How has typhoon intensity changed in the Philippines region over time?

A Case Study of Typhoon Haiyan

I. Abstract

Locally known as "typhoons", the Philippines region has an extensive history of tropical cyclone activity, with some reports dating back to the 16th century. A specific case of tropical cyclone activity in the Philippines region is Typhoon Haiyan in 2013, which formed over the western Pacific, and under extremely favorable ocean and atmospheric conditions, rapidly strengthened into one of the most intense typhoons ever recorded on Earth, and within three days since formation, made landfall over the Philippines, leaving widespread damage and casualties in its path.

II. Introduction

Tropical cyclones are low-pressure systems that under the right conditions, can grow to be massive storms capable of causing destruction and economic loss (Ribera et al. 2005). These massive storms can form over warm oceans where sea surface temperature exceeds 26.5ºC. There are several factors that influence tropical cyclone development and strength, including but not limited to SST, vertical wind shear, and thermodynamic instability (Ho et al. 2004), and under the right conditions, tropical cyclones can undergo rapid intensification (RI), with one-minute sustained winds increasing at least 30 knots every 24 hours (Wang, Zhou et al. 2008).

There are several names associated with tropical cyclones. In the Atlantic and Northeast Pacific basins, once a cyclone surpasses a certain strength, they are they are known as "hurricanes", while in the Western Pacific, they are known as "typhoons". To classify cyclone strength, forecasters use intensity scales, which vary across each basin. While the names can vary by basin, criteria are very similar. Typically, a storm exhibiting circulation, but with wind speeds less than 55 km/h (35 mph) are known as “tropical depressions”. Cyclones with wind speeds between 55-120 km/h (35-75 mph) are known as “tropical storms. Cyclones with wind speeds above 120 km/h (75 mph) are classified as “hurricanes” or “typhoons”. In the western Pacific, the criteria for a “super typhoon” varies by agency. The Japan Meteorological Agency (JMA) classifies super typhoons with wind speeds above 195 km/h (120 mph), while the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) classifies super typhoons with wind speeds above 220 km/h (140 mph).

The region of focus in this paper is the Philippines region of the Northwest Pacific, where more frequent and intense tropical cyclones occur compared to any other ocean basin. The average number of tropical cyclones that form in the region in a single year is around 27, with most of them forming between June and October (Ho et al. 2004). In 2013, the Philippines was struck by Super Typhoon Haiyan, one of the most intense tropical cyclones to form on the planet, and the most intense typhoon to make landfall over a populated area. At landfall, Haiyan produced a peak wind gust of 325 km/h (90 m/s; 200 mph) and had a minimum central pressure of 895 mb. This resulted in over 90 billion Philippine Pesos ($2 billion USD) in damages, thousands of casualties (including 6000+ fatalities, 1800+ missing, and 27,000+ injuries), and left tens of thousands of people homeless (Mori et al. 2014, Nakamura at al. 2016).

III. Tropical Cyclone History in the Philippines Region

a. Tropical Cyclones in the Philippines Region

The Philippines Region has an extensive history of tropical cyclone activity. Using Selga’s chronology, Ribera et al. 2005 found that between 1901 and 1934, roughly a third of tropical cyclones that formed in the basin passed near or over the Philippines (Figure 1). According to the Philippine Atmospheric, Geophysical, and Astronomical Services

Administration (PAGASA), this is due to the geographical location of the region, as tropical cyclones that form in the western Pacific tend to form closer to the equator and move west towards the Philippines.

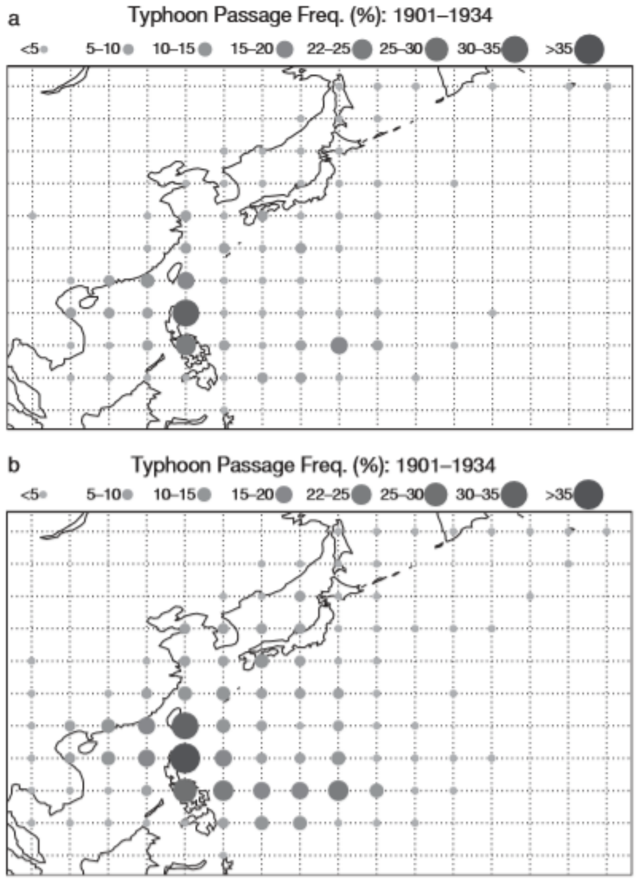

Figure 1. Geographical distribution of typhoon frequency from Selga's chronology (a), and using reconstructed trajectories (b) (Ribera et al. 2005)

b. Tropical Cyclone History (1566-1934)

I. Tropical Cyclone Frequency

Garcia-Herrera has determined that the number of typhoon reports has increased since the 16th century, although there is an annual fluctuation in typhoon reports, with some years yielding more reports, and others yielding fewer reports (Figure 2). Most of the reports come from ships out at sea, maps, and reports from locals in the area at the time (Garcia-Herrera et al. 2007).

Between 1566 and 1715, there was an average of less than one typhoon report per year, with several gaps – years where no tropical cyclones were reported. Meanwhile, there are a few noticeable spikes, where more than one tropical cyclone was reported. The most noticeable spikes occurred in 1596, with two tropical cyclones reported, one of them a typhoon; in 1630 and 1640, with two tropical cyclones reported, both of them typhoons; in 1660, with three tropical cyclones reported, all typhoons; and around 1710, with three tropical cyclones reported, two of them typhoons. Between 1716 and 1865, there is a minor increase in tropical cyclone reports with the average being between one and three tropical cyclone reports each year, with a smaller number of gaps present, and a noticeable peak in this graph, around 1865, with seven tropical cyclone reports made that year, all of them typhoons. Between 1866 and 1900, there was a gradual increase in tropical cyclone reports, particularly after 1881. Prior to 1881, the average was around five tropical cyclone reports. The peak during this period was in the late 1860s and early 1870s, with the average being around ten tropical cyclones, around eight of them typhoons. Starting in 1881, the number of tropical cyclone reports began to increase considerably, with the average being around 20 tropical cyclone reports per year, with a few peaks around 1886. 1891, 1893, and 1894, where more than 30 tropical cyclones were reported each year, with about 25 of them being typhoons (Garcia-Herrera et al. 2007). Overall, there is an increase in typhoon activity in the Philippines region between 1566 and 1900. (Figure 2)

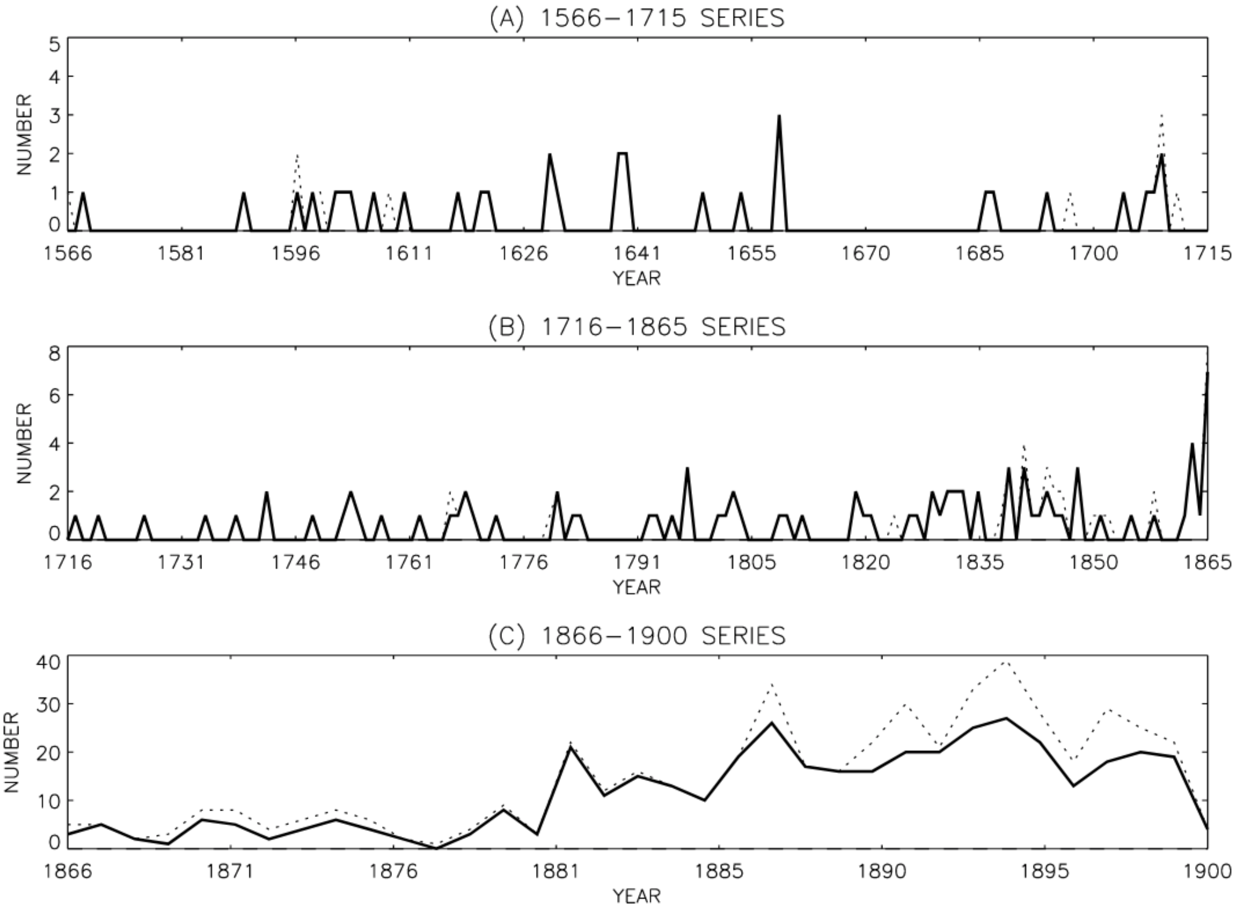

Figure 2. Annual frequency of tropical storms over the Northwest Pacific from (a) 1566-1715; (b) 1716-1865, and (c) 1866-1900. Solid line represents typhoons only, and light dotted line represents all tropical storms (Garcia-Herrera et al. 2007).

II. Typhoon Landfalls

Between 1866 and 1934, there is increase in typhoon landfalls across the region. Between 1866 and 1900, there was an average of five typhoon landfalls, with a noticeable peak around 1881, with twelve landfalls. Between 1900 and 1934, there was an increase in typhoon landfalls compared to the previous time period, with an average of roughly eight landfalls. There are a couple noticeable peaks, particularly 1911, where there were fifteen landfalls (Figure 3).

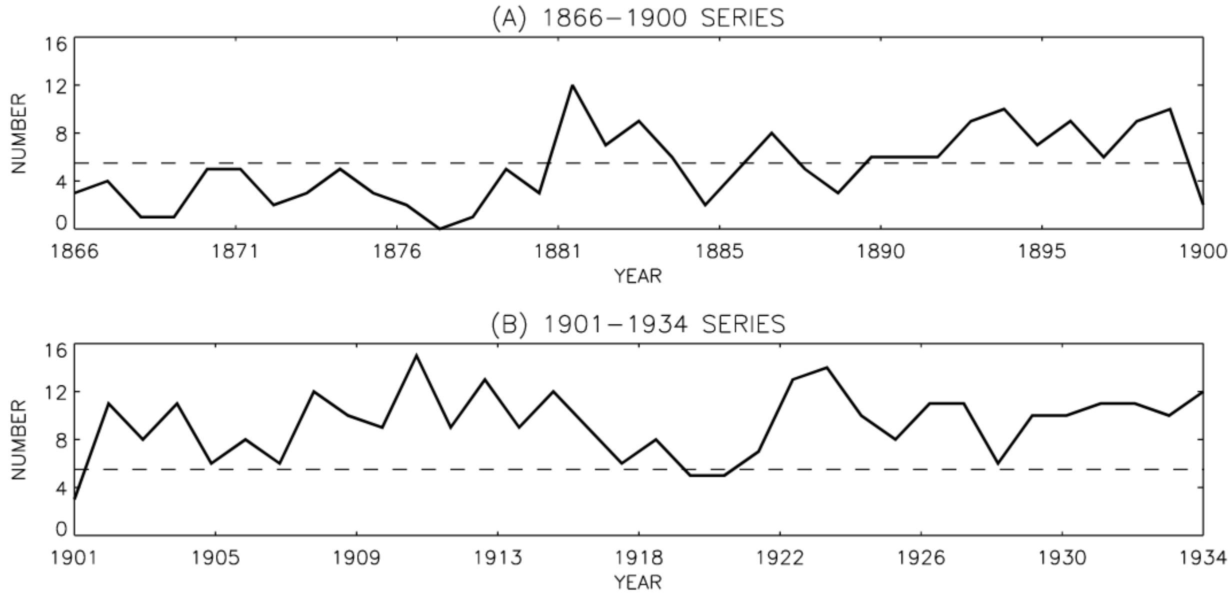

Figure 3. Annual frequency of typhoons land falling in the Philippines from (a) 1866-1900; (b) 1901-1934 (Garcia-Herrera et al. 2007).

c. Current Tropical Cyclone Trends

Between 1951 and 2001, there is a considerable increase in typhoon formation in the Northwest Pacific compared to the previously mentioned period between 1566 and 1900 (Ho et al. 2004). While there is an increase in typhoon formation, there is also a lot of annual variability, with some years producing more typhoons, and other years producing few. The typical year yields roughly 20 typhoons, although there are a few noticeable peaks, where 25 or more typhoons formed. The most noticeable peaks are between 1964 and 1967, when around 30 typhoons formed. There is also a noticeable low point in the late 1990s, when only 10 typhoons formed. One thing that seems to be consistent for most years is the fact between half and a majority of typhoons that form each year form during the summer and early fall months (Figure 4).

Estimations already show that tropical cyclones have become more frequent and stronger in the past thirty years (Takayabu et al. 2015).

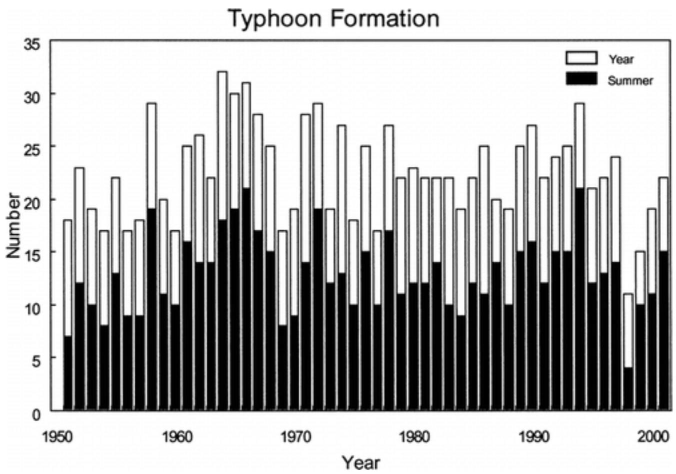

Figure 4. Number of typhoons formed annually and during the summer months over the Northwest Pacific from 1951-2001. (Ho et al. 2004)

IV. Meteorological History of Typhoon Haiyan

a. Formation and Rapid Intensification

Typhoon Haiyan of 2013 was the most intense typhoon in recorded history to make landfall over a populated area, causing millions of dollars in damage, as well as thousands of casualties (Mori et al. 2004). In order to better understand how Haiyan grew to be so large, it's a good idea to look back at its meteorological history, beginning at formation, focusing specifically on the conditions present in the Pacific that allowed the system that would become Haiyan to not only form, but to flourish.

Haiyan began on 02 November 2013 as a broad area of low pressure in the western Pacific, which within a day, gained enough strength to become a tropical depression. On 04 November at 00:00 UTC, the depression intensified into a tropical storm, and was given the name Haiyan (Soria et al., 2016, Mas et al., 2015). One key ingredient in the formation of powerful cyclones is warm ocean water, which transfers heat to higher altitude, fueling the storm. The sea surface temperature (SST) where Haiyan formed was 30 degrees Celsius (86 degrees Fahrenheit), which is ripe for tropical cyclone formation. The second key ingredient in powerful cyclones is wind shear, which is the difference in wind speeds between surface and higher altitudes, which can stunt the growth of tropical cyclones. There was very little wind shear involved with Haiyan, which allowed the storm to move harmoniously at all levels (Galvin 2013).

The combination of warm SST, and low wind shear extended uninterrupted across the Western Pacific towards the Philippines, which allowed Haiyan to develop rapidly within 24 hours, becoming a typhoon by 05 November. By the next day, on 06 November, Haiyan had strengthened into a Category 5-equivalent super-typhoon and continued to intensify steadily until it reached peak intensity. The peak intensity was around 895 mb, estimated by the Joint Typhoon Warning Center (JTWC) and Japan Meteorological Agency (JMA) using cloud patterns on visible and Infrared satellite images (Soria et al. 2016, Mas et al. 2015).

Below are two figures that demonstrate the sheer strength of this typhoon. A NOAA satellite image shows Haiyan at its peak strength just before landfall, as indicated by the presence of large amounts of water vapor (Figure 5). Takagi et al. 2014 created two simulations showing wind vectors (which indicate wind speed), and pressure (indicated by the colors). It is shown that Haiyan had a very strong counterclockwise rotation, and as well as a very high pressure drop, with the pressure in the center having dropped over 100 hPa (100 millibars) (Figure 6).

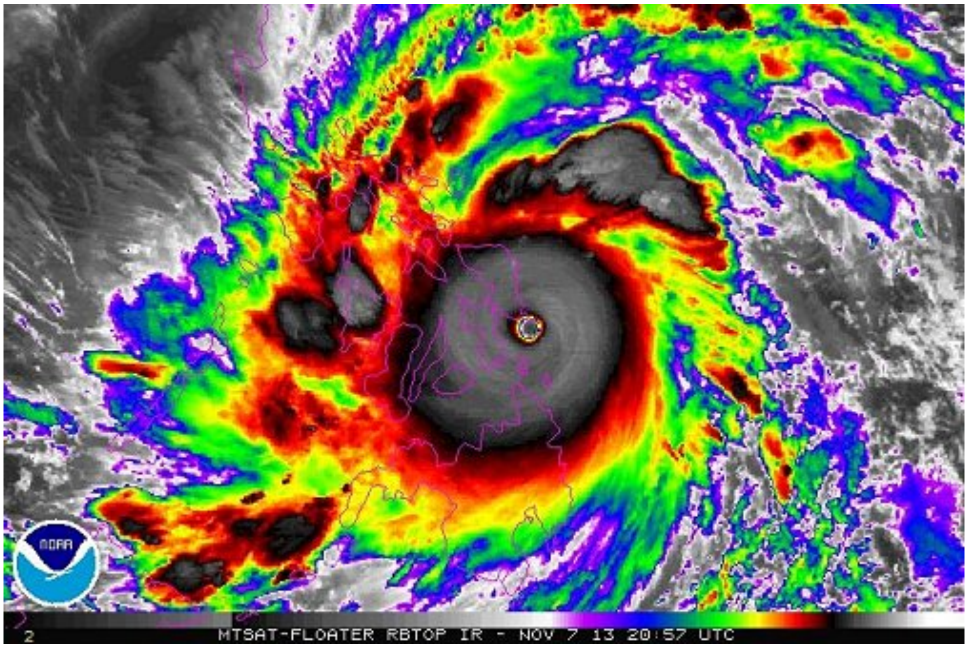

Figure 5. Satellite image of Super Typhoon Haiyan off the coast of the Philippines on 07 November 2013. Colors represent the amount of water vapor in the atmosphere. (NOAA)

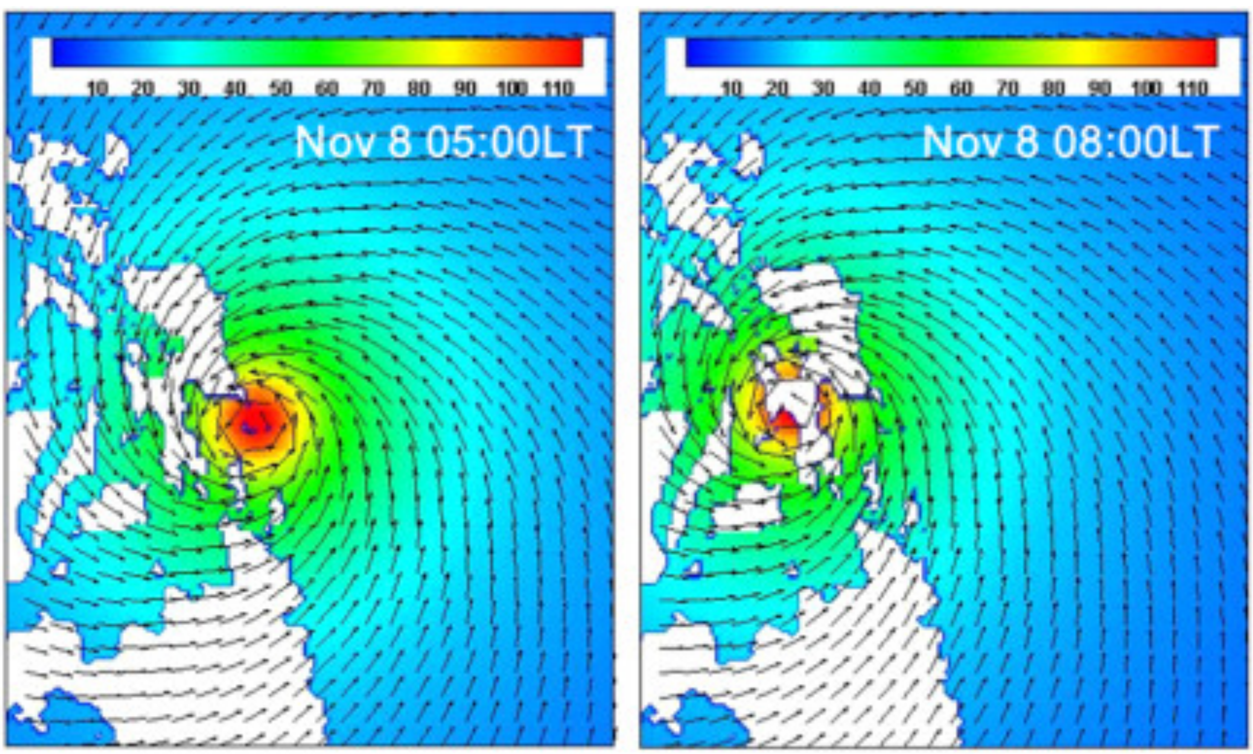

Figure 6. Simulated wind vector plot (wind directions) and pressure drops (color contour in hPa). Left: Haiyan makes landfall. Right: Largest storm surge at Tacloban (Takagi et al. 2014).

VI. Landfall over the Philippines and Impacts

On 08 November at 04:00 Philippine Time (PHT), a PAGASA doppler radar located in Guiuan indicated that Haiyan reached a minimum pressure of 910 mb, and winds of 160 km/h. The radar was destroyed about 15 minutes later by extreme winds as Haiyan crossed several small islands nearby. The main landfall occurred south of Tolosa around 07:00 PHT, followed by four subsequent landfalls (Soria et al. 2016). It was around this time when storm surge of 6 to 9 meters (20-30 feet) started to inundate at Leyte and Samar islands, and the highly populated city of Tacloban, washing away houses on the coast. There is video footage online of storm surge striking the city in a similar fashion to a tsunami – fast and destructive. A pair of satellite images obtained by Mas from Google Earth shows the widespread destruction that occurred along the coast of Tacloban city (Figure 7).

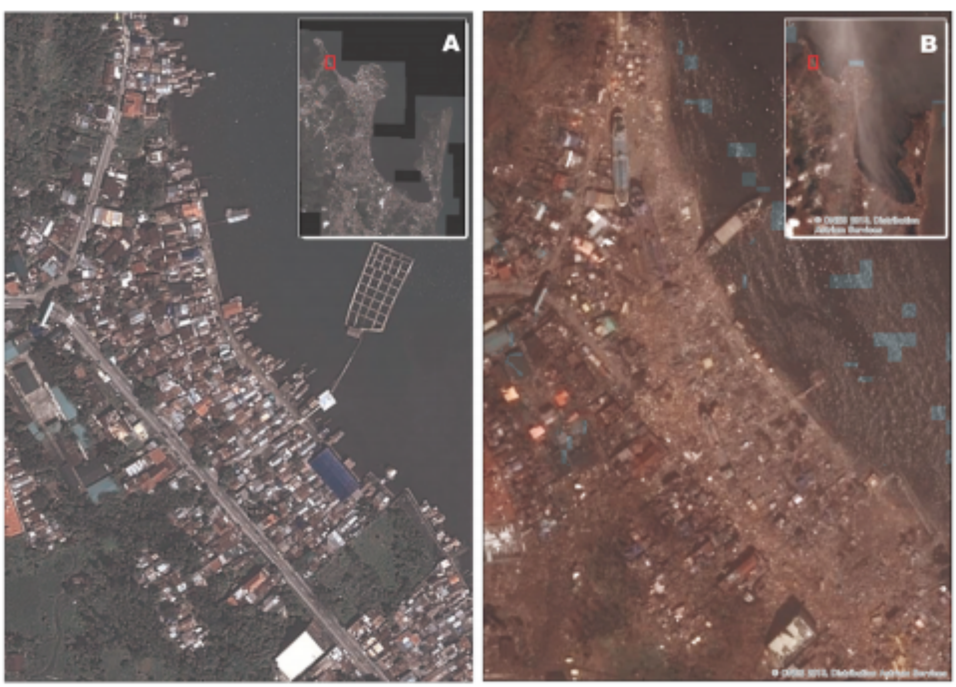

Figure 7. Pre-event (a) and post-event (b) satellite images obtained from Google Earth show widespread damage. Imagery date for (a) is 23 February 2012, and for (b) is 13 November 2013 (Mas et al. 2015).

A news article from The Weather Channel (TWC) published a month after Haiyan reported that entire blocks were washed away by storm surge, with little infrastructure remaining, and power was knocked out across the city – and in large swaths, still not available yet a month later. In the aftermath, the local government of Tacloban was unable to respond to cries for help because the damage was so severe, and people were reported breaking into shops, homes, and gas stations because of a lack of food (Kellogg, Becky 2013, TWC). In addition to news reports and satellite image, photos obtained from Soria (Figure 8) show catastrophic damage along the San Pedro Bay from storm surge and extreme winds from Haiyan (Soria et al. 2016).

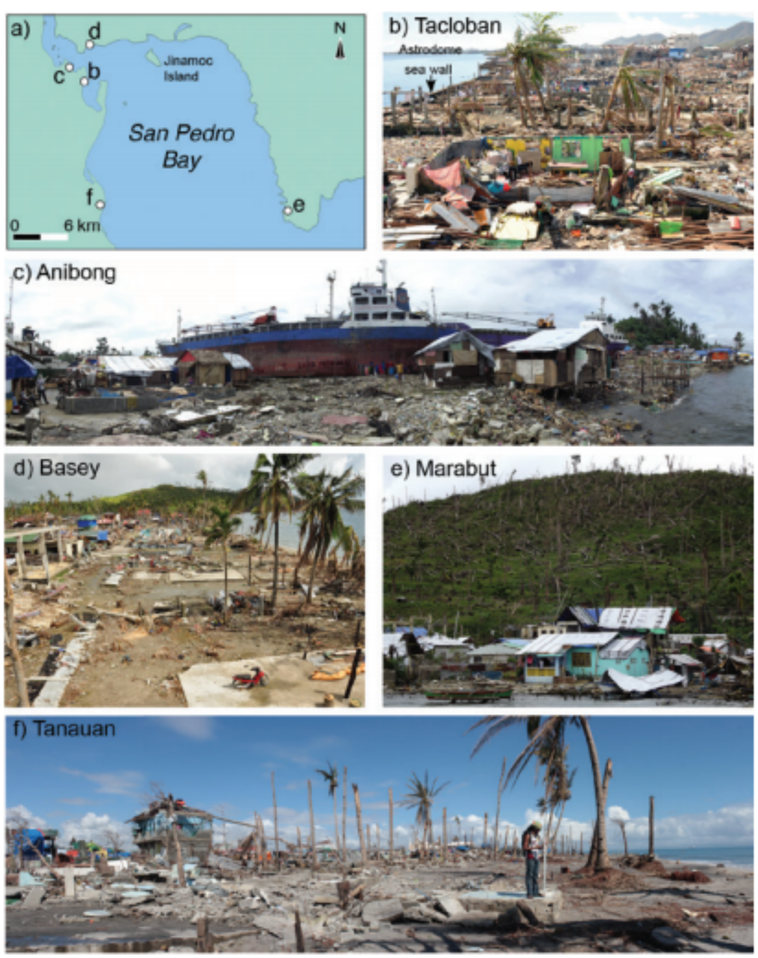

Figure 8. Photos of storm damage from locations around the San Pedro Bay (a). Most structures along the coast were destroyed by storm surge in (b) Tacloban, (c) Basey, and (f) Tanauan. (b) Houses are rebuilt in Anibong Village. (e) Wind damage in Marabut. (Soria et al. 2016).

In the aftermath of the storm, one of the many questions in the minds of scientists and researchers around the world is why Haiyan was so deadly. According to an article obtained from Phys.org, the typhoon was deadly because of low lying islands, inadequate warning, extreme poverty, and failure to evacuate. The Philippines is home to several islands, where sea level is only a few meters at most, that were in the path of Haiyan. The city of Tacloban sits less than five meters above sea level, leaving it defenseless against the storm surge. While there was early warning in these areas, there was a lack of education on the part of public officials that resulted in victims not being familiar with the term "storm surge", and to make matters more complicated, there are scores of regional languages in the area, which made it impossible for the government to communicate properly about the incoming storm surge. In other words, there was not a single term used to describe storm surge. As a result of extreme poverty, many homes were built on coastal plains of cheap materials, where residents lived off fishing and farming, which were also defenseless, resulting in 1.4 million homes destroyed by Haiyan. Finally, local authorities failed to evacuate much of the population from the coastline. The article mentions that part of this is because the people underestimated the threat, and the other part is the lack of shelters for evacuees. Many families along the coast who tried to ride out the storm were wiped out by storm surge (Morella, Cecil 2018).

VII. Discussion/Conclusion

How has typhoon intensity changed in the Philippines region over time? Using ensemble simulations, Takayabu found that Typhoon Haiyan is a case scenario of tropical cyclone intensity increasing over time, and they were able to come to this conclusion by creating simulations for Typhoon Haiyan, and for a hypothetical natural event without human influence (i.e. fossil fuel burning, etc.), and comparing them. They found that the conditions created by Haiyan were *worse* than the conditions created by the hypothetical storm – with 15 of 16 simulations showing Haiyan exceeding the intensity of any worst-case natural scenarios, as well as a 20% increase in storm surge height (Takayabu et al. 2015). Looking back to Section 4, which involves the formation and rapid intensification of Haiyan, Section 1, which discusses previous tropical cyclone trends, and using the conclusion found by Takayabu for support, we can conclude that tropical cyclone frequency has in fact changed over time, as well as tropical cyclone intensity. Using Takayabu's study, we can also tie this increasing trend in typhoon frequency and intensity with anthropogenic warming (i.e. climate change) that has been occurring since 1750, with the increase of sea-surface temperature in the western Pacific at the time of formation, which in turn resulted in one of the most intense tropical cyclones to ever form. It can also be speculated that if climate change cannot be curbed quick enough, more Haiyan-like storms will form, and it's only a matter of time before one forms in the Atlantic.

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