THE IMPACT OF TYPHOON LANDFALLS ON CHINA’S PRECIPITATION DURING 1977-2005

Sara Katarina Sunno
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Abstract

The purpose of this study has been to investigate the impact of typhoon landfalls on China’s precipitation during the past twenty nine years. Results show that the precipitation has significantly varied in China during the studied time period and that there has been no significant variation in typhoon landfall frequency, except in 2005 when an extreme year was noted. It has been shown that there is no direct correlation with either the positive nor negative departure in average normal precipitation and frequency of land fallen TYs in China. However it has been concluded that a single typhoon event has a significant impact on the overall precipitation. Furthermore the peak typhoon season precipitation anomalies have been shown to be greater than the annual precipitation anomalies. It has also been apparent through the case studies that no correlation could be found between the wind intensity and the intensity of the precipitation.

Keywords: Typhoon, Landfall, Precipitation, China, NWPAC.
Preface

This study completes the Master Degree Program in Physical Geography at the Department of Earth Sciences, Göteborg University, Sweden. The study was conducted during January-May of 2007 and was supervised by Professor Deliang Chen.

Acknowledgments

First of all I would like to thank my mentor and supervisor, Professor Deliang Chen. Thank you for your inspiration, support and patience.

I like to thank Associate Professor Asanobu Kitamoto at the National Institute of Informatics in Japan for all his help concerning typhoon data and for providing the public with useful typhoon information through his Digital-Typhoon webpage.

I would also like to thank Mr. Kenji Kisimoto at the Regional Specialized Meteorological Service (RSMS), Tokyo Typhoon Center, Japan Meteorological Agency (JMA) for supplying information concerning the best track data and for the clarification in some definitions.

A special thanks to Dr Scott Braun at the Tropical Rainfall Measuring Mission at National Aeronautics and Space Administration (TRMM/NASA) for providing me with important precipitation plots for my case studies.

To my dear family and friends, thank you for your understanding and support during the past years. To "Klimatvarianterna" I would also like to say: Thank you for a truly wonderful time. I will miss our "you tube-days" and all the crazy excursions.

Finally I would like to thank Felix Zhang: Thank you for all your caring, encouragement and support...thank you for the little things you do.
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1. Introduction

China has a long history in dealing with the destructiveness of typhoons (Louie & Liu 2003, Liu et al. 2001). The strong winds and heavy precipitation from the typhoons has often resulted in extensive collateral damage, and sometimes also in human casualty. To be able to diminish this outcome researchers have tried to understand the characteristics of typhoons, not only where they form but also where they might strike.

Through statistical studies on storm frequencies there is today a quite good understanding in where storm development is most likely to occur. Together with these studies, and with help from satellite images, meteorologists can today provide quite detailed forecasts. These forecasts can give the public time to make necessary preparations.

In this study focus will mainly be put on typhoon (TY) frequency/intensity and precipitation during the past twenty nine years in China (figure 1). The time period has been limited to the years 1977-2005 due to lack or uncertainties in wind data prior to 1977. A separate section of recent studies conducted on typhoon activity and precipitation in China is also incorporated in this study.

Figure 1. Map over China with outlined provinces.

China stretches almost five thousand kilometers across the East Asian landmass and has a changing configuration of extensive desert areas, magnificent mountain ranges and wide-ranging plateaus. Most of the eastern and southern parts of the country are mainly connected with seas, with the Yellow Sea in the north, East China Sea in the east and the South China Sea in the south. Altogether the coastline stretches a distance of about 18 000 kilometers.
where a great part is facing The Western Pacific Ocean (WPAC) in the east. The approximate geographical coordinates for China are: 18-53 °N; 74-135 °E.

The climate of China is extremely varied; subtropical in the south and sub artic in the north. Monsoon winds dominate the climate. The advance and retreat of the monsoons account in large degree for the timing of the rainy season and the amount of rainfall throughout the country. China south of the Qinling Mountains experiences abundant rainfall while the northwest has the lowest annual rainfall in the country. Temperature differences in winter are great, but in summer the diversity is considerably less.

Typhoons strike China mainly between July and September, but the whole season reaches from May to December. They usually affect an area 100 km from the coast, sometimes reaching as far inland as 400 km and they can maintain their strength for hours up to several days. The areas which get affected severest by the typhoons are Taiwan and Guangdong.

1.1 About Typhoons

A storm is named differently depending on where on Earth it develops. If it develops in the North Atlantic Ocean, the Northeast Pacific Ocean or the South Pacific Ocean it is called a hurricane. In the Southwest Indian Ocean it is called a tropical cyclone (TC) and in the NWPAC west of the dateline it is called a typhoon (TY) (www.aoml.noaa.gov).

Typhoons usually develop along a band about ten degrees north of the equator. After forming they follow a westerly or northerly path and strike Southeast and East Asia. Some typhoons then turn toward the east and move out into the central North Pacific Ocean (http://meted.ucar.edu).

A few requirements have to be met before a typhoon can develop. The sea surface temperature (SST) and the wind speed must exceed 26.5 °C respectively 33 ms⁻¹ (64 knots). In 1980 two Atlantic hurricanes formed over waters where the SST was only 20° and 23 °C, Barry & Carleton (2001). The vertical wind shear (Vertical wind shear is the magnitude of wind change with height) between the surface and the upper troposphere has to be less than 10 ms⁻¹. A minimum distance of at least 500 km from the equator is also required (www.aoml.noaa.gov).

The centre of a typhoon, or otherwise called the eye, is the area of lowest pressure. The conditions within the eye are characterized by little or no wind and often a cloudless sky. The eye is usually about 40 km in diameter, but it can also reach a width of more than 100 km (figure 2). Surrounding the eye is a wall of dense convective cloud called the eye wall. This wall usually rises about 15 km into the atmosphere. Conditions here are more severe with violent winds and heavy precipitation. The spiral bands surrounding the eye can extend up to 1000 km from the centre. These bands also contain heavy precipitation and wind squalls (www.ntlib.nt.gov.au).

The central pressure in an intense system may be 50-100 mb below that outside the vortex, but only 10-30 mb of this drop occurs between the eye wall and the center, Barry & Carleton (2001). When the storms centre crosses a coastline this is called a landfall. This means that the landfall area experiences half the storm by the time of actual landfall (www.cwb.gov.tw).
In this paper typhoon landfall is defined as a typhoon landfall when the typhoon has a wind speed exceeding 33 ms\(^{-1}\) (64 knots) at the time of landfall.

1.2 Recent studies done on typhoon activity and precipitation in China

A recent study has shown that the frequency and intensity of tropical storm surge disasters have significantly increased since the 1960s, although the frequencies of both the NWPAC TCs and the landfall events over China have on average decreased (Fan & Li 2006).

According to Webster et al. (2005) and Hoyos et al. (2006) the number of strong storms globally (i.e. category 4 and 5 on the Saffir-Simpson hurricane scale) has increased during 1970-2004, while weaker storms (i.e. category 1) have decreased during the same time period.

Klotzbach (2006) argues however that there is a 10 percent increase in category 4-5 hurricanes during the past twenty years.

Knutson & Tuleya (2004) have used different climate models to predict the future SST and thereby make estimation on TC frequency and intensity in the future. The authors came to the conclusion that if the frequency of TCs remains the same over the coming century, a greenhouse gas-induced warming may lead to a gradual increase of category-5 storms.

Ren et al. (2002) has shown that there has been a decrease in typhoon related precipitation during 1957-1996. They have concluded that the larger the TY impact area, the larger the TY precipitation volume (with a correlation coefficient reaching 0.85). In extreme situations a TY can produce more than 100 mm precipitation in southern NE China, 300 mm in the eastern and southeastern coastal regions and maximum of 613.2 mm in Hainan.

The precipitation volume in the TY-influenced region occupies about 80-90 % of overall precipitation. Generally the landfallen TY contributes more precipitation to China than a TY passing the offshore area around China. It has also been shown that the number of TYs and their intensity are very important factors in the extent of typhoon influence on Chinas precipitation (Ren et al. 2002).

Gemmer et al. (2004) have concluded that monthly precipitation trends over the time period 1951-2002 show regional variations in eastern China. Mainly the trends are negative in autumn-spring and positive in the summer.

Chinese meteorologists have conducted studies on the western Pacific subtropical high (WPSH) and recognized its influence on summer rainfall in China (Xue and He 2005). It seems that when the SH extends far to the east (west), the summer monsoon in the South China Sea is stronger (weaker) and established earlier (later). In addition, there exists a good relationship between the longitudinal position of SH and the summer rainfall in China. A positive correlation region is found in South China, showing the decrease of rainfall when the SH extends westward (Yang & Sun 2003).

1.3 Objectives

The objective of this study is to find out if a correlation can be found between the departure from normal average precipitation and the frequency of landfallen typhoons, during the past twenty nine years in China. The hypothesis is that the higher the TY landfall frequency is, the higher the positive precipitation anomaly should be, especially during the peak TY season.
A comparison between the frequencies of the land fallen TYs and the precipitation anomalies will be made. This comparison will be incorporated in the result section of the precipitation anomalies and will be executed for all the provinces, which have been affected by land fallen TYs. Trends for the annual departure from normal average precipitation will also be included, this to get a view over the difference in departure covering a whole year in comparison with the peak TY season precipitation anomalies.

Three case studies, on three separate typhoon events, will also be preformed. These will help in determining the amount of precipitation generated during one single typhoon event. In the case studies a correlation will also be made between the amount of precipitation and the intensity of the TY. The hypothesis is that the higher the TY intensity is, the higher the accumulated precipitation should be.
2. Data and Methods

2.1 Typhoon trends

The typhoon frequency data is based on the “best track” data from the webpage of Kitamoto Asanobu Laboratory at the National Institute of Informatics in Japan.¹ The Best Track is a representation of a tropical cyclone's location and intensity over its lifetime. It contains the cyclone's latitude, longitude, maximum sustained surface winds (knots), and minimum sea-level pressure (hPa) at 6-hourly intervals (0000, 0600, 1200, 1800 UTC) (www.prh.noaa.gov). During the peak of typhoon intensity there is also 3-hourly data available. The best track of each TY event is shown graphically but also in data table format. An animated representation of the best track is also available. This animation is shown on Google Earth (GE) and gives a graphic representation with date, time, intensity and latitude/longitude coordinates at the time of measurement. In the best track animation on GE it is also possible to zoom in on the area affected by the typhoon, this makes it easier to follow the path in between taken measurements.

The data retrieved from the Kitamoto webpage is primarily based on data from Japan Meteorological Agency (JMA) and the Joint Typhoon Warning Center (JTWC) in Hawaii U.S. Data from the JMA is updated every three hours under normal operation, but it is also updated every hour when typhoons approach Japan (usually within 300 km). Data from the JTWC is updated every six hours and the maximum sustained wind is expressed, while central pressure is not. The retrieved wind data from the Kitamoto webpage is based on a 10-minutes sustained wind speed (after comparing wind data from Kitamoto webpage and the JMA).

Method for the TY frequency in the NWPAC:

1. The time period, in the searchable database on Kitamoto website for the NWPAC, was selected to 1977-2005.
2. All developed storms which had a wind speed exceeding 65 knots (33.4 ms⁻¹) during the time period were then selected.
3. Another selection was then preformed on the tracks retrieved in (2) where the threshold value was set to 64 knots (33 ms⁻¹). This selection was only possible to do in this step.
4. The tracks were then entered into Excel.

Method for the TY intensity in the NWPAC:

To be able to create a plot of the mean annual typhoon intensity, the maximum wind speed of each TY was required. This was done by analyzing each TY track (which were retrieved in the previous section) separately. Each typhoon event was represented on its own page, linked from the result page. The values of all maximum measured wind speeds, for each TY event, were then registered in Excel where a mean value was calculated for each year.

Method for the land fallen TYs in China:

1. All storms with a wind speed exceeding 33 ms⁻¹ (64 knots) were selected in the searchable database.
2. The graphics of each TY event were analyzed. Only those TYs which entered Chinese coastal boundaries were selected.

¹ http://agora.ex.nii.ac.jp/digital-typhoon/index.html.en
3. In the next selection only those typhoons with TY strength, at the time of landfall, were chosen.
4. All the track animations were then analyzed in GE (see below).
5. Only the first province affected by the typhoon was counted for.
6. All land fallen TYs were then entered into Excel.

Due to poor resolution in the best track graphics the GE animation data was used to perform a more thorough analyze of the TY track. Since the measured data was only registered every three-six hours, it was in some cases hard to decide if it really was a typhoon landfall or not. In those cases where the wind intensity of a TY exceeded 33 ms$^{-1}$ (64 knots) just prior to landfall, it was classified as a typhoon landfall (figure 3A). In those cases where the distance between land and the last measured typhoon intensity was greater than half the distance between two measurements they were not accounted for (figure 3B). This method was developed for this study, due to the lack of wind data at the time of landfall, and is not known to have been used in previous studies.

![Figure 3A](image1.jpg) **Figure 3A.** This was counted for as a typhoon landfall. Red dot $\geq$ TY strength.

![Figure 3B](image2.jpg) **Figure 3B.** This was NOT counted as a typhoon landfall. Red dot $\geq$ TY strength.

**Method for mean annual maximum wind speed of land fallen TYs:**
A mean was calculated for each year. Only the intensity of the TY which made land fall in the first province was counted for.

**Method for the monthly distribution of land fallen typhoons in China:**
Each TY track retrieved in the selection for *Method for the land fallen TYs in China* were analyzed. The month of each land fall was registered in Excel and plotted.

**Method for the land fallen TYs in different provinces in China:**
All tracks retrieved in *Method for the land fallen TYs in China* (1-4) were analyzed in GE to see in which province the landfall occurred. Each province affected by the TY (with TY strength), was counted for. Each event was manually counted and entered in Excel.
2.2 Case studies

The 3-6 hourly wind data was retrieved from the Kitamoto webpage. Total daily precipitation data for two of the case studies was provided by Professor Deliang Chen at the Göteborg University. The precipitation data comes from two climate stations in China (stations: 58569 and 59758). The stations are situated closest to the area where the TYs made landfall.

The rainfall accumulation plots for two of the case studies, Haitang and Khanun, were provided by Dr Scott Braun at the Tropical Rainfall Measuring Mission at National Aeronautics and Space Administration (TRMM/NASA). The accumulated rainfall is that which comes only from rainfall within 6 degrees of the storm center. Anything further out is considered to be not associated with the storm. The accumulation period covers the entire lifecycle of the storm according to the JTWC best track data.

The data table containing the (3-6) hourly wind data of each TY was saved and entered into Excel. The unit was expressed in knots and was recalculated to m s\(^{-1}\). A graph was created with then new recalculated values. The precipitation data from the climate stations were recalculated (multiplied with 0.1). The days where data is missing have been labeled with an x in the graphs.

2.3 Precipitation anomalies

The precipitation data was retrieved through the Global Climate at a Glance (GCAG) database on the webpage of the National Climatic Data Center (NCDC). The data is based on datasets from the Global Historical Climatology Network (GHCN) and contains gridded precipitation anomalies calculated from the GHCN V2 monthly precipitation data set.

The GHCN V2 is a comprehensive global surface baseline climate data set. It is designed for monitoring and detecting climate change and is comprised of surface station observations of temperature, precipitation, and pressure. GHCN V2 is produced jointly by the National Climatic Data Center (NCDC), Arizona State University, and Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory (http://mercury.ornl.gov). Each month of data consists of 2592 gridded data points produced on a 5 X 5 degree basis for the entire globe (72 longitude X 36 latitude grid boxes). Gridded data for every month from January 1900 to the most recent month is available. The data shows the anomalies in precipitation in millimeters and have been calculated with respect to the base period 1961 - 1990 using a traditional anomaly method (www.ncdc.noaa.gov).

Method for the Precipitation anomalies for Southeast China, January-December & July-September, 1977-2005:

1. Global Time Series for was selected on the GCAG webpage.
2. Following Selected Dataset was submitted: Precipitation Anomalies and Totals: GHCN Land Surface Data [Anomalies].
3. The time period was set to 1977-2005, with beginning month in January and end month in December (July respectively September for the peak TY-season).
4. The following Longitude and Latitude coordinates were entered: longitude 108-122 E; latitude 21-31 N (Positive South and West coordinate values were entered).
5. The result was plotted directly on the GCAG website in a line plot but also displayed in table format (done with Java Applet version, see discussion).
6. The anomalies for each year (retrieved from the table in (5)) were entered in Excel, where a new graph was created.
Method for the Precipitation anomalies for the provinces, January-December & July-September, 1977-2005:

The same steps were taken as in "Method for the Precipitation anomalies for Southeast China, January-December & July-September, 1977-2005", with the exception of change in coordinates in step (4). The approximate North, South, East and West coordinates of each province, effected by the land fallen TYs, were retrieved through GE. The coordinates was as follows:

- Zhejiang province: selected region: Longitude 118.0 to 122.0 E, Latitude 27.0-31.0 N.
- Hainan province: selected region: Longitude 108.0 to 111.0 E, Latitude 18.0-20.0 N.
- Guangdong province: selected region: Longitude 110.0 to 117.0 E, Latitude 20.0-25.0 N.
- Fujian province: selected region: Longitude 116.0 to 120.0 E, Latitude 24.0-28.0 N.
- Taiwan province: selected region: Longitude 120.0 to 122.0 E, Latitude 22.0-25.0 N.

Method for the comparisment between TY frequency and precipitation anomalies.

Each province which was affected by land fallen TYs were analyzed separately. A first comparesment was made between the years of landfall and the departure in precipitation, where positive and negative anomalies for each landfall occasion were counted. The same procedure was preformed for the years where no TYs made landfalls. This comparesment was made to see the amount of impact that the TYs might have had on the precipitation.
3. Results

3.1 Typhoon trends

Altogether 423 typhoons formed in the NWPAC during 1977-2005 (figure 4). Of these only 53 made TY land fall with an annual mean of 1.8, striking mainly between July and September (figures 6 and 8). Altogether there were 59 TY landfalls. During six occasions a typhoon reached the border of a second province after landfall with TY intensity.

Concerning the TY intensity it can be seen that there has only been a minor decrease in intensity for all the developed TYs in the WPAC (figure 5), while as for the land fallen TYs the decrease is more noticeable (figure 7).

![Figure 4. Typhoon frequency in the NWPAC during the time period 1977–2005.](image)

![Figure 5. Mean annual typhoon intensity in the NWPAC during the time period 1977–2005.](image)

It can be seen in figure 6 that the number of landfallen TYs has varied between non to a maximum of three annually during the studied time period. However in 2005 altogether six TYs made landfall, two in Zhejiang, one in Hainan and three in Taiwan (figures 9-10 and 13). It can also be seen in the provincial plots that the distribution of the land fallen TYs has varied considerable over time (figure 9-13).
Figure 6. Land fallen typhoon frequency in China over the period 1977–2005. Only first-province landfalls are counted for.

Figure 7. Mean annual maximum wind speed of landfallen typhoons in China during the time period 1977-2005.

Figure 8. Monthly distribution of land fallen typhoons in China during the time period 1977-2005.
Figure 9: Annual counts of typhoon landfalls in Zhejiang province, during the time period 1977-2005.

Figure 10: Annual counts of typhoon landfalls in Hainan province, during the time period 1977-2005.

Figure 11: Annual counts of typhoon landfalls in Guangdong province, during the time period 1977-2005.
Figure 12. Annual counts of typhoon landfalls in Fujian province, during the time period 1977-2005.

Figure 13. Annual counts of typhoon landfalls in Taiwan province, during the time period 1977-2005.
3.2 Case Studies

3.2.1 Case study Typhoon 198008 (Joe)

Typhoon Joe developed near the equatorial trough on the 16th of July 1980. It hit eastern Luzon (Philippines) on the 20th. While passing the island Joe weakened in strength, but rebuilt it again over the South China Sea. Two days later, on the 22nd, Joe hit the coast of Hainan Island. At the time of landfall the maximum wind was measured to 36 m/s (figure 14) and the nearest climate station (34 km away) registered almost 110 mm of rain (figure 15). During the night of the 22nd Joe made its final landfall on northern Vietnam before dissipating on the 23rd.

Figure 14. Wind intensity registered for typhoon Joe (16th-23rd of July 1980).

Figure 15. Total daily precipitation measured at climate station 59758, located 34 km away from the land fallen impact area (x= no data available).
3.2.2 Case study Typhoon 200505 (Haitang)

Typhoon Haitang formed out on the WPAC on the 13th of July 2005. It made landfall first time near Hualien, Taiwan on the morning of July 18th. Next day Haitang hit mainland China and made a second landfall, although not with TY strength. Moving inland, through Fujian province, it rapidly lost its strength and finally dissipated over Jiangxi province. At the time of first landfall the maximum wind was measured to about 41 m/s (figure 16). Approximately 450-500 mm rain fell in the northern parts of Taiwan during Haitangs passing (figure 17). Table 1 shows the increase and decrease in precipitation and intensity for Haitang during the 13th-19th of July. It can be seen that during two occasions both the wind and the precipitation intensified and during two occasions the opposite occurred.

![Figure 16. Wind intensity registered for typhoon Haitang (11\textsuperscript{th}-21\textsuperscript{st} of July 2005).](image)

![Figure 17. Precipitation distribution associated with typhoon Haitang.](image)

<table>
<thead>
<tr>
<th>Day</th>
<th>Precipitation</th>
<th>Wind intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-14</td>
<td>$i$</td>
<td>$i$</td>
</tr>
<tr>
<td>14-15</td>
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<td>$i$</td>
</tr>
<tr>
<td>15-16</td>
<td>$i$</td>
<td>$i$</td>
</tr>
<tr>
<td>16-17</td>
<td>$d$</td>
<td>$d$</td>
</tr>
<tr>
<td>17-18</td>
<td>$i$</td>
<td>$d$</td>
</tr>
<tr>
<td>18-19</td>
<td>$d$</td>
<td>$d$</td>
</tr>
</tbody>
</table>
3.2.3 Case study Typhoon 200515 (Khanun)

Khanun developed on the 7th of September 2005 and made land fall in Shangpang, Zhejiang province, on the 11th (06:00 UTC). At the time of landfall the maximum wind was measured to 39 m/s (figure 18). The nearest climate station (54 km away) registered almost 80 mm (figure 19) of rain the same day that Khanun made landfall. The area around the site of landfall got as much as 150 mm of rainfall the same day (figure 20). Continuing north, it passed through Jiangsu province before making a north east bearing. On September the 13th it finally dissipated on the west coast of South Korea. Table 2 below shows the increase and decrease in precipitation and intensity for Khanun during the 7th-12th of July. It can be seen that during three occasions when the wind intensified the precipitation decreased. During one occasion when the wind intensity decreased the precipitation increased. During the last day after Khanun made landfall the wind intensity decreased so did the precipitation.

![Figure 18. Wind intensity registered for typhoon Khanun (5th-13th July 2005).](image1)

![Figure 19. Total daily precipitation measured at Climate station 58569, located 54 km away from the land fallen impact area (x= no data available).](image2)

<table>
<thead>
<tr>
<th>Day</th>
<th>Precipitation</th>
<th>Wind intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8</td>
<td>d</td>
<td>i</td>
</tr>
<tr>
<td>8-9</td>
<td>d</td>
<td>i</td>
</tr>
<tr>
<td>9-10</td>
<td>d</td>
<td>i</td>
</tr>
<tr>
<td>10-11</td>
<td>i</td>
<td>d</td>
</tr>
<tr>
<td>11-12</td>
<td>d</td>
<td>d</td>
</tr>
</tbody>
</table>
Figure 20. Precipitation distribution associated with typhoon Khanun.
### 3.3 Precipitation anomalies

It can be seen in figure 21A that the departure from average precipitation has varied in Southeast China during the studied time period. The years where no TYs made landfall it can be noted that all precipitation anomalies, during peak season, were all negative. On 12 occasions the departure, during peak season, was registered positive counting the years when a TY made landfall. During 14 occasions the departure was negative. Only a minor decrease can be noted for the annual and the seasonal precipitation trends (figure 21B). The highest negative anomaly was registered in 1986, both for the annual and for the peak season, when three TYs made landfall. In 2005 when six TYs made landfall a negative anomaly was also registered. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 3.

![Figure 21. Precipitation anomalies for Southeast China (longitude 108-122 E; latitude 21-31 N): A: January-December. B: July-September (peak TY-season), during the time period 1977-2005. The numbers above figure A represents the number of land fallen typhoons each year.](image)

Table 3. A summary of the frequency of positive and negative precipitation anomalies registered for Southeast China during peak season for landfall and non-landfall events, in numbers (n) and in percent (%).

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>12</td>
<td>14</td>
<td>46</td>
<td>54</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>
Zhejiang Province:

Altogether six TYs made landfall during the studied time period in Zhejiang (figure 22A). The highest positive anomaly (33.5 mm) during the peak season was registered in 1994 when one TY made landfall (figure 20B). In 2005 when two TYs made landfall there was a negative anomaly (-26.1 mm). In 1998, when no TYs made landfall, the highest annual departure from average precipitation was registered. It can be seen that during the years of no landfalls there has been a quite equal distribution in positive (13) and negative anomalies (11) during the peak season. Only a minor decrease can be noted for the annual and the seasonal precipitation trends. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 4.

![Figure 22. Precipitation anomalies for Zhejiang province (longitude 118.0 to 122.0 E, latitude 27.0-31.0 N) during 1977-2005. A: January-December. B: July-September (peak TY-season). The numbers above figure A represents the number of land fallen typhoons each year.](image)

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>3</td>
<td>2</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>13</td>
<td>11</td>
<td>54</td>
<td>46</td>
</tr>
</tbody>
</table>
Hainan Province:

Hainan experienced the highest positive annual anomalies in 1994 and in 2001 when no TYs made land fall (figure 23A). In 2005 the highest negative anomaly, during the peak TY season, was registered to -12.3mm, this year one TY made land fall. In 1996 the highest positive anomaly was registered to 32.9mm, also this year one TY made landfall. During six of the ten occasions when TYs made landfall, the departure from average precipitation during peak season was registered negative (figure 23B). It can be seen that during the years of no landfalls there were registered 12 positive and 7 negative anomalies registered, during the peak season. An increase can be noted for the annual and the seasonal precipitation trends. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 5.

![Graph A](image1.png)

![Graph B](image2.png)

**Figure 23.** Precipitation anomalies for Hainan province (longitude 108.0 to 111.0 E, latitude 18.0-20.0 N) during 1977-2005, A: January-December, B: July-September (peak TY-season). The numbers above figure A represents the number of land fallen typhoons each year.

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>4</td>
<td>6</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>12</td>
<td>7</td>
<td>63</td>
<td>37</td>
</tr>
</tbody>
</table>

Table 5. A summary of the frequency of positive and negative precipitation anomalies registered for Hainan province during peak season for landfall and non-landfall events, in numbers (n) and in percent (%).
Guangdong Province:

For Guangdong the highest positive anomaly for the peak season was registered in 1996, when one single TY made land fall. It can be seen that during the years of landfalls there were an equal distribution in positive (5) and negative anomalies (5), during peak season (figure 24B). It can be seen that during the years of no landfalls there were registered 11 positive and 8 negative anomalies registered, during the peak season. Also in Guangdong an increase can be noted for the annual and the seasonal precipitation trends. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 6.

![Graph A](image1)

![Graph B](image2)

*Figure 24. Precipitation anomalies for Guangdong province (longitude 110.0 to 117.0 E, latitude 20.0-25.0 N) during 1977-2005, A: January-December. B: July-September (peak TY-season). The numbers above figure A represents the number of land fallen typhoons each year.*

Table 6. A summary of the frequency of positive and negative precipitation anomalies registered for Guangdong province during peak season for landfall and non-landfall events, in numbers (n) and in percent (%).

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>5</td>
<td>5</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>11</td>
<td>8</td>
<td>58</td>
<td>42</td>
</tr>
</tbody>
</table>
Fujian Province:

It can be seen that during the years of landfalls in Fujian there were only positive anomalies registered, during peak season (figure 25B). It can be seen that during the years of no landfalls there were registered 8 positive and 15 negative anomalies registered, during the peak season. There is only a slight decrease in trend for the annual departure from average precipitation. It can be seen that during the years of landfalls all registered departures from average precipitation, during peak season, were positive (figure 25B). Only a minor decrease can be noted for the annual and the seasonal precipitation trends. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 7.

![Figure 25](image-url)

Figure 25. Precipitation anomalies for Fujian province (longitude 116.0 to 120.0 E, latitude 24.0 - 28.0 N) during 1977-2005, A: January-December. B: July-September (peak TY-season).

The numbers above figure A represents the number of land fallen typhoons each year.

Table 7. A summary of the frequency of positive and negative precipitation anomalies registered for Fujian province during peak season for landfall and non-landfall events, in numbers (n) and in percent (%).

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>6</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>8</td>
<td>15</td>
<td>35</td>
<td>65</td>
</tr>
</tbody>
</table>
Taiwan Province:

During the peak of TY season in 1993 one of the highest positive precipitation anomalies was measured to 32.1 mm in Taiwan. This year no TY made land fall. However in 2003 the anomaly was -22.5 mm, also this year with no land fallen TYs. In 1986 and in 2005 where the highest frequencies of typhoons, three each year, were recorded the anomalies were negative with -22.0 mm and -13.8 mm respectively. It can be seen that during the years of landfalls there were 11 positive anomalies registered and 5 negative anomalies, during peak season (figure 26B). It can be seen that during the years of no landfalls there were registered 6 positive and 7 negative anomalies during the peak season.

An increase can be noted for the annual and the seasonal precipitation trends. A summary of the distribution of positive and negative precipitation anomalies during landfall and non-landfall events is shown in table 8.

![Graph A](image1.png)

![Graph B](image2.png)

Figure 26. Precipitation anomalies for Taiwan province (longitude 120.0 to 122.0 E, latitude 22.0 - 25.0 N) during 1977-2005, A: January-December. B: July-September (peak TY-season).

The numbers above figure A represents the number of land fallen typhoons each year.

<table>
<thead>
<tr>
<th>Landfalls/Precipitation Anomalies</th>
<th>Positive (n)</th>
<th>Negative (n)</th>
<th>Positive (%)</th>
<th>Negative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During landfall events</td>
<td>11</td>
<td>5</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>During non landfall events</td>
<td>6</td>
<td>7</td>
<td>46</td>
<td>54</td>
</tr>
</tbody>
</table>

Table 8. A summary of the frequency of positive and negative precipitation anomalies registered for Taiwan province during peak season for landfall and non-landfall events, in numbers (n) and in percent (%).
4. Discussion

It has been shown through this study that the frequency of developed TYs in the NWPAC has varied greatly during the past decades and a minor decrease in trend is noted. The TY intensity has only varied slightly and also here a slight decrease in trend is noted. The result in intensity differ from resent studies where it has been shown that there has been an increase in intensity, Webster et al. (2005), Hoyos et al. (2006) and Klotzbach (2006). The difference might be explained by the type of datasets that has been used, as there is a difference in the definition of maximum sustained wind between the JMA and the JTWC-namely 10 minutes mean in Japan, while 1 minute mean in the U.S. In this study a 10 minutes mean has been used while as for the studies conducted by Klotzbach (2006) and Webster et al. (2006) a 1 minutes mean was used. It has however also been suggested by Klotzbach that most of the increase is most likely due to improved observational technology. The difference in results may also be a result of studied time period. Preferably the definition of sustained wind should be that of WMO, where 10 minutes mean is used.

It has been shown that the there has been no significant variation in typhoon landfall frequency during the past thirty years in China. However 2005 was an extreme year when altogether six TYs made land fall; two in Zhejiang, one in Hainan and three in Taiwan. To see what might have caused this peak, a minor analyze between the large scaled oceanic and atmospheric processes El-Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), was made. During a positive phase of the PDO and ENSO the NWPAC experiences a cooling (www.cses.washington.edu). This means that fewer typhoons will develop. However international climate data has shown that 2005 was one of the warmest years on record. During eight of the eleven years (including 2005), when the PDO and ENSO were both in positive phase, the TY frequency did not exceed the mean value in the NWPAC. There were also no extremes in intensity for the land fallen TYs that year (33-43 ms\(^{-1}\)). If this was the case the TYs might have been able to maintain there strength during a longer time period, long enough to cross the coast of China. So what can explained the drastic increase of land fallen TYs in 2005? One thing could be the Western Pacific Subtropical High (WPSH). To what extent the WPSH has affected the movement of the TYs should be the subject of another study.

There might be a minor bias in the TY landfall frequency as there might be missing some real landfalls events or there might even be included events which are not real landfalls. So in retrospect each landfall even, where it was hard to see if it was a land fall or not, should have been analyzed more thoroughly. There should be some information on the intensity at the time of landfall available in other sources, such as news event or even in other major reliable sources. Change of method might also be a way of getting rid of the bias.

The high peak in 2000 in TY landfall intensity was contributed by one single TY and should not be treated as an extreme year. Higher intensities have been registered during the studied time period although they do not show in the calculated mean values.

It is true that one would expect that a correlation would be found with the TY frequency and the precipitation, however in this study the TY’s that merely strike the coast of China has not been counted for. This means that all the precipitation gathered from these TY’s are also included in the annual and seasonal precipitation. Also important to notice is that the season precipitation may already include the heavy precipitation amounts which might gather during occasions like that of Haitang.
5. Conclusions

It has been shown in this study that there is no direct correlation with either the positive nor negative departure in average normal precipitation and frequency of land fallen TYs in China. However, through the case studies, it has been evident that a single typhoon event can have a significant impact on the precipitation. It has also been shown through two of the case studies that no correlation could be found between the wind intensity and the intensity of the precipitation. The results from the precipitation anomalies show that the peak season precipitation anomalies are greater compared with the annual precipitation anomalies; this indicates that the landfallen typhoons have a great impact on the overall precipitation in the Southeast China. However the positive and negative precipitation anomalies in comparison with the TY landfall frequency are quite equally distributed in all the provinces, except in Fujian where all precipitation anomalies showed positive values. It is hereby sufficient to say that this kind of study can only give an idea about the impact that the landfallen TYs have on the precipitation in China. A study should be conducted in which each TY landfall is analyzed as those in the case studies. This can give a better understanding in the mean accumulated precipitation from each TY land fall event which then can be correlated with the mean annual precipitation.
6. References

6.1 Articles


6.2 Internet references


6.3 Figure references

Figure 1. **Map of China with outlined provinces.** 2007-05-03 <http://www.glasslinks.com/images/chinamap.gif> **World map with China highlighted.** 2007-05-03 <http://www.muddlepuddle.co.uk/The%20World/Country%20outlines/worldchina.jpg>.

Figure 2. **Satellite image of a typhoon** 2006-12-28. <http://meted.ucar.edu/hurrican/strike/text/images/eye.gif>.


Figure 3B. **Example of a non typhoon land fall** 2007-04-30. <http://agora.ex.nii.ac.jp/digital-typhoon/kml/wnp/197709-t.en.kml>.


