The triggered mechanism of typhoon-induced debris flows and landslides over mainland China

G. P. Zhang, J. Xu, F. W. Xu, L. N. Zhao, Y. M. Li, J. Li, X. D. Yang & J. Y. Di
National Meteorological Center, Chinese Meteorological Administration, China

Abstract

Typhoon-induced rainstorms can trigger debris flow and landslide, causing severe losses and casualties in China. Analysis of antecedent precipitation ($P_A$), threshold precipitation ($P_C$), mean precipitation intensity ($P_{M}$), precipitation duration ($T_D$) and the lag time ($T_L$) for typhoon- and non-typhoon-induced shows that: 1) $P_C$ is greater and $P_A$ is lower for typhoon-induced rainstorms. For typhoon-induced rainstorms, when $P_A$ is within 50–100mm and $P_C$ is greater than 200mm/d, landslides and debris flows are mostly likely to happen. As for non-typhoon-induced rainstorms, $P_A$ is within 100–150mm and $P_C$ is within 150–200mm/d. 2). After one day of typhoon precipitation, debris flow and landslides are more likely to happen. However, for non-typhoon-induced rainstorms it is usually 2–3 days. 3) For typhoon-induced rainstorms, 75% of debris flow and landslides happen during the day when maximum precipitation intensity occurs; for non-typhoon-induced rainstorms, 45% of hazards happen 2–12 days after the maximum precipitation day. 4) Typhoon-triggered debris flow and landslides have a lower environmental danger value compared to those that are non-typhoon triggered.

Keywords: debris flow and landslide, typhoon, non-typhoon, China.

1 Introduction

China is one of the countries that has the most landfall typhoons. In the coastal areas of south-east and southern China, due to the north-to-south direction of the
mountain ranges, the terrain plays an important role in strengthening the precipitation intensity. When a typhoon meets the cold air from the north, the precipitation will also be intensified. The break-record precipitation is always induced by landing typhoons in southeast China. The daily precipitation of landing typhoons is about 300–900mm, with several cases more than 1000mm. The storm induced by the typhoon triggers a great number of debris flows and landslides in southeast China.

Many studies show that for typhoon- and non-typhoon-induced rainstorms, the precipitation triggering mechanism is quite different. The duration of precipitation for typhoon-triggered debris flows and landslides is less than that of non-typhoon-triggered debris flows and landslides in Zhejiang province, southeast China; the antecedent and threshold precipitation for typhoon-induced debris flows and landslides are both higher than that of non-typhoon-induced debris flows and landslides [1–3]. Typhoon-triggered debris flows often happen within one hour of the moment of peak precipitation in Chinese Taiwan province [4]. Typhoons trigger shallow landslides followed by debris flows in Hong Kong [5]. For typhoon-triggered debris flows and landslides, antecedent precipitation is not the most important factor [6].

This paper plots the typhoon zonation map and analyzes the mechanism of typhoon- and non-typhoon-triggered debris flows and landslides.

2 Mapping typhoon intensity

To analyze the typhoon- and non-typhoon-triggered debris flows and landslides, a zonal map is needed. So, within the typhoon influence area, the landslides and debris events can be classified as typhoon- and non-typhoon-triggered.

The track data of tropical cyclones provided by the Joint Typhoon Warning Center (JTWC) of the USA navy over the western North Pacific, including the South China Sea from 1950 to 2009, are spatially mapped with GIS software. The typhoon routes are plotted as a line shape. The intensity of typhoons is spatially mapped with the following formula:

\[ T_{i,j} = \sum_{n=1}^{N} \sum_{m=1}^{M_n} S_m \times L \]  

(1)

where, \( T_{i,j} \) is the intensity of the typhoon at grid site \((i, j)\), the unit is \( \text{km/km}^2 \); \( N \) is the total number of typhoon routes; \( M_n \) is the total number of components when the \( n \)th typhoon route is cut into small parts with unit length of \( L \) and \( S_m \) is the Boolean value, defined as follows:

\[ S_m = \begin{cases} 1, & d_{mij} \leq R \\ 0, & d_{mij} > R \end{cases} \]

(2)

where \( d_{mij} \) is the geographical distance from the centre of grid \((i, j)\) to the \( m \)th partition of typhoon route and \( R \) is the average radius of the typhoon.
The total number of typhoon routes is 1888, the average radius of typhoons is supposed to be 400km. The paper uses the spatial analysis model of ArcGIS software to fulfil the above work. The raster map is generated and then converted to a contour map, see fig. 1.

From Fig. 1, the typhoon-influenced area of China can be divided into three regions. Region I, including Hainan Island and Taiwan Island, is the most serious. Region II includes Zhejiang, Fujian and Guangdong Province. Region III includes all the coastal provinces except for region I, II, and many inland provinces that are attacked frequently by typhoons, see fig. 2.

![Figure 1: The spatial distribution of typhoon intensity.](image1)

![Figure 2: The zonation of typhoon intensity.](image2)
3 Precipitation analysis between typhoon- and non-typhoon-induced debris flows and landslides in regions II and III

To analyze the difference between typhoon and non-typhoon induced debris flows and landslides, eight cases of typhoon-induced storms and eight cases of non-typhoon-induced storms were selected based on the integrity of the events of debris flows and landslides, as shown in table 1. For each debris flow and landslide event, the 15 days precipitation data before the event were processed. All of the analysis is based on the hazards and precipitation data as shown in table 1.

The debris flow and landslide hazard during the period listed in table 1 is extracted from the hazard database. The precipitation observation is processed and interpolated to the hazard site.

The antecedent precipitation ($P_A$), threshold precipitation ($P_C$), mean precipitation intensity ($P_M$), precipitation duration ($T_D$) and lag time ($T_L$) are calculated and analyzed for typhoon-induced and non-typhoon-induced storms. The antecedent precipitation is calculated with the formula below:

$$ P_A = \sum_{i=1}^{15} 0.8^i P_i $$

where $P_A$ is antecedent precipitation and $P_i$ is the $i$th day precipitation before the debris flow and landslide event.

Since the precise hour of the debris flow and landslide is not recorded, $P_C$ in the paper is approximately replaced with the precipitation of the day when the debris flow and landslide happened. $P_M$ refers to the average daily precipitation within continuous precipitation days before the landslide and debris happened. $T_D$ refers to the precipitation duration in days before the landslide and debris flow happened. $T_L$ refers to the number of days after the maximum precipitation day.

Table 1: The list of landslide and debris hazards for precipitation analysis.
3.1 $P_A$ and $P_C$ analysis

Fig. 3 shows the $P_A$ distribution for typhoon- and non-typhoon-induced storms. Compared to non-typhoon-, typhoon-induced debris flows and landslides need less $P_A$. It is mostly within 50–100mm for typhoon-induced debris flows and landslides, but for non-typhoon-induced debris flows and landslides it is mostly within 100–300mm.

Fig. 4 shows the $P_C$ distribution for typhoon- and non-typhoon-induced debris flows and landslides. Compared to non-typhoon-, typhoon-induced debris flows and landslides need greater $P_C$. It is mostly within 0–50mm/d for non-typhoon-induced debris flows and landslides, but for typhoon-induced debris flows and landslides it is mostly more than 200mm/d.

The relation between $P_C$ and $P_A$ for typhoon-induced and non-typhoon-induced debris flows and landslides is plotted in figs. 5 and 6, respectively. $P_C$ is decreasing while $P_A$ is increasing both for typhoon- and non-typhoon-induced debris flows and landslides, but their features are quite different.
When $P_A$ is within 0–100mm, greater $P_C$ is needed to trigger typhoon-induced debris flows and landslides, and when $P_A$ is greater than 100m, lower $P_C$ is needed, see fig. 5. When $P_A$ is within 50–100mm, 27% of debris flows and landslides happened when $P_C$ is greater than 200mm. Greater $P_A$ is needed for non-typhoon-induced debris floss and landslides, see fig. 6. Nearly 52.8% of debris flows and landslides happened when $P_A$ was greater than 150mm.

The difference between typhoon- and non-typhoon-induced debris flows and landslides is that $P_C$ is greater and $P_A$ is lower for those that are typhoon induced. When $P_A$ is within 50–100mm and $P_C$ is greater than 200mm/d, typhoon-induced debris flows and landslides are mostly likely to happen, but non-typhoon-induced debris flows and landslides are most likely when $P_A$ is within 100–150mm and $P_C$ is within 150–200mm/d.

3.2 Comparison of $T_D$ between typhoon- and non-typhoon-triggered debris flows and landslides

For typhoon-triggered debris flows and landslides, $T_D$ is mainly within 2–3 days, in which more than 70% of hazards happened. However, for non-typhoon-
triggered debris flows and landslides, $T_D$ is in a greater range, and it shows a relatively high peak within 4–5 days, see fig. 7.

It can be seen from fig. 7 that after one day of typhoon precipitation, debris flows and landslides are more likely to happen. However, for non-typhoon-triggered debris flows and landslides it is usually 2–3 days.

The relation of $T_D$ and $P_M$ for typhoon- and non-typhoon-triggered debris flows and landslides are plotted in fig. 8. Although for typhoon- and non-typhoon-triggered debris flows and landslides the $T_D$ are both great, they are temporally quite different. The precipitation for typhoon-triggered debris flows and landslides is mostly distributed within or one day before the hazards happened, but for non-typhoon-triggered debris flows and landslides this is 1–7 days after the typhoon.

### 3.3 Lag time after the maximum precipitation intensity

The period after the maximum precipitation day is called lay time ($T_L$) and is plotted, for typhoon- and non-typhoon-triggered debris flows and landslides, in fig. 9. It can be seen that 75% of debris flows and landslides happened during the maximum precipitation day of the typhoon, and 10% happened just one day before the maximum precipitation day.

![Figure 7](image-url) Duration for typhoon- and non-typhoon-triggered debris flows and landslides.

![Figure 8](image-url) Duration and mean intensity of precipitation for typhoon- and non-typhoon-triggered debris flows and landslides.
Figure 9: Lag time after the maximum precipitation day for typhoon- and non-typhoon-triggered debris flows and landslides.

Figure 10: Precipitation duration ($T_D$) and threshold precipitation ($P_C$) for typhoon-triggered debris flows and landslides.

Figure 11: Precipitation duration ($T_D$) and threshold precipitation ($P_C$) for non-typhoon-triggered debris flows and landslides.
Non-typhoon-triggered debris flows and landslides are roughly the same as typhoon-triggered debris flows and landslides during or one day before the maximum precipitation day, but there still 45% of hazards happened 2–12 days after the maximum precipitation day.

3.4 Analysis of $T_D$ and $P_C$

It is shown that shorter $T_D$ corresponds to lower $P_C$, see fig. 10. For typhoon-triggered debris flows and landslides, 23.7% happen when $T_D$ is two days and $P_C$ is greater than 200mm/d; while 19.6% happen when $T_D$ is three days and $P_C$ is within 100–200mm/d.

For non-typhoon-triggered debris flows and landslides, the frequency is distributed more evenly, see fig. 11. When $T_D$ is 3–4 days and $P_C$ is within 100–200mm/d, the debris flows and landslides are more likely to happen. They are also more likely to happen when $T_D$ is greater than 9 and $P_C$ is greater than 50mm.

4 The environmental background in region II

The environmental background, which is made up of several topography, geology and land-use factors, plays an important role for debris flow and landslide occurrence. Six factors, altitude, aspect, slope, lithology, geological fault line density and land-use, are taken into consideration. Each factor is rasterized and reclassified with GIS tools, then the Information Model is used:

$$I_i = \sum_{j=1}^{m_i} \ln\left(\frac{N_{i,j}}{N} / \frac{S_{i,j}}{S}\right)$$

$$I = \sum_{i=1}^{6} W_i I_i$$

where, $m_i$ is the number of classes for factor $X_i$, $N$ is the total number of debris flow and landslide hazard occurrences, $N_{i,j}$ is the total number of debris flows and landslides at the pixel where the factor $X_i$ is equal to $j$ ($i=1,2,...,m_i$), $S$ is the total number of pixels within the research area, $S_{i,j}$ is the total number of the pixels where factor $X_i$ is equal to $j$, $W_i$ is the weight of the factor $X_i$, $I_i$ is the information for factor $X_i$, and $I$ is total information.

The value of $I$ reflects the debris flow and landslide hazard vulnerability. It is reclassified to be the hazard danger value. The environmental danger value for typhoon- and non-typhoon-triggered debris flows and landslides are extracted respectively and plotted in fig. 12. The environmental background is described with a danger value of 1–5, the larger the value, the more likely the debris flow and landslide is to happen.

The danger zoning map shows the vulnerability to debris flows and landslides. Both typhoon- and non-typhoon-triggered debris flows and landslides happen more frequently when environment danger value is increased, see fig. 12. However, the two triggers are quite different. For typhoon-triggered debris flows and landslides, a lower danger value of environmental background is needed when compared to non-typhoon-induced debris flows and landslides.
5 Conclusions

The typhoon-influenced area of China can be divided into three regions. The typhoon intensity is has neither increased nor decreased persistently for the entire region II since 1950. It varies from north to south within different decades.

The difference between typhoon- and non-typhoon-triggered debris flows and landslides is that $P_C$ is greater and $P_A$ is lower for those induced by typhoons. Typhoon-induced debris flows and landslides are most likely to happen when $P_A$ is within 50–100mm and $P_C$ is greater than 200mm/d, but non-typhoon-triggered debris flows and landslides are most likely to happen when $P_A$ is within 100–150mm and $P_C$ is within 150–200mm/d. After one day of typhoon precipitation, debris flows and landslides are more likely to happen. However, for non-typhoon-triggered debris flows and landslides it is usually 2–3 days. For typhoon-triggered debris flows and landslides, 75% happened during the day when maximum precipitation intensity appeared; for non-typhoon-triggered debris flows and landslides, 45% happened 2–12 days after the maximum precipitation day.

Typhoon-induced debris flows and landslides need a lower danger value of environmental background to be triggered compared to those that are non-typhoon triggered.

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References


