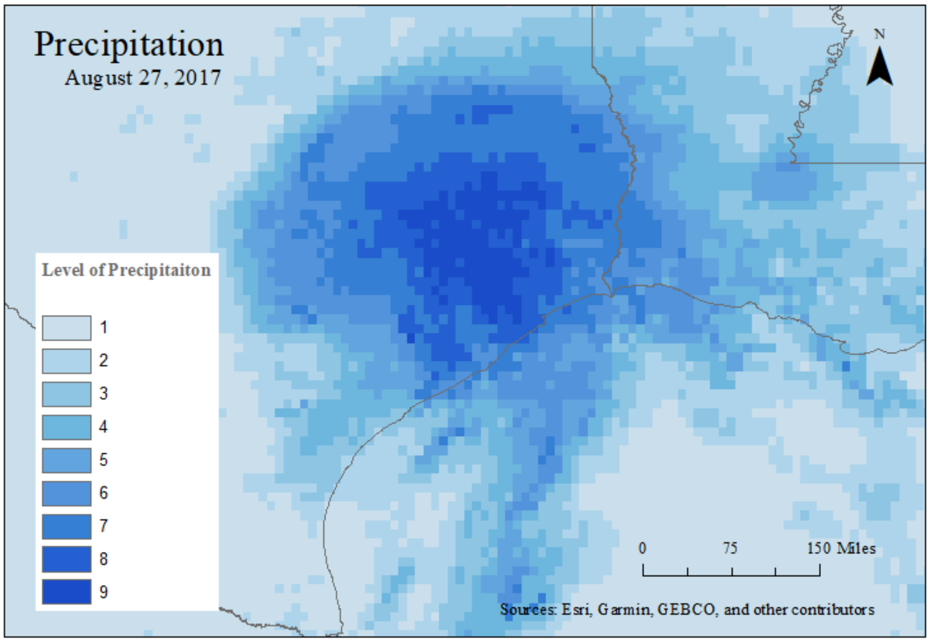

Figure B3.3: Precipitation Map for August 27, 2017

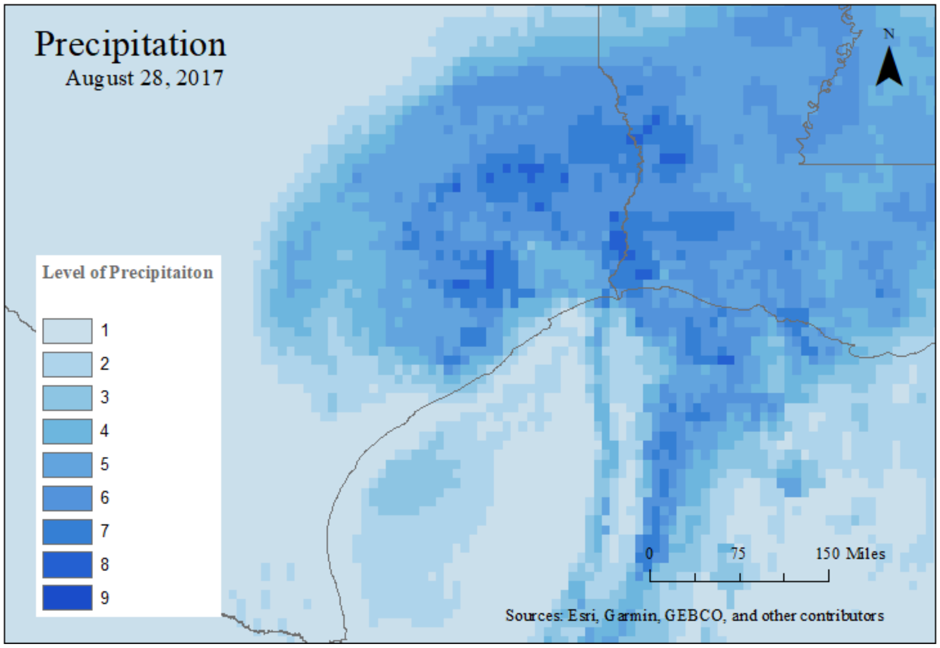

Figure B3.4: Precipitation Map for August 28, 2017

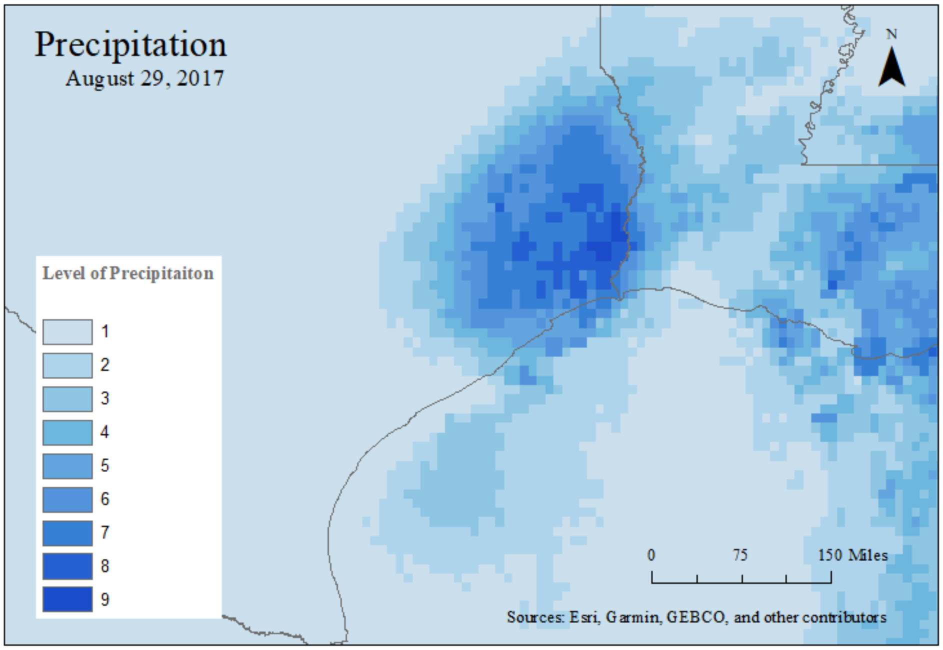

Figure B3.5: Precipitation Map for August 29, 2017

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Robert Griffin <reg0005@uah.edu> Wed, Apr 15, 2020 at 3:26 PM
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All,

Please accept this email as my approval for Ms. Blankenship's honors capstone. Let me know if you have any questions or if I have to do anything else.

Thanks.
-Rob

--
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