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Discussion on the Turning Probability of the Typhoons Affecting Taiwan

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Abstract

This research examines the factors that influence typhoon turning by reviewing literature and applying everyday reasoning. We collected typhoon data that hit Taiwan from 2002 to 2022 from the typhoon database, and analyzed the proportion of typhoon turning and its direction during the period of maximum turning angle.

Research motivation and purpose

1. Research motivation

   The western Pacific Ocean is the hotbed of tropical cyclones with the largest area in the world, so Taiwan is often hit by many typhoons in summer and autumn. Whether the typhoon turns is often one of the key items of the track forecast. Therefore, I decided to explore the reasons for typhoon turning. By analyzing the statistics on the proportion of typhoons that turn, I hope to understand the relevant characteristics and laws of typhoon turning. This information could be used as a reference for future typhoon forecasts in Taiwan.

2. Purpose

   (1) Examine the potential causes of a typhoon turning.
   (2) Describe the fundamental aspects of typhoon turning.
   (3) Data on the percentage of typhoons that hit Taiwan.
   (4) To investigate the typhoon's steering path that struck Taiwan during the peak steering angle.

Literature Research

In which direction are typhoons most prevalent? What primary variables are influencing the typhoon's path?

The Pacific subtropical high pressure, which has a major impact on typhoons created in this region, is the cause of the typhoon to the northwest.

1. Subtropical high
   During the summer months of June to August, the sun is directly overhead the northern hemisphere, causing temperatures to rise. This creates a chilly high pressure in the northern section of the Asian continent, which gradually retreats, reducing its force and causing the Pacific high pressure to move northward. Due to the clockwise rotation of high pressure in the northern hemisphere, these areas become susceptible to typhoons. The typhoon typically moves from the edge of the Pacific high pressure towards the Philippines, then turns northwest towards Taiwan before heading towards China and finally northeast towards Japan.

2. Fujiwhara effect
   When two typhoon centers are less than 1350 kilometers apart, they can exert a mutual influence on each other's movement due to their respective circulations, a phenomenon known as the Fujiwara effect. This interaction can significantly affect the course of typhoons, causing them to loop, spin, or even reverse direction relative to their height.

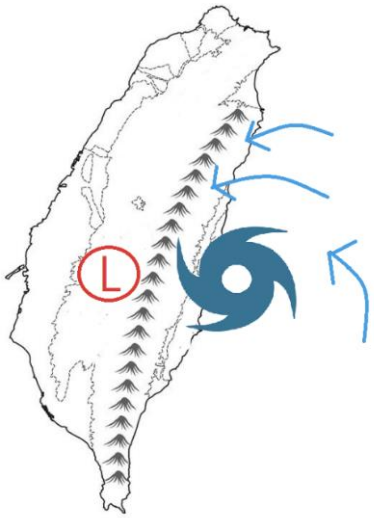
3. Channeling effect
   The leading edge of the typhoon will first be impacted by the terrain when it is close to the land, increasing the speed of the northerly wind and causing the typhoon to change its course southward before making landfall. When a typhoon is in the Taiwan Strait, China's geography blocks the front of the storm, accelerating the northerly or northeasterly wind and changing the typhoon's course to the south, as seen in Figure 1. Also, when a typhoon is close to a piece of land, the wind speed on the west side of the storm will increase. With the greatest vortex variability, a positive vortex field forms on the southeast side of the typhoon and shifts its center southward.

(Figure 1. An illustration of the Channeling effect in the Taiwan Strait)

4. Induced Low

   When a typhoon hits Taiwan or is active in Taiwan's east, southeast, south, or east, the terrain can have an impact on the typhoon or the peripheral airflow, causing it to establish a sub-low pressure center on the leeward side of the mountain range, as shown in Figure 2. In Taiwan's northwest and center, the occurrence rate is the highest.

   After some typhoons hit eastern Taiwan, the low-level typhoon circulation is blocked by the mountains, remaining on the east side of the mountains. Only the middle and upper typhoon circulation cross the central mountain range, connecting with the ground sub-low pressure circulation on the west side of the mountains. This is why the sub-low pressure center takes the place of the main typhoon center and replaces the previous surface low-pressure center by reintegration.



(Figure 2. An illustration of the Induced Low)

Research Methods and Introduction

1. Research methods

   (1) Academic resources: The study utilized the Central Meteorological Administration's typhoon database to gain insight into typhoons that have struck Taiwan between 2002 and 2022, covering nearly 20 years of data.

   (2) Tools for gathering and analyzing data: The Central Meteorological Administration's typhoon database contains a wealth of information, but only the relevant details were included in this study. A list of typhoons that hit Taiwan during the past 20 years was compiled, and any facts and information that may impact the typhoon's path were gathered. Data analysis was performed using Excel, including cross-discussion and the use of quantitative statistics.

   (3) Typhoon Turning Definition: The term "considered the typhoon turning" has no defined meaning. Therefore, this analysis predicts whether a typhoon would turn or not, depending on the amount of change in the direction of typhoon movement per unit time. Two angles, 30 degrees and 90 degrees, were chosen for this study to understand how different angle definitions affect the analysis outcomes, providing a foundation for further research. As a result, the criteria for typhoon turning in this study were when the typhoon intensity reaches a mild typhoon and the turning angle exceeds the threshold angle within a day. The typhoon's left and right sides represent the turning directions. The threshold angles chosen for this investigation were 30 degrees and 90 degrees, respectively.

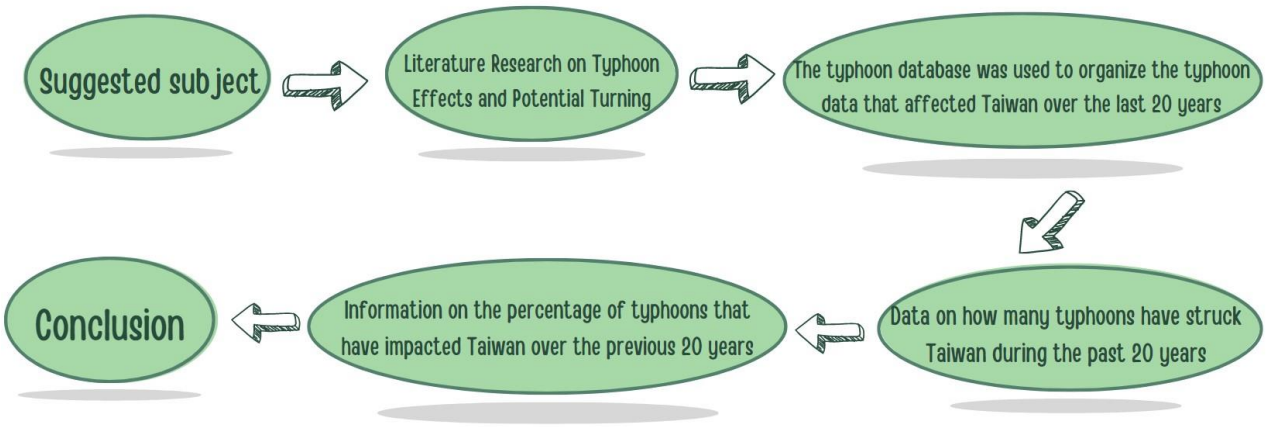
2. Research Process

   (1) Review relevant literature discussing the causes of typhoon turns.

   (2) Utilize the typhoon database from 2002 to 2022 to create an Excel quantitative statistical table containing information about typhoons that have affected Taiwan.

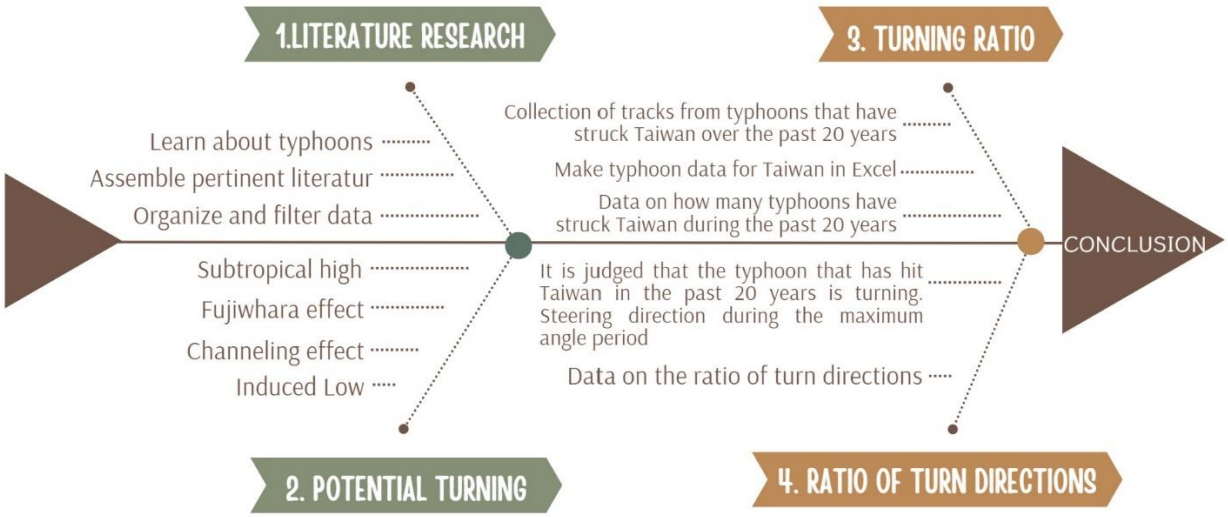
   (3) Generate pie charts and bar charts based on quantitative statistics to illustrate the turning ratio of the typhoons that struck Taiwan during this time.

   (4) Perform a statistical analysis of the ratio of each turning direction and the direction that the invading typhoon turned at its maximum turning angle during this period.



(Figure 3. Flowchart for research)

3. Conceptual Framework



(Figure 4. Research Architecture Diagram)

Research Data, Results, and Discussion

As previously stated, this study determines whether a typhoon will turn based on the rate of change in its movement direction over time. The study uses a threshold angle of 30 degrees and 90 degrees. If the typhoon's direction changes by more than the threshold angle within a day, and its intensity reaches at least "mild typhoon" level, it is considered to have turned.

1. Turning ratio of typhoons hitting Taiwan

We analyzed the maximum turning angle and turning direction from the typhoon track map and organized typhoon data from 2002 to 2022 into an Excel table, including the typhoon year, name, path number, and the intensity. Table 1 shows that we used the typhoon track map to determine whether the typhoon had turned, based on two steering definitions. We recorded the date with the largest angle and the steering direction during that time in our Excel table.

Year	Name	Path Number	Intensity	The Maximum Angle	The date with the largest angle	The steering direction during the time period with the largest steering angle	More than 30 degrees	More than 90 degrees
2022	Xuan Lannuo	6	Severe	130	9/1~9/2	Right	Yes	Yes
2021	Chanthu	6	Severe	90	9/15~9/16	Left	Yes	Yes
2020	Atsani	5	Mild	90	11/3~11/4	Right	Yes	Yes
2019	Bailu	4	Mild	68	8/22~8/23	Right	Yes	No
2019	Mitag	6	Moderate	45	10/1~10/2	Right	Yes	No
2019	Lekima	1	Severe	42	8/6~8/7	Right	Yes	No
2018	Maria	1	Severe	17	7/8~7/9	Left	No	No
2017	Haitang	7	Mild	137	7/30~7/31	Left	Yes	Yes
2017	Nesat	2	Moderate	54	7/26~7/27	Right	Yes	No
2016	Megi	3	Moderate	86	9/27~9/28	Right	Yes	No
2016	Nepartak	4	Severe	61	7/8~7/9	Right	Yes	No
2016	Meranti	7	Severe	43	9/14~9/15	Right	Yes	No
2015	Soudelor	3	Moderate	77	8/8~8/9	Right	Yes	No
2015	Dujuan	2	Severe	65	9/24~9/25	Right	Yes	No
2014	Matmo	3	Moderate	64	7/19~7/20	Right	Yes	No
2014	Fung-wong	Special	Mild	61	9/20~9/21	Right	Yes	No

2013	Usagi	5	Severe	68	9/19~9/20	Left	Yes	No
2013	Fitow	1	Moderate	63	10/4~10/5	Left	Yes	No
2013	Trami	1	Mild	53	8/18~8/19	Right	Yes	No
2013	Kong-rey	6	Mild	42	8/28~8/29	Right	Yes	No
2013	Soulik	2	Severe	25	7/12~7/13	Right	No	No
2012	Tembin	Special	Moderate	50	8/27~8/28	Left	Yes	No
2012	Talim	9	Mild	33	6/18~6/19	Left	Yes	No
2012	Saola	2	Moderate	124	8/1~8/2	Right	Yes	Yes
2011	Nanmadol	4	Severe	49	8/26~8/27	Right	Yes	No
2010	Fanapi	4	Moderate	51	9/17~9/18	Left	Yes	No
2010	Megi	9	Moderate	90	10/19~10/20	Right	Yes	Yes
2010	Lionrock	9	Mild	69	8/30~8/31	Right	Yes	No
2009	Parma	Special	Moderate	180	10/4~10/5	Special	Yes	Yes
2009	Morakot	3	Moderate	88	8/4~8/5	Left	Yes	No
2009	Linfa	9	Mild	81	6/19~6/20	Left	Yes	No
2008	Fung-wong	3	Moderate	29	7/27~7/28	Left	No	No
2008	Jangmi	2	Severe	90	9/29~9/30	Right	Yes	Yes
2008	Kalmaegi	2	Moderate	66	7/16~7/17	Right	Yes	No
2008	Sinlaku	2	Severe	53	9/10~9/11	Right	Yes	No
2007	Pabuk	4	Mild	32	8/6~8/7	Left	Yes	No
2007	Wutip	3	Mild	12	8/8~8/9	Left	No	No
2007	Sepat	3	Severe	68	8/15~8/16	Right	Yes	No
2007	Krosa	2	Severe	43	10/5~10/6	Right	Yes	No
2007	Wipha	1	Moderate	23	9/17~9/18	Right	No	No
2006	Bilis	2	Mild	62	7/14~7/15	Left	Yes	No
2006	Kaemi	3	Moderate	30	7/21~7/22	Left	Yes	No
2006	Bopha	4	Mild	25	8/6~8/7	Left	No	No
2006	Chanchu	9	Moderate	81	5/14~5/15	Right	Yes	No
2005	Haitang	3	Severe	47	7/12~7/13	Left	Yes	No
2005	Matsa	1	Moderate	41	8/5~8/6	Left	Yes	No
2005	Talim	3	Severe	31	8/27~8/28	Left	Yes	No

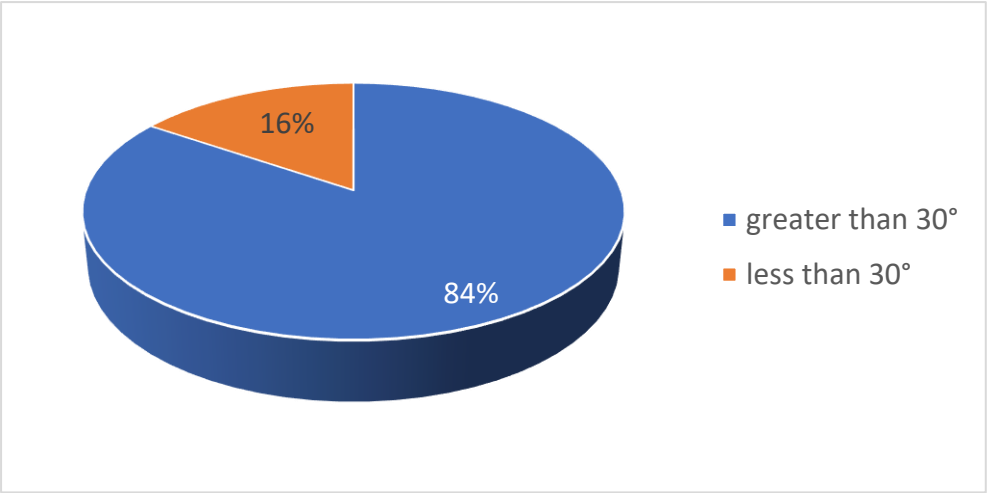
2005	Longwang	3	Severe	27	9/27~9/28	Left	No	No
2004	Aere	1	Moderate	68	8/20~8/21	Left	Yes	No
2004	Haima	6	Mild	32	9/12~9/13	Left	Yes	No
2004	Nanmadol	9	Moderate	97	12/3~12/4	Right	Yes	Yes
2004	Nock-ten	6	Moderate	81	10/25~10/26	Right	Yes	No
2004	Mindulle	6	Moderate	80	6/30~7/1	Right	Yes	No
2003	Melor	8	Mild	66	11/2~11/3	Right	Yes	No
2003	Morakot	4	Mild	26	8/3~8/4	Right	No	No
2003	Dujuan	5	Moderate	25	8/30~8/31	Right	No	No
2002	Nakri	9	Mild	90	7/11~7/12	Left	Yes	Yes
2002	Sinlaku	1	Moderate	32	8/30~8/31	Left	Yes	No

(Table 1. Typhoon Information Sheet)

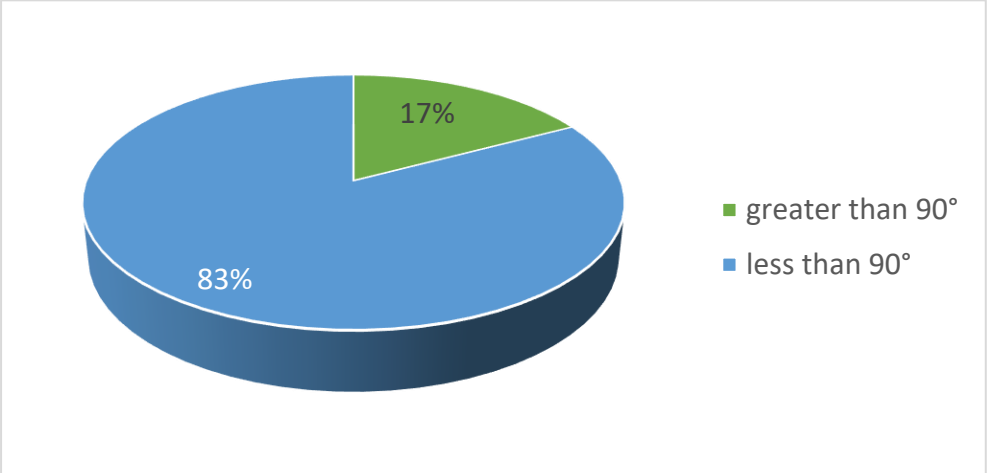
Calculate the ratio of typhoon turning, which is described in Table 1 as follows, based on the two definitions of turning.

(1) When it becomes a light typhoon in intensity and has a turning angle higher than 30 degrees in a single day: The percentage of typhoons that struck Taiwan between 2002 and 2022 and turned more than 30 degrees in a single day is much higher than the percentage of those that did not turn at all.Of these, 49 typhoons turned, making up over 84% of the total, while the remaining 9 typhoons did not turn, making up roughly 16% of the total. Figure 5 displays the results, with the blue region representing steering angles more than 30 degrees and the orange region representing steering angles less than 30 degrees.

(2) When its intensity reaches a mild typhoon and it turns more than 90 degrees in one day: Out of the 58 typhoons that hit Taiwan from 2002 to 2022, the proportion of those that turned more than 90 degrees in one day was much lower than the proportion of those that did not turn at all. Among them, only 10 typhoons turned, accounting for about 17% of the total, while the other 48 typhoons did not turn, accounting for about 83% of the total. Figure 6 illustrates this, with the green area denoting steering angles greater than 90 degrees, and the blue area denoting angles less than 90 degrees.

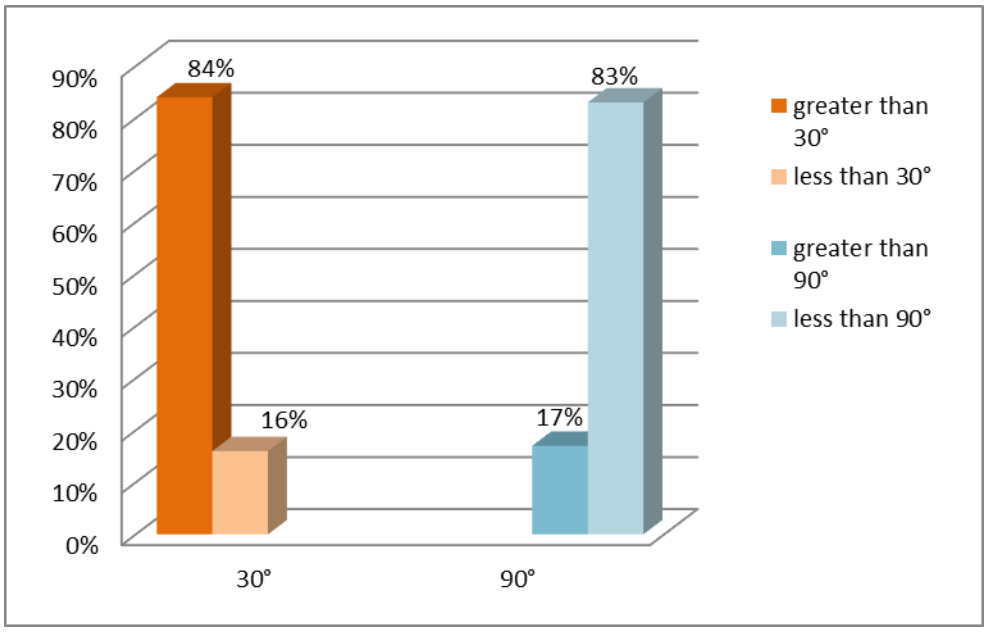


(Figure 4. Percentage Map of Typhoons with Maximum Turning Angle Greater Than 30 Degrees in Taiwan in the Past 20 Years)



(Figure 5. Percentage Map of Typhoons with Maximum Turning Angle Greater Than 90 Degrees in Taiwan in the Past 20 Years)

Combining the two conclusions above, we can create Figure 6, where the dark orange area represents steering angles greater than 30 degrees, the light orange area represents steering angles less than 30 degrees, the dark blue area represents steering angles greater than 90 degrees, and the light blue area represents steering angles less than 90 degrees. It can be seen that typhoon turning is a normal phenomenon, and the majority of typhoons turn at angles greater than 30 degrees, while only a few typhoons turn at angles greater than 90 degrees.

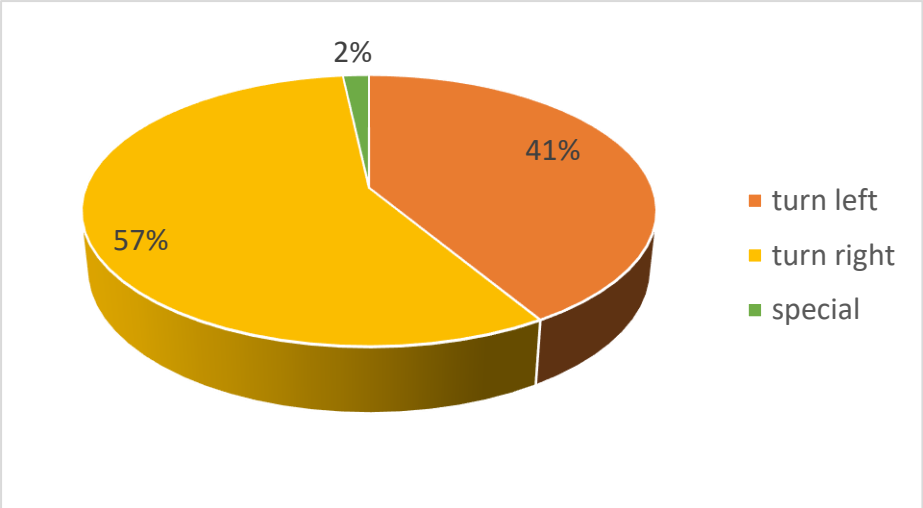


(Figure 6. Comparison of Maximum Turning Angles of Typhoons that Hit Taiwan in the Past 20 Years)

2. Steering Direction of Typhoons During Maximum Steering Angle

(1) For all typhoons that hit Taiwan: We can determine the steering direction of the typhoon during the period of maximum steering angle by analyzing the typhoon track map in the typhoon database and using the definition of typhoon steering in this study. The ratios can be calculated and summarized in Table 1.

According to the statistics of this study, out of the 58 typhoons that hit Taiwan between 2002 and 2022, 24 typhoons turned left during the period with the largest steering angle, accounting for about 41% of the total, while the other 33 turned right, accounting for about 57% of the total. There was one typhoon (Parma) where the maximum steering angle was 180 degrees, making it impossible to determine its steering direction, and thus it was classified as a special category, as shown in Figure 7. The yellow area in the figure represents typhoons that turned right, the orange area represents typhoons that turned left, and the green area represents the special case of Typhoon Parma.



(Figure 7. Steering Direction of Typhoons during Maximum Steering Angle in Taiwan)

(2)Typhoon turning greater than 90 degrees: This study sorted out the typhoon data that hit Taiwan from 2002 to 2022 through the typhoon database and obtained the turning ratio of typhoons under two different definitions of 30 degrees and 90 degrees. The study draws three conclusions related to the typhoon's steering direction during the period of the maximum steering angle. If the typhoon greater than 90 degrees is combined with the steering direction during the period of maximum steering angle, it can be concluded that when the intensity of the typhoon reaches a mild typhoon and the typhoon turns greater than 90 degrees in a day, there are 10 typhoons. Out of these, 60% of typhoons steer to the right during the period of maximum steering angle.

Conclusion

1. According to literature research, Subtropical high, Fujiwhara effect, Channeling effect, and Induced Low are the variables influencing the typhoon's turn. The subtropical high is the major contributor among them.
2. From 2002 to 2022, a total of 58 typhoons made landfall in Taiwan with an average turning angle of approximately 61.26 degrees. Among them, Typhoon Parma had the highest turning angle of 180 degrees, while Typhoon Wutip had the lowest.

3. According to the statistical analysis of this study, in the past 20 years, if the typhoon intensity reaches a mild typhoon, the proportion of turning over 30 degrees in one day is about 84%, which is much higher than the proportion of not turning; if defined as the current If the intensity reaches a mild typhoon and turns more than 90 degrees in one day, the turning ratio is about 17%, which is much lower than the non-turning ratio, as shown in Figure 6.
4. Figure 7 shows that during the past 20 years, 57% of the typhoons that hit Taiwan turned to the right, which is higher than the 41% that turned to the left. This indicates that, in the life cycle of typhoons, the period with the largest steering angle tends to have a higher proportion of right-turning typhoons compared to left-turning ones. Taking into account only the typhoons with a steering angle greater than 90 degrees, it was found that 60% of them turned to the right during the period of maximum steering angle. This finding can be useful as a reference for future typhoon prediction.

Future Work

1. This research mainly focuses on the turning direction of the typhoon during the period of maximum turning angle. Therefore, it is recommended that future research can expand its investigation to the turning direction data of the typhoon during its formation and cessation. This will assist in providing accurate predictions for the overall path of the typhoon and revising the forecast during the course of the typhoon, resulting in more precise typhoon track predictions.
2. This research did not calculate the proportion of factors that affect the typhoon's turn, such as the proportion of the subtropical high that affects the typhoon's turn. Therefore, future research could investigate this relationship, examine the factors that influence each typhoon's turn, and calculate the proportion of each factor. This approach would enhance the study's uniqueness and increase its reference value

Review of Literature

SCIENTIFIC AMERICAN - Typhoons: monsters with swirling air currents
https://sa.ylib.com/MagArticle.aspx?id=1054

Sci-Tech Vista - Fujiwhara effect:The waltz of typhoons and typhoons
https://scitechvista.nat.gov.tw/Article/c000008/detail?ID=4c9cbb84-1985-4a52-a283-73d1822e4982

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NATIONAL TAIWAN NORMAL UNIVERSITY - Numerical Simulation and Study of Typhoon Soudelor(2015)
https://etds.lib.ntnu.edu.tw/thesis/detail/8a49e6f4a00014f3921dec823feb6648/

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http://ir.lib.ncu.edu.tw:88/thesis/view_etd.asp?URN=966201002&fileName=GC966201002.pdf#

MADF - Typhoon and Taiwan Terrain
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