The Effects of the El Niño Southern Oscillation on Typhoon Landfalls in the Western North Pacific

White Paper

October 15, 2015

Risk Management Solutions, Inc.

7575 Gateway Boulevard, Newark, CA 94560 USA
http://support.rms.com/

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Contents

Introduction

The western North Pacific Basin is the most active tropical cyclone basin on Earth, with an average of almost 27 tropical cyclones developing every year. The basin has produced some of the most intense tropical cyclones on record, with the highest sustained wind speed, heaviest rainfall and lowest central pressure records belonging to typhoons that formed in the western North Pacific. Although typhoons can form in the western North Pacific throughout the year, the peak typhoon season is between July and October.

Several nations in eastern Asia are at risk from the hazards posed by typhoons in the western North Pacific. Of these, China receives the most tropical cyclone landfalls overall, while the Philippines is subjected to the highest number of strong typhoons. Japan also experiences several landfalls per year on average, both on the mainland and outlying islands. Tropical cyclones also regularly affect Taiwan, Vietnam, the Pacific Island of Guam, and the Korean peninsula.

Natural variances in climatic conditions associated with periodic El Niño and La Niña events affect weather patterns around the globe, including the morphology of typhoons in the western North Pacific. Various studies describe the changes in typhoon genesis location, intensity and track direction during the warm and cool phases of the El Niño Southern Oscillation (ENSO). This study investigates the effect of ENSO on typhoon landfalls in the western North Pacific Basin. Additionally, it discusses the impact of changes to landfall rates due to El Niño and La Niña on modeled typhoon losses modeled using the RMS typhoon models for Japan, China, and Guam.

The El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) is a naturally occurring phenomenon that involves fluctuations in sea surface temperatures in the tropical Pacific Ocean. The term *El Niño* applies to the warm phase of ENSO, when sea surface temperatures (SSTs) in the central and eastern Pacific are higher than usual. Conversely, *La Niña* applies to the contrasting cold phase during which SSTs are lower than normal. Neutral conditions, when the SST is within 0.5°C of the average, occur in the transitional periods between warm and cold phases of ENSO. The oscillations tend to occur on irregular time scales ranging between two and seven years, with an average period length of five years.

The different phases of ENSO arise due to variations in the strength of the *Walker circulation* across the Pacific Ocean. The pressure gradient between high pressure over the eastern Pacific Ocean and low pressure over Indonesia drives the Walker circulation. This gradient makes trade winds blow from east to west, causing warm water to pool in the western Pacific, and colder water to upwell in the east, close to the coast of South America. During El Niño conditions the Walker circulation weakens or reverses, causing a band of warmer than average sea surface temperatures to develop in the central and eastern Pacific (Figure 1). In contrast, during La Niña conditions the Walker circulation strengthens, resulting in increased upwelling and cooler waters in the eastern central Pacific.

The National Oceanic and Atmospheric Administration (NOAA) defines a standard of measure, the Oceanic Niño Index (ONI) which normalizes the sea surface temperature (SST) conditions to a base average SST that spans the period 1971-2000. This index defines an El Nino event as a positive SST departure from normal, greater than or equal in magnitude to 0.5°C in the Niño 3.4 region, averaged over five consecutive three-month periods. Conversely, La Nina conditions occur when the SST departure from normal is greater than or equal to -0.5°C.

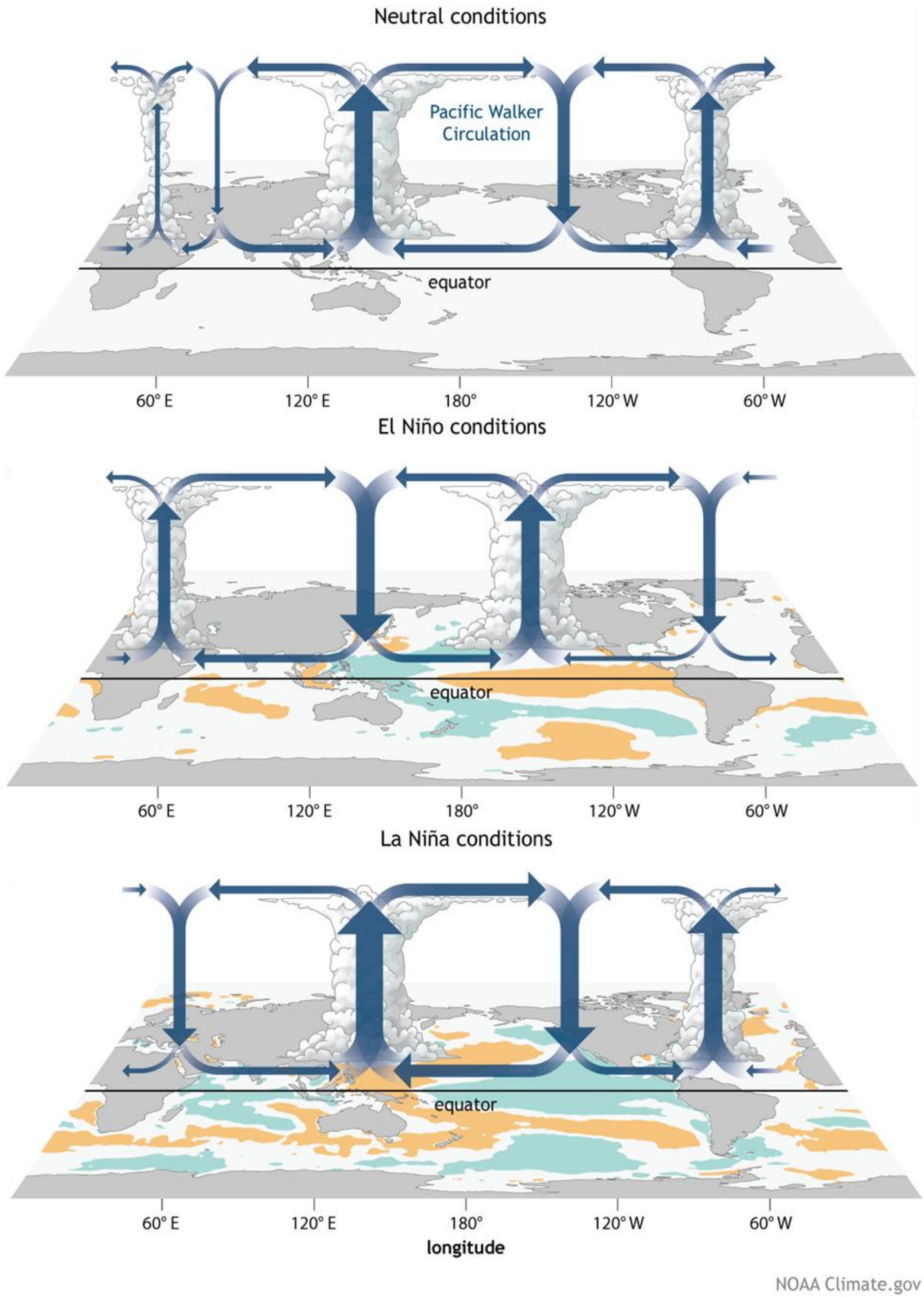
El Niño and La Niña events affect temperature and rainfall patterns throughout the globe. During El Niño conditions, the west coast of South America experiences increased rainfall, the northern United States experiences warmer and drier conditions, while southern United States and Mexico are cooler and wetter, particularly during the winter months. The effects are also felt across the Pacific Ocean, where dry conditions persist across Southeast Asia and Australia, and east China and Japan experience milder winters.

In contrast, during La Niña events, the coastal regions of Peru and Chile experience droughts, while higher than average precipitation falls in the central Andes region. In North America, rainfall increases in the Midwest, whereas precipitation in the southwest and southeast states decreases. Southeast Asia is warmer and wetter throughout the year, but southern Africa sees wetter and colder conditions.

The ENSO also affects the genesis and pathways of tropical cyclones in the Atlantic and Pacific basins. In El Niño years, increased vertical wind shear depresses cyclone activity in the tropical Atlantic, resulting in fewer hurricanes affecting the eastern United States and Caribbean (see the *2015 North Atlantic Hurricane Season Outlook* for further detail). At the same time, the Pacific basin east of the date line experiences above average activity, due to warmer SSTs and decreased wind shear.

La Niña conditions reverse this pattern, with increased hurricane activity in the Atlantic and fewer cyclones in the eastern Pacific.

Figure 1: Changes in the Walker Circulation During El Niño and La Niña Conditions—Source: NOAA



The Effects of ENSO on Typhoons in the Western North Pacific

In the tropical western Pacific, several studies document the effects of the El Niño Southern Oscillation (ENSO) on typhoons. The shifts in atmospheric pressure gradients and dominant wind patterns, and the anomalies in sea surface temperatures caused by the different phases of ENSO combine to influence the genesis location, preferred tracks, intensity, and overall number of tropical storms in the western North Pacific.

The main cyclogenesis region in the western North Pacific is influenced by interannual variations in the monsoon trough (Wu, et al., 2004). Due to the weakening of the Walker circulation system over the Pacific Ocean during El Niño conditions, the monsoon trough extends eastward from its usual position around 150°E to reach 170°E. This eastward displacement, coupled with increased SSTs in the central and eastern Pacific, results in an eastward shift in the main cyclogenesis region (Chu, 2004). In addition, Camargo et al. (2007) suggests that variations in several other environmental factors, including wind shear, vorticity, relative humidity, and potential intensity, also influence the genesis potential of typhoons throughout the Pacific Basin during El Niño events.

During the late season of El Niño years, the subtropical ridge splits into two separate cells at approximately 130°E. As the genesis of typhoons shifts eastward during an El Nino event, the systems have an increased tendency to recurve away toward higher latitudes following the break in the subtropical ridge, which favors landfall along the Japanese archipelago and Korean peninsula (Elsner and Liu, 2003). Areas west of Japan tend to experience fewer typhoon impacts during El Niño years, particularly later in the season between September and November (Wu, et al., 2004).

The eastward shift in cyclogenesis during El Niño also increases the time and distance a typhoon travels over water before making landfall. Combining this effect with above average SSTs provides more energy for tropical cyclone development in El Niño years, and thus the potential to obtain greater intensities than in neutral ENSO conditions. By investigating the relationships between ENSO and Accumulated Cyclone Energy (ACE), Camargo and Sobel (2005) noted that there is a large tendency toward higher ACE during El Niño years. This increase in ACE tends to be concentrated in the region to the east of the Philippines and East China Sea.

The total number of recorded cyclone days is also markedly higher during El Niño years, although this is due to the increased travel time of tropical cyclones as opposed to a greater number of storms overall (Lander, 1994; Chu, 2004). Indeed the frequency of tropical cyclones formation within the entire western North Pacific Basin does not vary significantly from year to year, irrespective of ENSO conditions (Wang and Chan, 2002).

Contrastingly, during La Niña years, typhoon activity in the western North Pacific is directed by the strengthening of the Walker circulation and below average SSTs in the central and eastern Pacific. The monsoon trough retreats westward to 135°E and the subtropical ridge strengthens, shifting the main cyclogenesis region westward toward the Philippines and the South China Sea, and forcing the majority of tropical cyclones to track directly westward toward the Asian continent. This increases the landfall risk to southern China, the Philippines, and Vietnam relative to neutral years (Wu et al., 2004). The reduced travel time and distance prior to landfall leads to fewer intense typhoons, but a larger number of cyclones with tropical storm intensity (Camargo and Sobel, 2005).

Many previous studies of the effects of ENSO on tropical cyclones in the western North Pacific have focused on the shift in cyclogenesis regions and tropical storm intensity. Few studies have explicitly investigated the impact of ENSO phases on tropical cyclone landfall patterns.

Study of Typhoon Landfall Rates during ENSO Events

The RMS study on the effects of ENSO on the landfall rates of tropical cyclones in the western North Pacific focuses on the regions for which RMS either has existing or planned typhoon catastrophe models (Figure 2). These regions include Japan, China, and the U.S. territory of Guam, for which RMS has existing models, and South Korea, Taiwan, the Philippines, and Vietnam, for which future models are planned.

Figure 2: Countries in the Western North Pacific Basin for Which RMS has Existing or Planned Typhoon Models

Data Sources

Track Data

This study uses historical storm tracks between 1951 and 2011 from the Japan Meteorological Agency (JMA) and the Joint Typhoon Warning Centre (JTWC). RMS used an in-house conversion factor to convert the maximum wind speed reported by JMA from a 10-minute averaging time to a one-minute averaging time. This conversion enables RMS to derive the Saffir-Simpson Category for each storm using the resulting one-minute average maximum wind speed before landfall, which is the basis of the Saffir-Simpson scale. JTWC typhoon wind speeds were used for storms before 1977, which are not recorded by JMA.

Sea Surface Temperature Data

NOAA provided a database of sea surface temperature (SST) anomalies from 1950 to 2014. The database contains the three month running mean of SST anomalies in the Niño 3.4 region based on centered 30-year base periods, which are updated every five years. NOAA defines warm and cold episodes as persistent temperature anomalies exceeding a threshold of ±0.5°C for five consecutive three month periods.

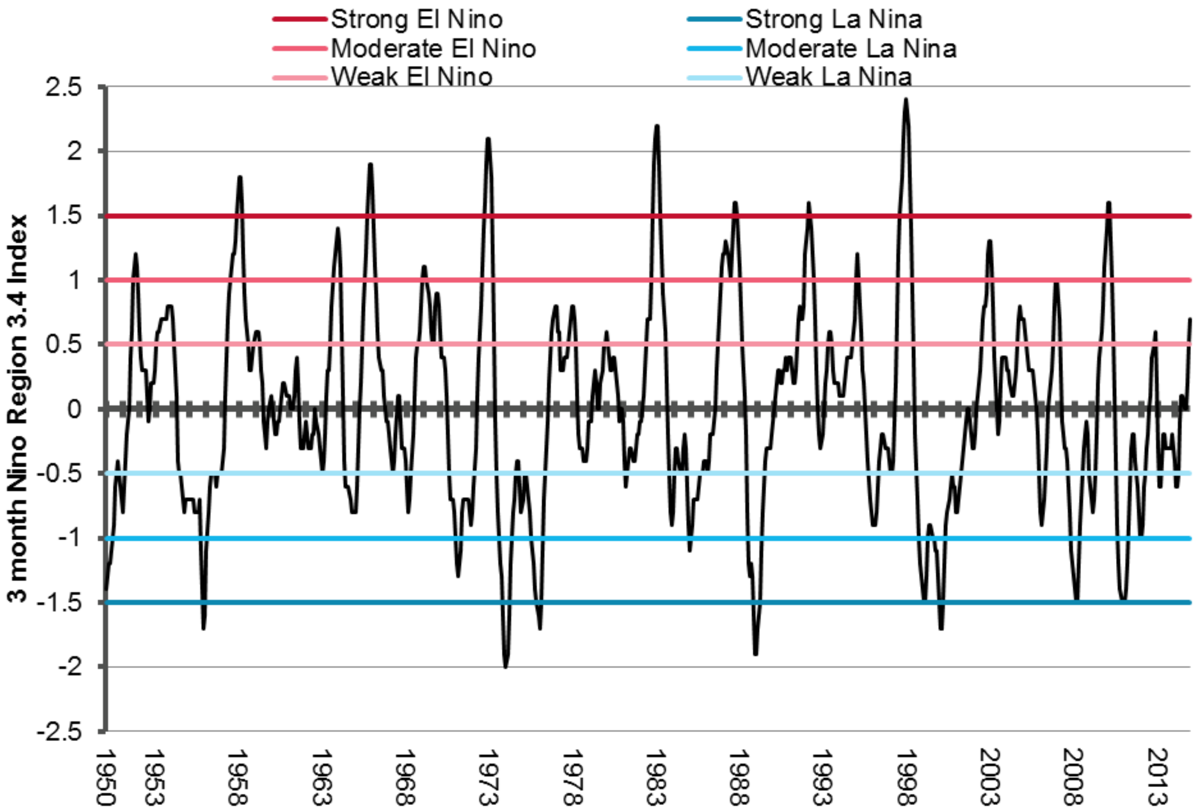
Methodology

Definition of ENSO Events

ENSO events can fall during any time of the year, but often tend to reach their peak during the Northern Hemisphere winter months. However, the peak typhoon activity in the western North Pacific occurs between July and October, with comparatively few tropical cyclones affecting the region over the winter months. Therefore, for this study, RMS defined El Niño and La Niña years as the years during which El Niño or La Niña conditions prevailed for five consecutive three month running periods including the months of July and October (MJJ to OND).

This method resulted in 14 El Niño years and 13 La Niña years between 1951 and 2011, with the remaining 34 years defined as neutral. Figure 3 highlights the El Niño and La Niña years on a graph of SST anomalies in the Niño 3.4 region. Although the SSTs also exceeded the required thresholds on some other years, in those cases either the SST variations did not endure for five consecutive three month periods or the SST thresholds were exceeded in months outside of the peak typhoon season.

Figure 3: SST Anomalies in the Niño 3.4 Region Between 1950 and 2014—El Niño (Red) and La Niña (Blue) Years Defined Using SST Anomalies During the Peak Typhoon Season, are Highlighted



Landfall Statistics

RMS defined coastal gates in the western North Pacific to determine the countries in which historical storms made landfall. For some countries, the gates extend slightly out into the sea to capture storms that pass within a close enough proximity to cause damage.

RMS used the following process to capture, for the 14 El Niño years, 13 La Niña years, 34 Neutral years, and for the entire historical storm track set between 1951 and 2011, historical landfall statistics for each gate:

- Link the database of JMA and JTWC historical storm tracks to the coastal gates, to determine the location, month, and year of storm landfalls, and the maximum wind speed at landfall.
- Use the maximum wind speed at landfall to determine the category of each typhoon on the Saffir-Simpson Hurricane Wind Scale.
- For typhoons making landfall in more than one country, record the landfall statistics for each country. For typhoons making more than a single landfall in one country, record only the statistics for the landfall with the highest maximum wind speed.

Results

Landfall Patterns

The historical track set contains 1,040 cyclone tracks that made landfall in one or more of the countries included in this study. Accounting for historical typhoons that made landfall in more than one country, there were a total of 1,436 landfalls between 1951 and 2011 across the study area. Table 1 displays the historical landfall statistics by country and Saffir-Simpson Category. The average number of storms per year includes tropical cyclones of all Saffir-Simpson categories, from “tropical storm” to “Category 5.”

Table 1: Number of Historical Typhoon Landfalls Per Country by Saffir-Simpson Category Between 1951 and 2011

Saffir-Simpson Category (1-Minute Sustained Wind Speed m/s)	China	Guam	Japan (Including Okinawa)	Japan (Mainland Only)	South Korea	Philippines	Taiwan	Vietnam
5 (≥70)	1	1	6	1	0	7	2	0
4 (59–69)	9	2	20	2	0	30	12	0
3 (50–58)	11	2	39	20	2	34	18	3
2 (43–49)	38	3	61	36	1	35	18	7
1 (33–42)	109	6	83	79	13	51	32	40
0 (18–32)	245	16	147	123	48	109	36	139
Total 1951–2011	**413**	**30**	**356**	**261**	**64**	**266**	**118**	**189**
Average per year	**6.77**	**0.49**	**5.84**	**4.28**	**1.05**	**4.36**	**1.94**	**3.10**

During the period between 1951 and 2011, China experienced the highest landfall rate of tropical cyclones with an average of 6.77 landfalls per year. The small island of Guam was subjected to the fewest tropical cyclones over the period. The average of 5.84 landfalls per year for Japan includes statistics for the Ryukyu Islands, where most of the strongest typhoon impacts to affect the country occurred. The Philippines experienced the highest number of strong Category 5 typhoons, whereas South Korea and Vietnam did not experience any typhoons with a category greater than 3 at landfall.

Figure 4 and Figure 5 are heatmaps, illustrating the density of genesis locations of tropical cyclones that go on to make landfall in the western Pacific. Comparing the two maps highlights the shift in cyclogenesis locations during El Niño and La Niña years. Figure 4 shows that the majority of landfalling typhoons that form during El Niño years develop to the south and southeast of Guam, between 140°E and 160°E, although a number of tropical cyclones form even further east than this as a result of warm sea surface temperatures in the Niño 3.4 region. By contrast, as seen in Figure 5, the main area of cyclogenesis during La Niña years is just to the east of the Philippines, around 130°E. Very few typhoons form east of 160°E during La Niña due to the cooler SSTs in the central Pacific.

Figure 4: Heatmap of Genesis Locations of Landfalling Tropical Cyclones in the Western Pacific During El Niño Years

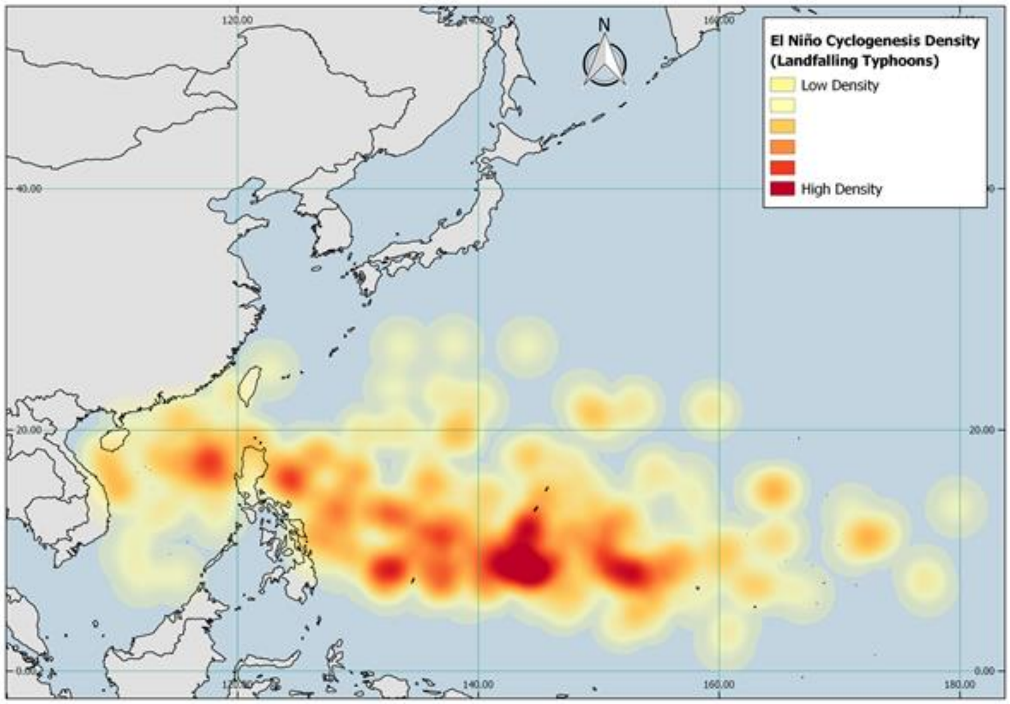


Figure 5: Heatmap of Genesis Locations of Landfalling Tropical Cyclones in the Western Pacific During La Niña Years

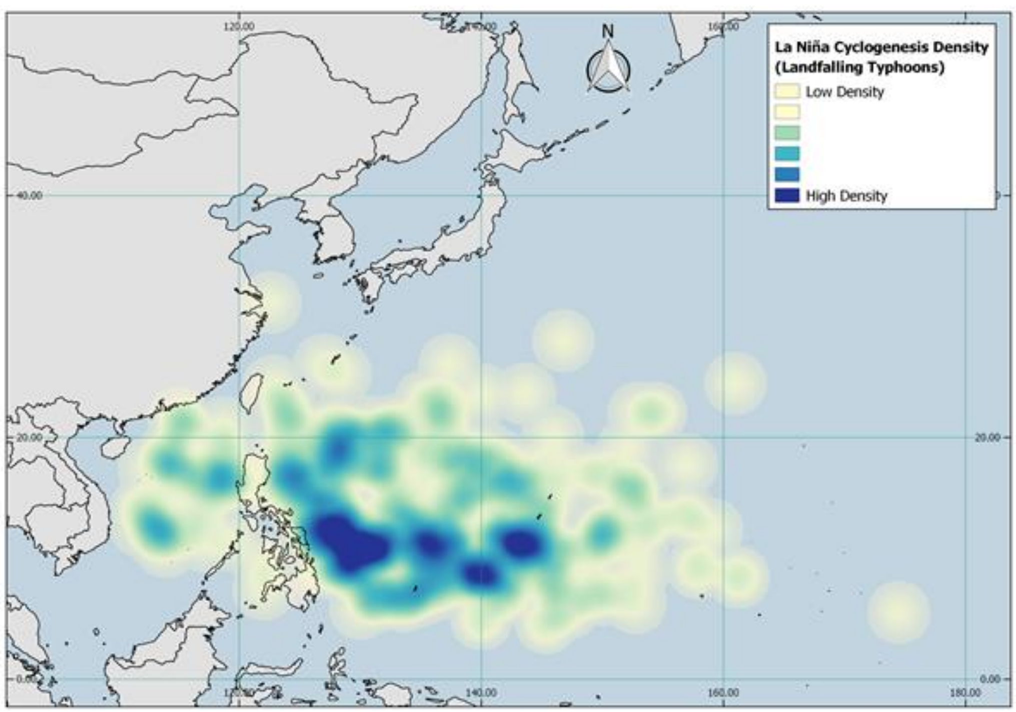


Figure 6 indicates the dominant paths of tropical cyclones that make landfall in the western Pacific during El Niño years. In the figure, dominant tracks are westerly or northwesterly, passing to the north of the Philippines. The density of cyclone paths suggests that southeastern China, northern Philippines, Taiwan, and the southern islands of Japan are at the greatest risk of tropical cyclone landfalls during El Niño years, relative to other countries in the region. The heatmap covers the entire Japanese archipelago and South Korea, which confirms the prevalence of recurving and northward cyclone tracks during El Niño years.

Conversely, Figure 7 shows a heatmap of the dominant paths of tropical cyclones that make landfall in the western Pacific during La Niña years. More tropical cyclones tend to pass to the south of Taiwan under La Niña conditions, mainly affecting the eastern Philippines, southern China, and Vietnam. This observation supports the reported westerly shift in cyclogenesis and dominant westerly storm tracks during La Niña events. Very few tropical cyclones pass over Guam during La Niña years, and although the density of storm tracks over the Okinawan Islands is relatively high, South Korea and mainland Japan are covered to a lower geographical extent than during El Niño years.

Figure 6: Heatmap Of Tracks of Landfalling Tropical Cyclones in the Western Pacific During El Niño Years

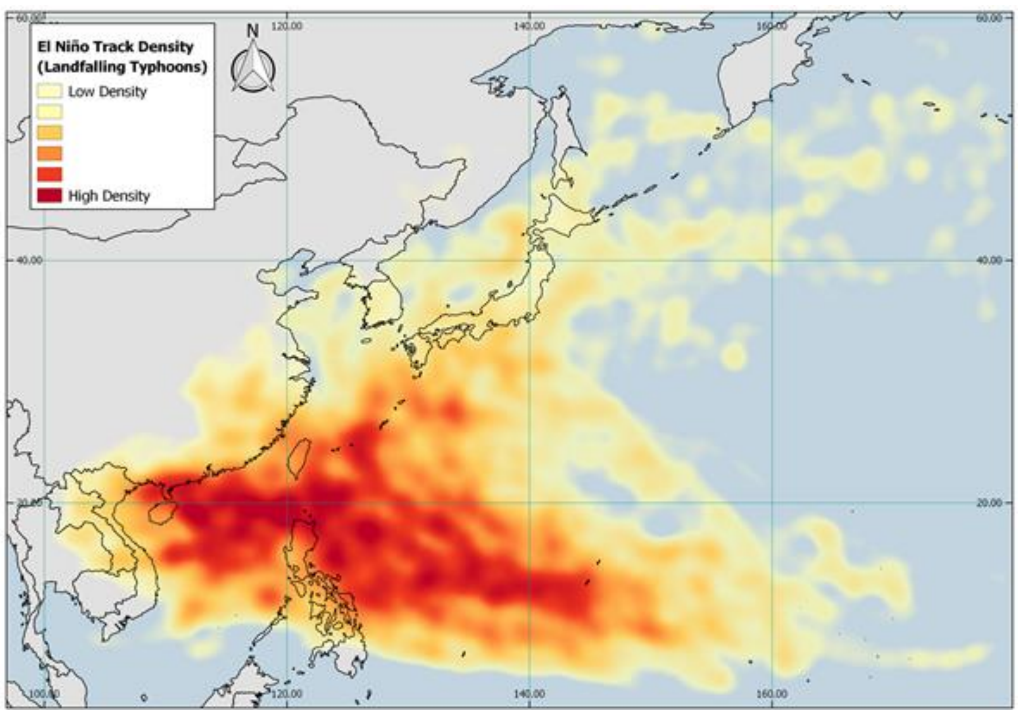
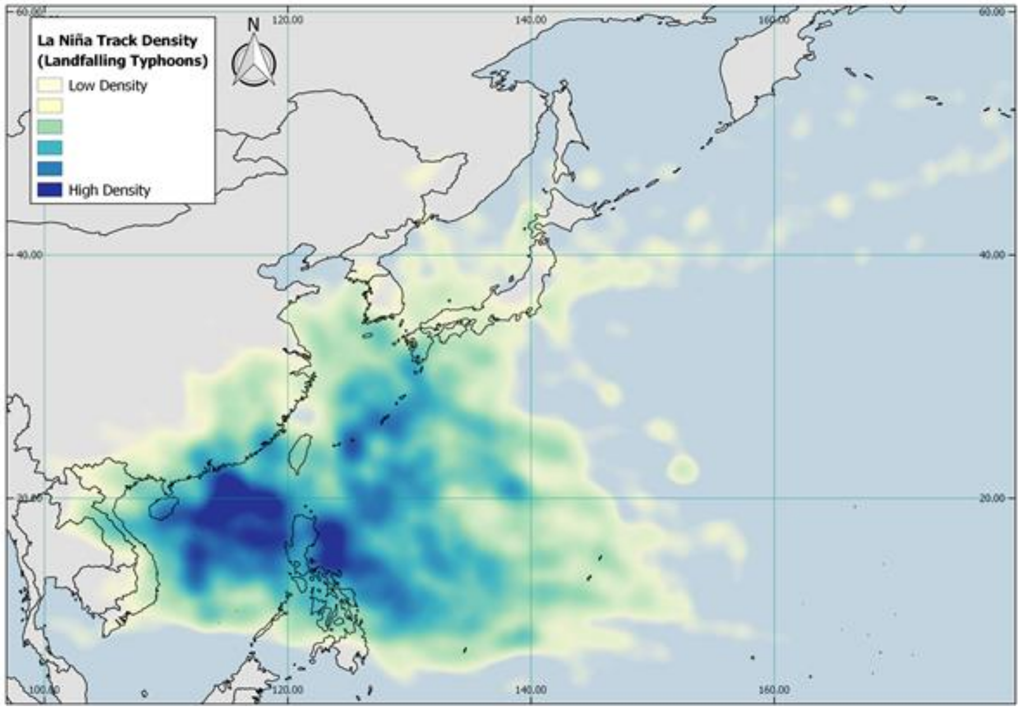


Figure 7: Heatmap of Tracks of Landfalling Tropical Cyclones in the Western Pacific During La Niña Years



To investigate the impacts of El Niño and La Niña events on tropical cyclone landfall in the western Pacific, RMS grouped storms by their Saffir-Simpson Category at landfall. Table 2 shows the statistics for tropical cyclone landfalls over the entire 1951–2011 period compared to El Niño and La Niña years.

During El Niño years, Guam and Japan experience a greater rate of both weak (Category 0–2) and strong (Category 3–5) tropical cyclone landfalls. This outcome illustrates the eastward shift in cyclogenesis location during El Niño, with a greater proportion of storms forming in the central Pacific close to Guam and following a recurving track toward the Japanese archipelago. At the same time, the landfall rate decreases for China, the Philippines, and Vietnam compared to neutral and La Niña years, as fewer tropical cyclones follow westward tracks toward these landmasses. The landfall rate for Category 3–5 storms in China during El Niño years exceeds the 1951–2011 average, which demonstrates the increased intensity of typhoons during El Niño years.

During La Niña years, South Korea, Philippines, and Vietnam experience higher than average tropical cyclone landfall rates. Conversely, the landfall rate decreases slightly overall for Japan and significantly for Taiwan and Guam. Previous studies have shown that more southwesterly countries, including the Philippines and Vietnam, are at a greater risk of typhoon landfalls during La Niña years due to the westward shift in cyclogenesis.

Table 2: Average Annual Landfall Rate (Displayed by Country and Storm Intensity at Landfall; Category 0–2 Weak; Category 3–5 Strong) Between 1951 and 2011 Compared to El Niño and La Niña Years

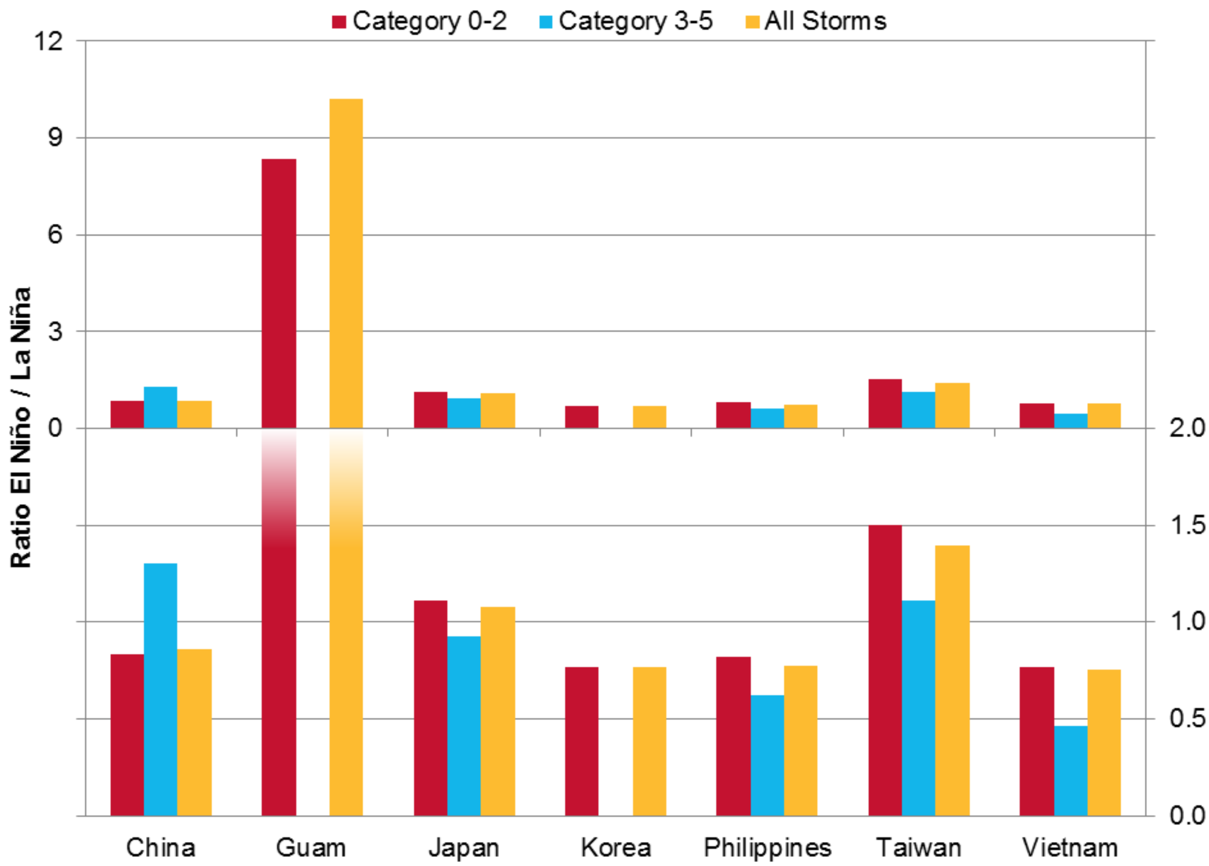
Year Type	SS Category (1-Minute Sustained Wind Speed m/s)	China	Guam	Japan	South Korea	Philippines	Taiwan	Vietnam
1951–2011 Average	**0–2 (18–49)**	**6.42**	**0.41**	**4.77**	**1.02**	**3.20**	**1.41**	**3.05**
El Niño	0–2 (18–49)	5.29	0.64	4.86	0.79	2.86	1.29	2.50
La Niña	0–2 (18–49)	6.31	0.08	4.31	1.15	3.54	0.85	3.23
1951–2011 Average	**3–5 (≥50)**	**0.34**	**0.08**	**1.07**	**0.03**	**1.16**	**0.52**	**0.05**
El Niño	3–5 (≥50)	0.50	0.14	1.14	0.00	1.00	0.43	0.07
La Niña	3–5 (≥50)	0.38	0.00	1.23	0.00	1.62	0.38	0.15

However, the finding that during La Niña years, South Korea experiences higher landfall rates, and Japan experiences a greater number of strong typhoon landfalls, contradicts the patterns described in previous studies. For Japan, the increase is partially attributable to a greater number of Category 3 typhoons; there have been no typhoon landfalls at Category 5 strength in Japan during La Niña years. In addition, tropical cyclones tend to form further west and north during La Niña so any typhoons that follow northward or recurving tracks are more likely to strike South Korea or the southern Japanese Islands. On the other hand, due to the displacement of cyclogenesis further eastward during El Niño, tropical cyclones that track northwards or recurve may not strike land; instead, they may track over the Pacific Ocean to the east of Japan before dissipating.

Figure 8 displays the ratio of tropical cyclone landfalls between El Niño and La Niña years. Guam exhibits the greatest difference in the number of landfalls in El Niño and La Niña years, with ten times as many historical landfalls of all strength categories in El Niño years. Similarly, Taiwan experiences approximately 1.4 times the number of landfalls during El Niño years compared to La Niña years. Ratios close to 1.0 for Japan indicate that there are similar numbers of typhoon landfalls during both the El Niño and La Niña phases of ENSO.

South Korea, Philippines, and Vietnam experience fewer typhoon landfalls during El Niño years across all storm categories. The difference is greatest for strong typhoons from Category 3 to 5 in Philippines and Vietnam, although South Korea did not experience any historical typhoon landfalls at Category 3 strength or above in El Niño or La Niña years. No historical typhoons made landfall in Guam at Category 3 to 5 during La Niña events.

Figure 8: Graph to Show the Ratio of Tropical Cyclone Landfalls by Saffir-Simpson Category Per Country Between El Niño and La Niña Years



Statistical Significance

RMS performed T-test analyses on the difference between the mean average numbers of tropical cyclone landfalls by country during El Niño and La Niña years. These tests indicate whether the differences in the number of average landfalls in El Niño and La Niña years are statistically significant at the 95 percent confidence level.

The only differences in mean average landfalls that can be described as statistically significant at the 95 percent confidence level are for Guam. The overall average landfall rate and landfall rate for Category 0–2 tropical cyclones in El Niño years are much higher than in La Niña years, with these differences being statistically significant. For Category 3–5 typhoons, the landfall rate is very low in El Niño years and zero in La Niña years but this difference is not statistically significant.

For the other countries in the western North Pacific, the difference between the rates of typhoon landfalls in El Niño and La Niña years is not statistically significant at the 95 percent confidence level. Because of the relatively small sample size (14 years for El Niño, and 13 years for La Niña), and the small variance in the total number of landfalls per year, the difference in means is not statistically significant for most countries.

The ratios close to 1.0 for Japan and China between landfall rates in El Niño and La Niña years shown in Figure 8 indicate that observed differences are not statistically significant. For other countries, including the Philippines, Taiwan, and Vietnam where the differences in mean landfall rates are more pronounced, the significance levels are around 80 percent.

Figure 11 to Figure 17 in the Appendix plot the landfall rates for each country and grouped Saffir-Simpson storm category along with the standard deviation of landfall rates. For South Korea, the Philippines, Taiwan, and Vietnam, the standard deviation values are relatively high comparative to the mean annual landfall rates. This indicates a high degree of variability around the average landfall rates which contributes to the lower statistical significance of the difference between the typhoon landfall rates in El Niño and La Niña years.

Seasonality

The El Niño and La Niña phenomena affect the seasonality of typhoons in the western Pacific. In El Niño years there are fewer tropical cyclone landfalls in areas to the west of Japan (China, Philippines, Taiwan, and Vietnam) during the later months of the Pacific typhoon season. Conversely, the landfall risk is greater for this region during the later months of the typhoon season in La Niña years.

Figure 9: Graph to Show the Average Landfall Rate by Month Between 1951 and 2011 Compared with El Niño and La Niña Years for the Countries of China, Philippines, Taiwan, and Vietnam

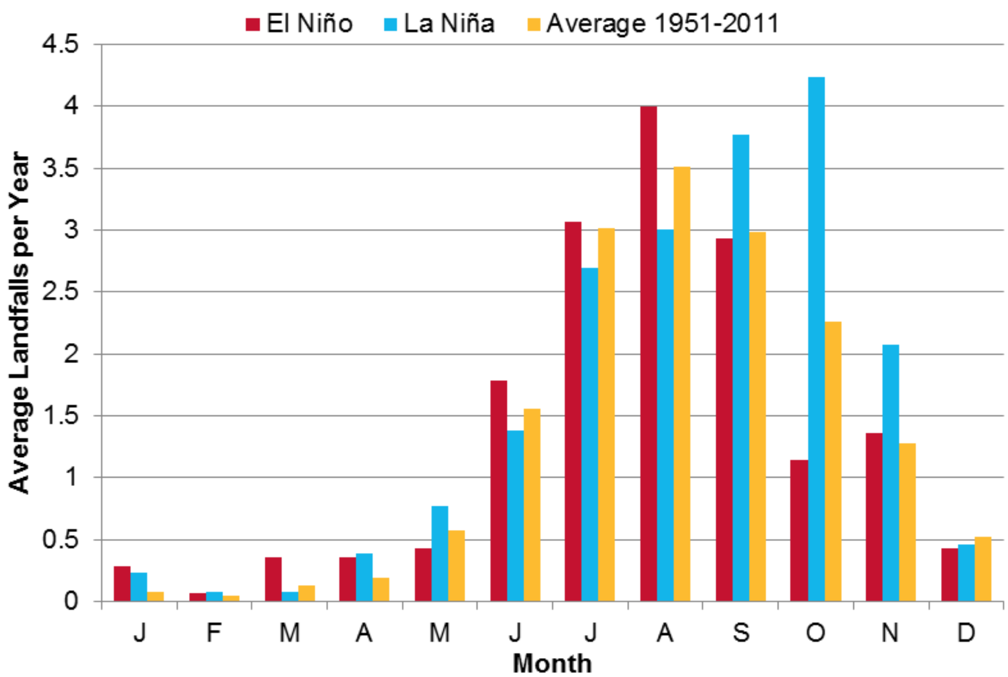
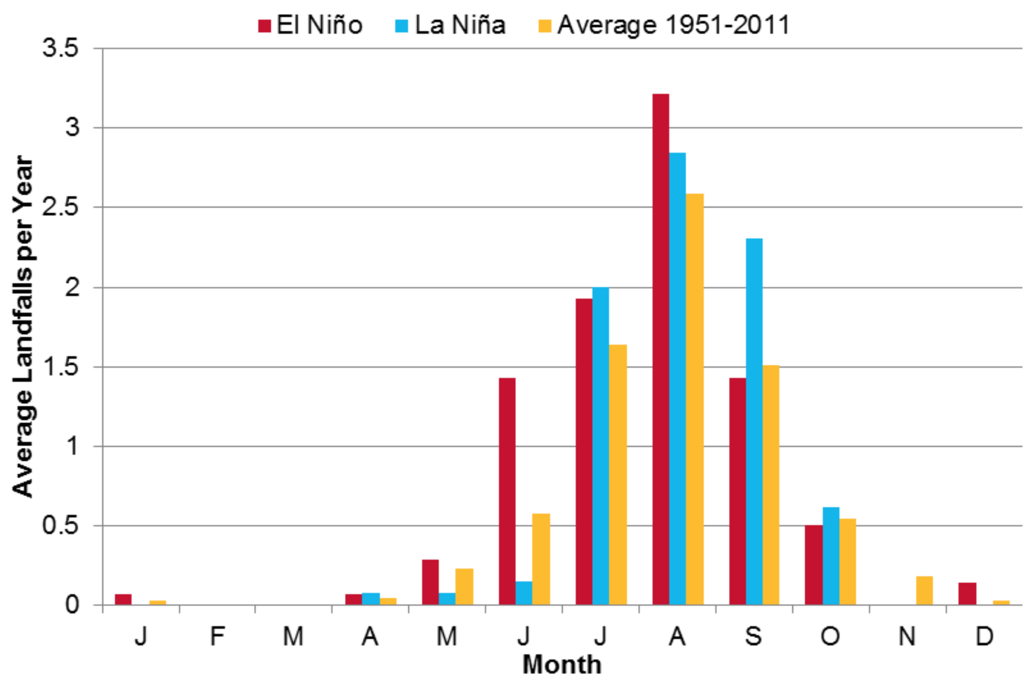


Figure 9 displays the landfall rates per month for China, Philippines, Taiwan, and Vietnam. For the first few months of the peak typhoon season, the landfall rate is lower than average during La Niña years. However, from September onward there are more landfalls than average during La Niña years whereas the landfall rate for El Niño years is lower than average over the same months.

Figure 10 shows that the more eastern countries (Guam, Japan, and South Korea) in the western North Pacific Basin tend to experience fewer tropical cyclone landfalls during the early part of the season in La Niña years compared to the 1951–2011 average. However, from July onward, the rate of tropical cyclone landfalls is fairly consistent between El Niño years, La Niña years, and the long-term average.

Figure 10: Graph to Show the Average Landfall Rate by Month Between 1951 and 2011 Compared with El Niño and La Niña Years for the Countries of Guam, Japan, and South Korea



The Effects of ENSO on Modeled Losses in Japan, China, and Guam

Event Rates

In the last 20 years, three of the top 10 most damaging tropical cyclones occurred during El Niño events, as defined in this report, whereas two occurred during La Niña episodes. However, there is no statistically significant signal, and these statistics are difficult to interpret, for a number of reasons:

- Numerous typhoons prior to this period caused extensive damage. However, inflation and currency fluctuations in succeeding years mean that reported losses at the time are lower compared to more recent events.
- Thanks to population growth and urban expansion in the rapidly developing western Pacific region, exposure concentrations have become denser since typhoon losses began to be consistently reported decades ago.
- The biggest loss causing events overall almost exclusively occur in the more developed nations such as Japan, Taiwan, and China, even though the ENSO phases also affect typhoon landfalls in less developed economies such as Vietnam and the Philippines.

This investigation and previous studies demonstrate clear impacts of different ENSO phases on aspects of typhoon morphology, including cyclogenesis, dominant track directions, and landfall rates. However, the effects on monetary losses from tropical cyclones during El Niño and La Niña years are more difficult to quantify.

To investigate the impact of El Niño and La Niña phases on modeled typhoon losses in the western Pacific, RMS used existing RMS typhoon models for Japan, China, and Guam.

To reflect the differences in tropical cyclone landfall rates between El Niño and La Niña years, RMS modified the event rates within the typhoon event sets for the specific countries as follows:

- Calculate adjustment factors for tropical cyclones of different Saffir-Simpson categories and for each of the three countries, based on the landfall rates observed in this study (see Table 2)
- Apply these adjustment factors to the event rates within the RMS typhoon event sets for Japan, China, and Guam.

With these modified event rates, RMS analyzed representative RMS industry exposure databases for Japan and China using the RiskLink DLM (detailed loss models). For Guam, the project employed a portfolio including residential, commercial, and industrial lines with flat exposure values.

The results presented in this section indicate the percentage difference in aggregate exceedance probability (AEP) losses between El Niño and La Niña years and the 1951–2011 average. The results presented here do not definitively represent typhoon losses in El Niño years, La Niña years, and the 1951–2011 average, for the following reasons:

- The event rate adjustment factors, calculated using the landfall rates of different strength tropical cyclones, introduce additional uncertainty into the models.
- The adjustment factors are applied to all events within the individual event sets of each model. However, this and previous studies have shown that certain typhoon tracks may be more prominent in El Niño and La Niña years.

Instead, these results approximate the differences in potential losses between the different ENSO phases.

Japan

In Japan, results indicate slightly above average numbers of landfalls in El Niño years compared to the 1951–2011 average, whereas in La Niña years fewer tropical cyclone landfalls of weak Category 0–2 typhoons occur, but more Category 3–5 typhoon landfalls occur than average. This increase in strong typhoons during La Niña years is mainly due to higher landfall rates of Category 3 typhoons; no Category 5 landfalls occurred in Japan during La Niña events between 1951 and 2011.

To generate the loss analyses presented here, RMS changed the event rates to reflect the historical landfall patterns during El Niño years, La Niña years and the 1951–2011 average. These exceedance probability (EP) results cannot therefore be directly compared to the losses produced on the Japan Industry Exposure Database using the standard RMS Japan Typhoon DLM.

By modifying the event rates as discussed in the Event Rates section, typhoon losses increased slightly during El Niño events compared to the long-term average, as shown in Table 3**Error! Reference source not found.**. The modeled average annual loss (AAL) is approximately 34 percent higher in El Niño years than loss produced using the 1951–2011 average event rates.

The percentage difference in return period losses also suggest that significantly lower losses of over -40 percent may be expected during La Niña years compared to the 1951–2011 average. However, these differences are based on a near-zero rate of landfalling strong Category 5 typhoons, as there have been no historical Category 5 landfalls in Japan during La Niña events in the 61 years between 1951 and 2011.

In reality, the risk of a Category 5 typhoon making landfall in Japan during a La Niña event is not zero. Although this has not occurred in the 13 sampled La Niña years, the possibility remains that a Category 5 typhoon will make landfall in Japan during a La Niña event in future. Therefore, RMS further altered the La Niña event rates for Saffir-Simpson Category 5 typhoons in the RMS® Japan Typhoon Model based on the ratios between the landfall rates of different storm categories between 1951 and 2011. This additional step still causes lower landfall rates of Category 5 typhoons in La Niña years than the 1951–2011 average, but reflects the reality that such events may possibly occur in future.

Table 3 displays the percentage difference in losses using the estimated Category 5 event rates for landfalls in La Niña years. The percentage difference in losses for the estimated Category 5 event rates are closer to the 1951–2011 average compared to the original La Niña losses, particularly at longer return periods. The percentage difference in AAL between La Niña years and the 1951–2011 average decreases from -41 percent, using near-zero Category 5 rates, to -17 percent using the estimated Category 5 event rates. This observation highlights the influence of strong Category 5 typhoons on modeled losses in Japan. Nevertheless, the modified La Niña losses remain lower than the 1951–2011 average and El Niño years across all return periods.

Table 3: Percentage Difference in Modeled Typhoon Losses for Japan (Wind Only) at Key Return Periods

Return Period (Years)	El Niño / 1951–2011 Average	La Niña / 1951–2011 Average	La Niña / 1951–2011 Average - Estimated Category 5 Rates
AAL	34%	-41%	-17%
10	35%	-43%	-20%
50	21%	-44%	-17%
200	16%	-42%	-14%
1,000	10%	-40%	-10%

China

In China, the landfall rates of all categories of tropical storms are close to the 1951–2011 average during La Niña years. During El Niño years, the landfall rate of weak tropical storms (Saffir-Simpson Category 0–2) is significantly lower than average, whereas the landfall rate of Category 3–5 typhoons is slightly higher than the 1951–2011 average.

Only one typhoon made landfall in China at Category 5 strength during the period between 1951 and 2011.

As with the Japan Typhoon Model event rates presented in the last section, this study calculated loss results presented here using adjusted rates of Category 5 events in the RMS® China Typhoon Model for El Niño and La Niña years. The study based these adjustments on the ratios between the landfall rates of different category storms for the overall 1951–2011 period.

RMS ran separate wind and flood analyses using the RMS® China Typhoon Model in addition to the combined peril analysis. Table 4 shows the percentage difference in losses at key return periods with the adjusted event rates for El Niño years, La Niña years and the 1951–2011 average. For the combined wind and flood analysis both the El Niño and La Niña losses are similar to the 1951–2011 average across all return periods , with very small percentage differences across all year types. The AAL for El Niño years is just 3 percent below the long-term average, while for La Niña event rates it is 5 percent lower.

In El Niño years, the landfall rates are higher for Category 3–5 storms, which has the effect of increasing the losses contributed by strong winds, particularly at the longer return periods. The wind only analysis of the China Typhoon Model produces the highest losses for the El Niño event rates, with losses for the La Niña rates also slightly higher than the 1951–2011 average. The difference in loss becomes more pronounced at increasing return periods.

However, weaker tropical cyclones (Saffir-Simpson Category 0–2) often tend to produce greater amounts of rainfall than stronger typhoons, which leads to a higher risk of flooding. Therefore, the lower landfall rates of weak tropical cyclones during El Niño years compared to La Niña years and the 1951–2011 average reduces the flood loss component. The El Niño losses are slightly below the 1951–2011 average up to a return period of about 600 years, where the losses converge.

Table 4: Percentage Difference in Modeled Typhoon Losses for China (Wind and Flood) at Key Return Periods

Return Period (Years)	El Niño / 1951–2011 Average - Estimated Category 5 Rates	La Niña / 1951–2011 Average - Estimated Category 5 Rates	El Niño / La Niña - Estimated Category 5 Rates
AAL	-3%	-5%	3%
10	0%	-6%	7%
50	0%	-2%	2%
200	-2%	-1%	-1%
1,000	2%	2%	0%

Guam

The typhoon landfall rates for Guam are higher for all storm categories during El Niño years compared to the 1951–2011 average due to the eastward shift in the main cyclogenesis region. In the La Niña phase of ENSO, the landfall rates are greatly reduced, with only one historical landfall taking place between 1951–2011 in La Niña years (as defined in this study). The cooler SSTs in the Niño 3.4 region during La Niña mean that most tropical cyclones form to the west of Guam and there is a very low risk of typhoon landfalls.

Due to the relatively low number of tropical cyclones that make landfall in Guam (being a small and easterly island) there are some Saffir-Simpson categories that are not represented in the historical landfall records during El Niño and La Niña years. For events of these categories, RMS estimated event rate adjustment factors using the ratios between events of different categories from the 1951–2011 average. RMS does not currently have an industry exposure database for Guam, so a flat exposure database containing residential, commercial, and industrial lines of business was used for the analysis.

Table 5 displays the percentage difference in losses for Guam using different adjustment factors for the event rates. The 1951–2011 historical track record contains no Category 5 typhoon landfalls in Guam during El Niño years, and across all La Niña years there has only been one historical landfall, at Category 2 strength. Table 5 displays the percentage difference in losses for events with estimated rate adjustment factors based on the ratios between storms of different categories for the entire 1951–2011 period.

The overall landfall rate of typhoons during El Niño years is 0.78 compared to the 1951–2011 average of 0.49. To reflect this ratio and provide an estimate on the long-term risk of landfalls in Guam, RMS modified event rate adjustment factors for Category 5 storms. The resultant percentage difference in losses indicates higher losses across all return periods than the 1951–2011 average. The AAL is 36 percent higher using El Niño event rates than the long-term average, although the losses begin to converge at longer return periods, with just a 6 percent difference at the 1,000 year return period.

Similarly for La Niña years, RMS modified the landfall rates for Saffir-Simpson categories with no historical occurrences to produce a more complete view of the risk. The La Niña losses still fall far below the 1951–2011 average, with a decrease in AAL of -73 percent and differences of -70 percent or greater across all return periods. Although typhoon landfalls in Guam are relatively rare occurrences during such years, the possibility remains of a strong and damaging typhoon striking the island during a La Niña episode.

Table 5: Percentage Difference in Modeled Typhoon Losses for Guam (Wind Only) at Key Return Periods

Return Period (Years)	El Niño / 1951–2011 Average - Estimated Category 5 Rates	La NIña / 1951–2011 Average - Estimated Category 5 Rates	El Niño / La Niña - Estimated Category 5 Rates
AAL	36%	-73%	410%
10	1067%	-89%	10400%
50	42%	-70%	381%
200	29%	-79%	509%
1,000	6%	-72%	273%

Conclusions

This study defines El Niño and La Niña years based on SST anomalies in the Niño 3.4 region during the peak months of the western North Pacific typhoon season. Previous studies on the effects of ENSO on typhoons in the western North Pacific defined El Niño and La Niña years using different methodologies. Wang and Wang (2012) classify El Niño using the Niño 3 index where the five month running mean SST anomalies are +0.5°C or higher for at least six consecutive months. Goddard and Dilley (2005) use the upper and lower 25 percent of the distribution of five consecutive 3-month running Niño 3.4 SST anomalies to denote El Niño and La Niña events respectively. Similarly, Camargo and Sobel (2005) define El Niño and La Niña years as the top and bottom 25 percent of the sampled years, but using the Niño 3.4 values averaged over the peak of the typhoon season, from July to October.

RMS investigated how historical landfall rates vary using different definitions of El Niño and La Niña events. The results of this investigation indicate that using the Goddard and Dilley (2005), and Camargo and Sobel (2005) definitions of El Niño and La Niña years results in very little difference to the landfall rates for all countries and typhoon categories compared to the methodology used in this study. Increasing the temperature anomaly threshold from ±0.5°C to ±1°C to focus on the most extreme ENSO events also has little impact on the overall landfall rates in the western North Pacific Basin.

Many of the findings presented in this investigation agree with the conclusions from previous studies into the effects of the El Niño Southern Oscillation on typhoon morphology in the western North Pacific Basin. The heatmaps created from the track set of historical storms between1951–2011 confirm the shift in the main cyclogenesis region to the southeast in El Niño years and the northwest during La Niña. They also highlight the dominant typhoon pathways, with more recurving storms in El Niño conditions and straight westerly tracks during La Niña. Additionally, the statistics show that there are more tropical cyclone landfalls in China, Vietnam, Taiwan, and the Philippines late in the typhoon season and fewer in Japan, South Korea, and Guam early in the season during La Niña years, compared to El Niño years.

Overall, slightly fewer tropical cyclones make landfall in the western North Pacific during El Niño years than the 1951–2011 average, although this difference is due to fewer Category 0–2 storms. During La Niña, the number of landfalls remains very close to average. Individual countries see more variation in the rate of tropical cyclone landfalls during El Niño and La Niña. China, Vietnam, and the Philippines experience greater overall numbers of landfalls in La Niña years, while Guam, Japan, and Taiwan see more landfalls during El Niño. Testing the significance of the differences between the average landfall rates in El Niño and La Niña indicates that only for Guam is the difference in landfall rates significant at the 95 percent confidence level.

The lack of statistical significance in the difference between average landfall rates during El Niño and La Niña years highlights the unpredictable nature and uncertainties surrounding the ENSO phenomenon. Forecasting El Niño and La Niña events in advance remains challenging, and it can also be difficult to determine the intensity and duration of an event. Average sea surface temperatures have been increasing in the past few decades, constantly raising the benchmark against which ENSO fluctuations are measured. Numerous theories have been proposed about the effects of global warming on El Niño and La Niña events but further research is needed to establish any firm links between the two phenomena.

This paper uses the current RMS Japan, China, and Guam typhoon models to explore the impact of the variations in typhoon landfall rates in El Niño and La Niña years on RMS modeled losses. For Japan and Guam, the increase in landfall rates of strong Category 3–5 typhoons during El Niño events serves to increase the modeled losses. Likewise, the lower typhoon landfall rates during La Niña years results in lower losses for these two countries.

For China, modeled wind losses increase during El Niño years as the rate of strong typhoons is greater, but overall losses are similar between El Niño and La Niña years and the 1951–2011 average. China receives greater numbers of tropical cyclone landfalls at tropical storm strength in La Niña years; such storms can bring more rainfall than stronger typhoons, and therefore pose a greater risk of flood damage to a nation where up to 80 percent of tropical cyclone related losses are due to flooding. Of the other nations in this study, Vietnam and the Philippines may also be more vulnerable to flood than wind damage, whereas South Korea, like Japan, is at greater risk from strong winds associated with tropical cyclones.

El Niño and La Niña events are relatively short-lived phenomena that have unpredictable durations and intensities and occur at irregular year intervals. This investigation, along with previous studies, has illustrated changes in typhoon morphology during El Niño and La Niña events, but the link between landfall rates and typhoon damage and loss is more difficult to establish due to a variety of factors. RMS will continue to monitor the influence and effects of the El Niño Southern Oscillation on typhoon landfalls in the western North Pacific.

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Appendix: Landfall Rates and Standard Deviations by Country

Figure 11: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in China During El Niño, La Niña, 1951–2011 and Neutral Years

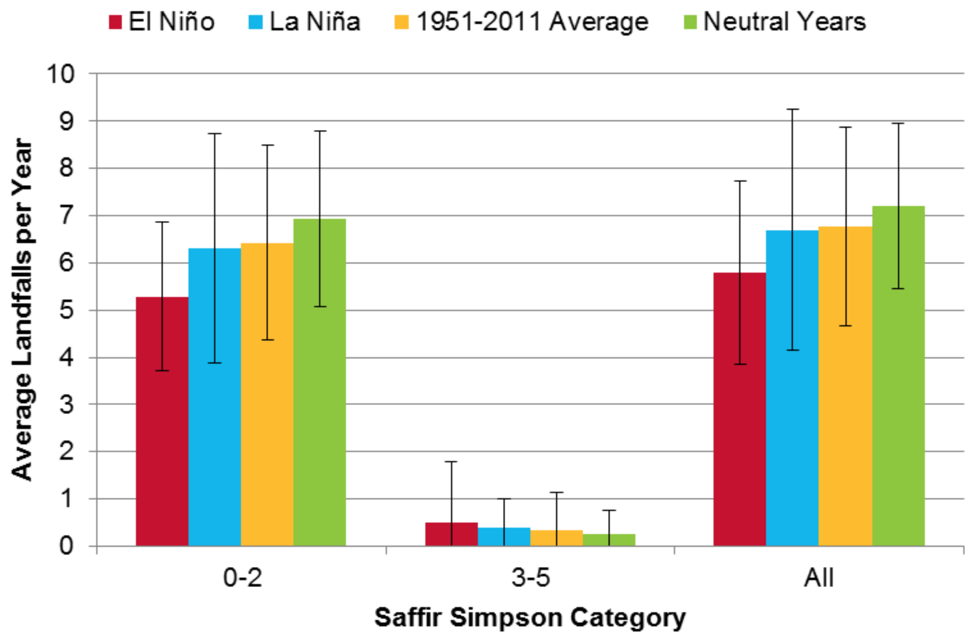


Figure 12: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in Guam During El Niño, La Niña, 1951–2011 and Neutral Years

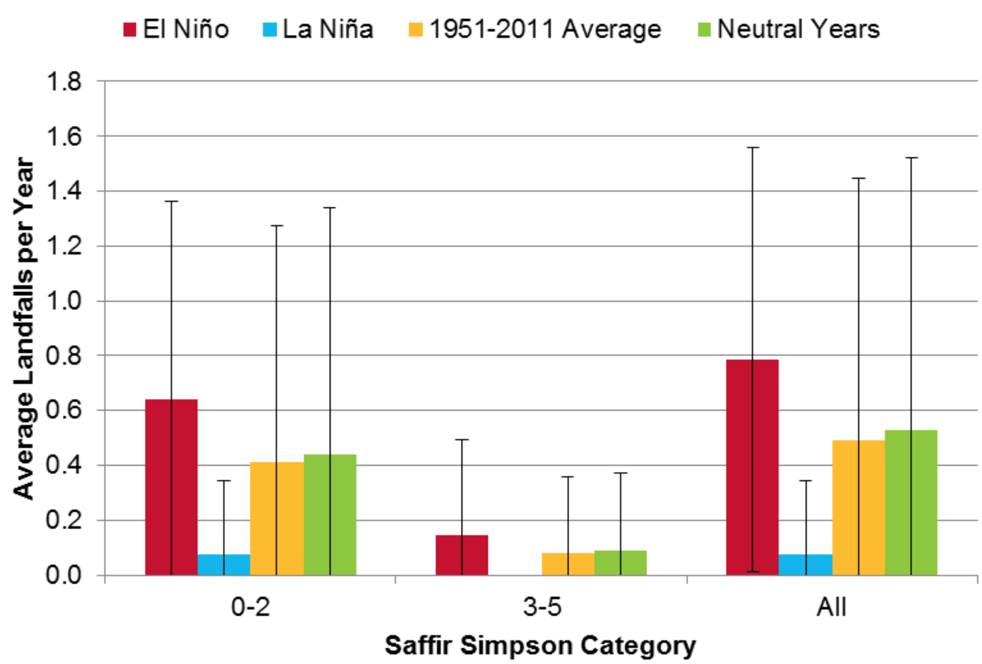


Figure 13: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in Japan During El Niño, La Niña, 1951–2011 and Neutral Years

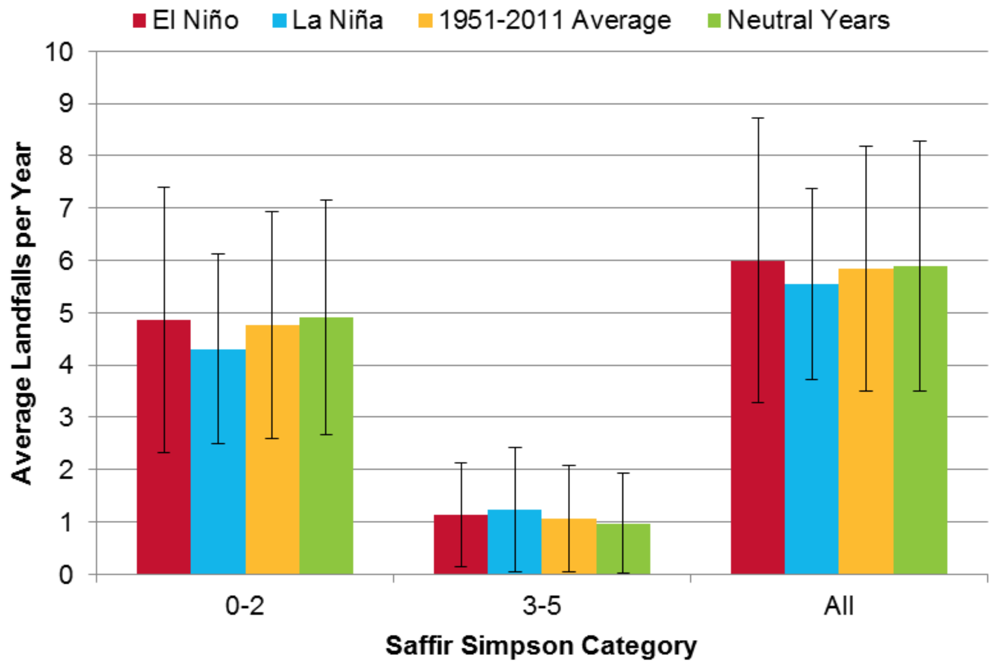


Figure 14: Average Annual Landfall Rates and Standard Seviation of Tropical Cyclones in South Korea During El Niño, La Niña, 1951–2011 and Neutral Years

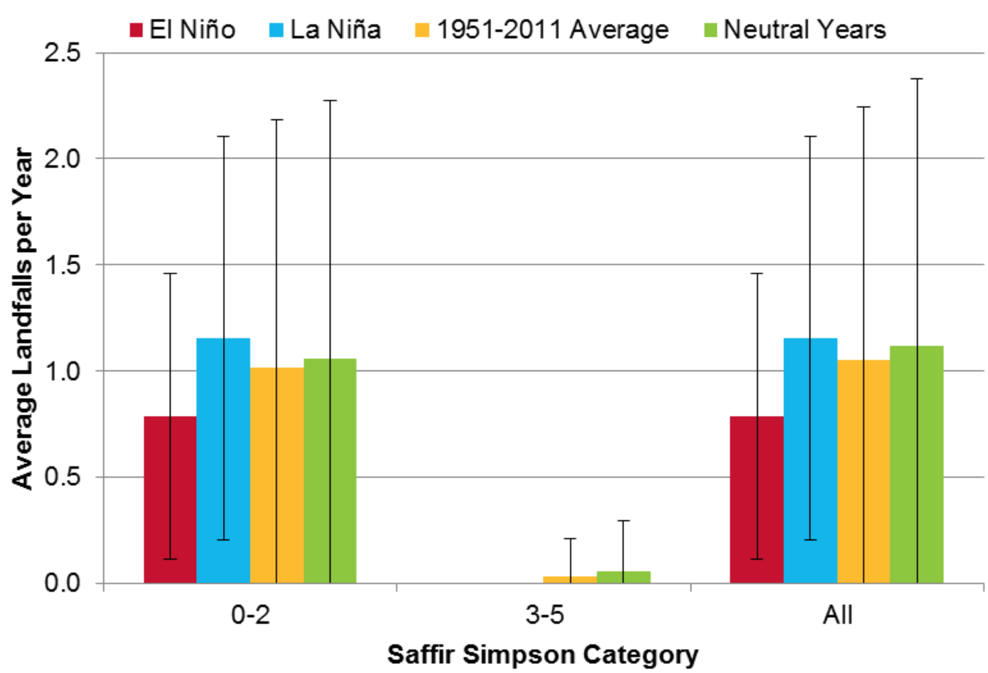


Figure 15: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in the Philippines During El Niño, La Niña, 1951–2011 and Neutral Years

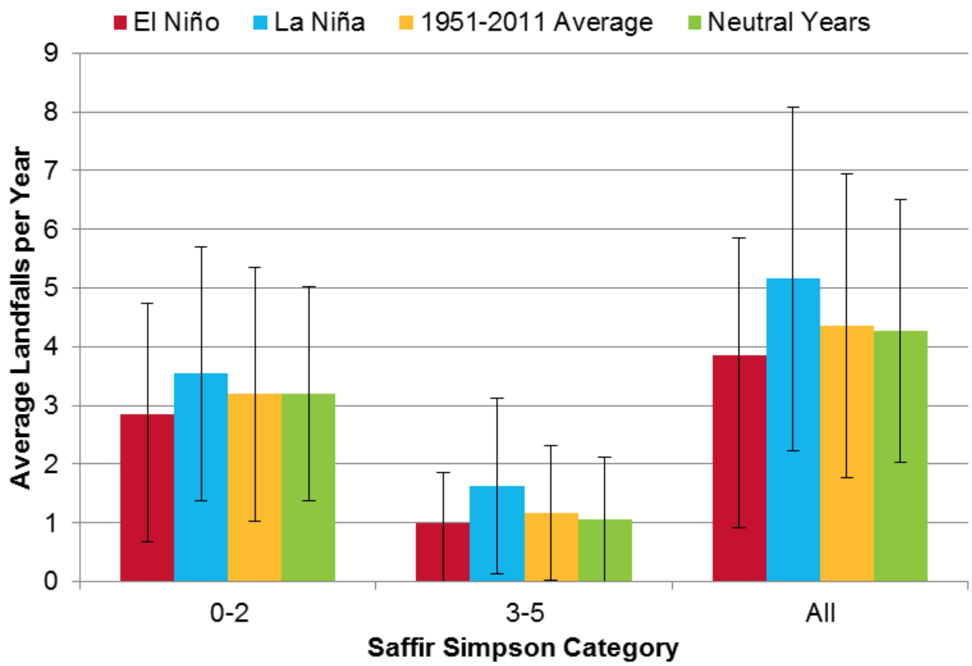


Figure 16: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in Taiwan During El Niño, La Niña, 1951–2011 and Neutral Years

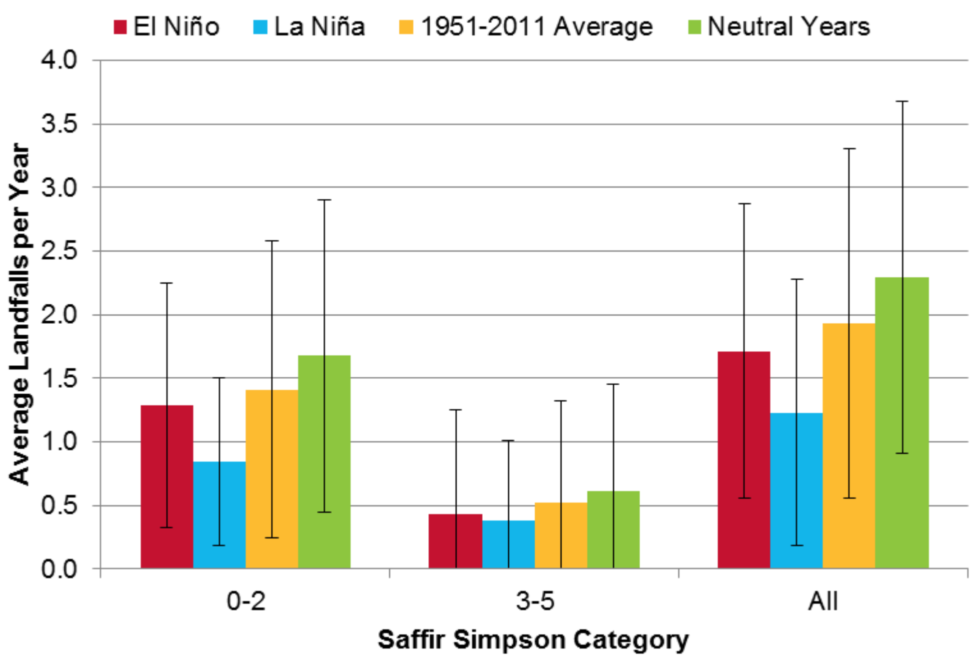
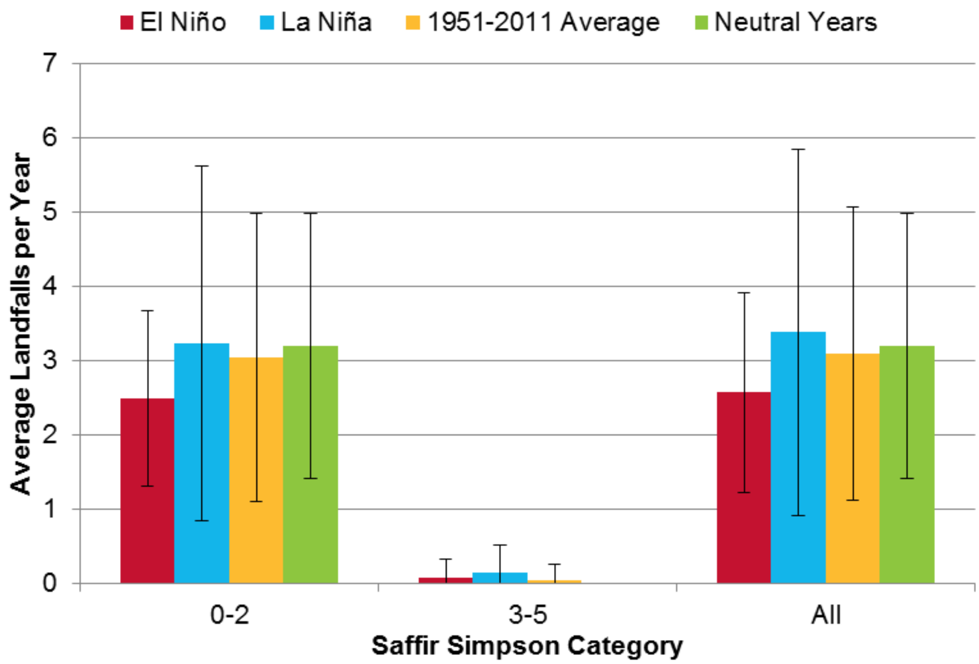


Figure 17: Average Annual Landfall Rates and Standard Deviation of Tropical Cyclones in Vietnam During El Niño, La Niña, 1951–2011 and Neutral Years



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