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# Diversity and Geographical Pattern of Altitudinal Belts in the Hengduan Mountains in China

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**Abstract:** This paper analyses the diversity and spatial pattern of the altitudinal belts in the Hengduan Mountains in China. A total of 7 types of base belts and 26 types of altitudinal belts are identified in the study region. The main altitudinal belt lines, such as forest line, the upper limit of dark coniferous forest and snow line, have similar latitudinal and longitudinal spatial patterns, namely, arched quadratic curve model with latitudes and concave quadratic curve model along longitudinal direction. These patterns can be together called as "Hyperbolic-paraboloid model", revealing the complexity and speciality of the environment and ecology in the study region. This result further validates the hypnosis of a common quadratic model for spatial pattern of mountain altitudinal belts proposed by the authors. The spatial pattern of altitudinal belts is closely related with moisture-related exposure effect in the Hengduan Mountains. Different combinations (spectra) of altitudinal belts and different base belt types appear in windward and leeward flanks and even in the same flanks of different ranges. This is closely related with the parallel mountain ranges of the Hengduan Mountains, which, at nearly right angle with the moving direction of prevailing moisture-laden air masses from west and east, hold up the warm and humid monsoon wind from moving into the core region and result in different moisture conditions in windward and leeward flanks. However, how to quantitatively describe the moisture-related exposure effect needs further study. In addition, the data quality and data accuracy at present also affect to some extent the result of quantitative modeling and should be improved with RS/GIS in the future.

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## Introduction

Globally and generally, the upper and lower limits of altitudinal belts vary (increase) from high latitudes to low latitudes, from continental peripheries to inland areas, and from very humid to desert-like systems (Troll 1972a, 1973). In exploring the correlation between alpine timberline elevation and latitude, a tropical plateau model has been identified, i.e., the timberline is high between 32° northern and 20° southern latitudes, and falls gradually toward poles (Hermes 1955, Körner 1998). In immense mountains and plateaus, the spatial distribution of altitudinal belts is actually very complicated due to climatic variation in all directions, e.g., the three-dimensional zonation in the Himalayan system (Troll 1972b). Actually, the altitudinal position of any given altitudinal belt is decided also by other factors, especially regional factors, including mountain effect, slope aspect and prevailing wind. In temperate arid and semi-arid areas, the elevations of altitudinal belts are found quite different in northern and southern slopes (Troll 1972c, Miehe 1994), mainly due to the difference in solar radiation, and the resulted temperature and soil moisture conditions. This phenomenon can be named “Radiation-related exposure effect.” In other cases, several closely and parallel ranking mountain ranges, when at nearly right angle with the moving direction of prevailing moisture-laden air masses, have different combinations (spectra) of altitudinal belts both in windward and leeward flanks and even for the same flanks of different ranges. This could be named “Moisture–related exposure effect.” The most outstanding pattern of close and parallel mountain ranges is the Hengduan Mountains in the southeastern Tibetan Plateau. From west to east, altitudinal belts and their combinations in vertical direction on the west flanks and east flanks of the ranges of the Hengduan Mountains show considerably different.

The study region is characterized by the alternation of great rivers and high mountains from east to west, just like a country of rivers and gorges (Schweinfurth 1972). Joseph Rock had worked there for many years. The northern part of the Hengduan Mountains was listed as a world natural heritage site “Three Parallel Rivers” thanks to its magnificent landscapes, high biodiversity, geological history and diverse cultures. The altitudinal belts of the Hengduan Mountains are most complicated and considerably distinct in the Eurasian continent. The analysis of altitudinal belts in the Hengduan Mountains, especially of the exposure effect of the mountains, greatly helps reveal the spatial pattern of altitudinal belts in the world.

Chinese botanists and physical geographers have investigated the altitudinal belts of the Hengduan Mountains since the late 1950s, and published many reports and papers on the altitudinal types and their distribution. A total of 17 vegetation types were identified, and the quantitative relationship between vegetation distribution and hydrothermal factors was studied (LI 1983). About 9 types of basic belts were outlined, with some works on the structure of altitudinal belt spectra along latitude and longitude (ZHENG 1986). A total of 11 types and 18 sub-types of vegetation were identified, and their distribution along latitude, longitude and on different flanks was elaborated (LIU 1983). These researches gave a general picture of altitudinal belts and their distribution in the Hengduan Mountains. However, it was still very difficult to effectively compare and analyze the altitudinal belts in different mountains because of lack of a consistent and standard classification system for altitudinal belts, and there was no systematical and quantitative analysis of the spatial pattern of altitudinal belts. Although scientists observed the exposure effect and had tried to study it, no remarkable quantitative results have been made because of extremely disperse altitudinal data on different flanks.

76 spectra of altitudinal belts and 9 snow line data of the Hengduan Mountains were collected from published papers and books (Department of Biology of Yunnan University 1957, Institute of Geography, CAS 1982, Geography Institute of Chendu, CAS 1983, HOU 1963, HOU 1982, Integrated Survey Group of Tibet, CAS 1985, Investigating Group for South to North Water Transfer Project 1966, Investigating Group for South to North Water Transfer Project 1980, JIANG 1980, LI 1990, LI 1983, LIU 1983, 1984, 1985, QIAN 1956, Yunnan Agricultural Geography Writing Group 1980, ZHENG 1984, LI 1983, LIU 1981, YANG 1984), and these belts were standardized. Among these spectra, 35 on east flanks and 41 on west flanks of the Hengduan Mountains. The location of spectra and snow lines is shown in Figure 1.

## 1 Base and Altitudinal Belts

7 types of base belts are totally identified, and their general distribution is shown in Table 1. Subtropical monsoon evergreen broad-leaved forest mainly distributes from 1100 m to 2200 m on the windward flank, for examples, the west flanks of mountains west of the Nujiang River or the east flanks of mountains east of the Qionglai Mountains. Subtropical evergreen broad-leaved forest is the most common forest type for the base belts of the west flanks or the east flanks, and it occurs mostly from 1200 m to 2800 m. Subtropical evergreen coniferous forest is the common forest type on the east flanks of the Hengduan Mountains and its distribution ranges from 1000 m to 3200 m.

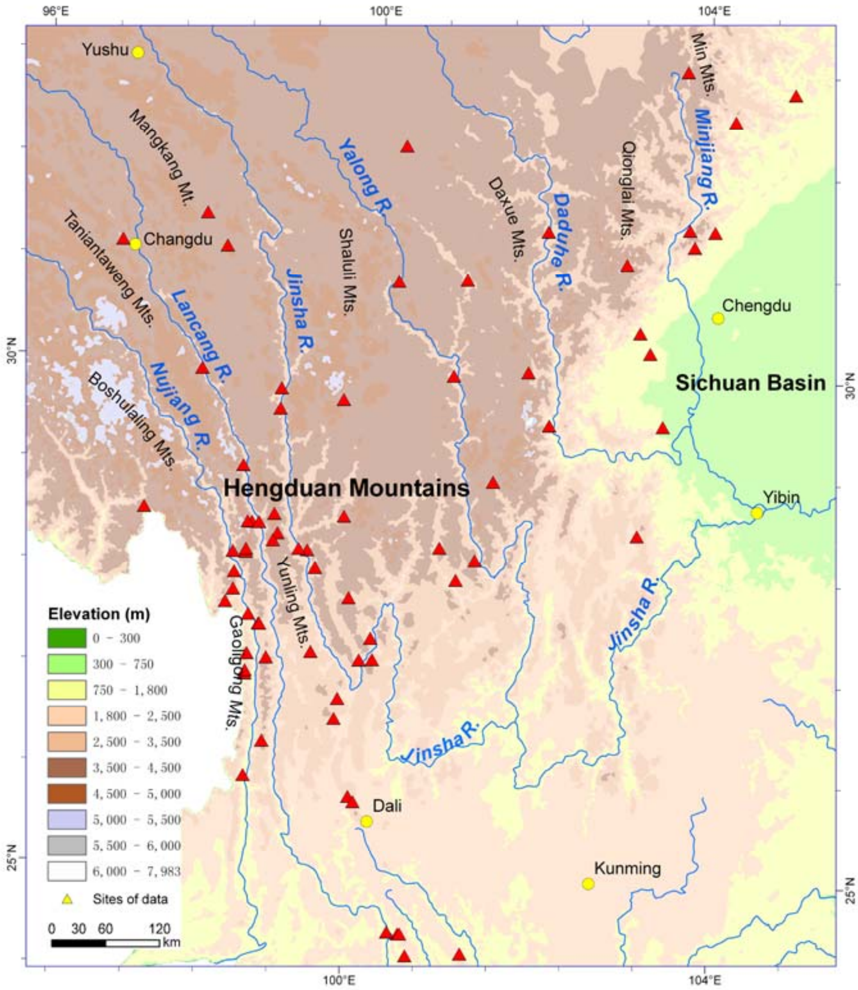


**Figure 1** Location of altitudinal belt spectra in the Hengduan Mountains

**Table 1** Base belts and their distribution in the Hengduan Mountains

| Base belt | East flank | West flank | Base belt | East flank | West flank |
|---|---|---|---|---|---|
| Subtropical monsoon evergreen broad-leaved forest | 2200 m-3000 m | 1 100 m - 2200 m | Subtropical dry and hot valley bush belt | 800 m - 3200 m | 1000 m - 3400 m |
| Subtropical evergreen broad-leaved forest | 600 m - 2800 m | 1200 m - 2700m | Subtropical evergreen sclerophyllous shrub belt | 2700 m - 2900 m | 1780 m - 1980 m |
| Subtropical evergreen coniferous forest | 1000 m - 3200 m | 1500 m - 3200 m | Frigid temperate dark coniferous forest | --- | 2900 m - 4300 m |
| Subtropical evergreen sclerophyllous & broad -leaved forest | --- | 2400 m - 4200 m | | | |

Subtropical evergreen sclerophyllous broad-leaved forest mainly distributes on the relatively dry and sunny flanks or in the dry-hot valleys, usually from 2400 m to 4200 m. Subtropical dry and hot valley bush belt widely distributes in the valley area of this region, especially in the valleys between 28°-29° N, normally from 1000 m to 3500m. Frigid-temperature dark coniferous forest normally

**Table 2** Mountain altitudinal belts and their distribution in the Hengduan Mountains

| Altitudinal belt | East flank | West flank | Altitudinal belt | East flank | West flank |
|---|---|---|---|---|---|
| Monsoon evergreen broad-leaved forest | Windward flank south of 25° N, 1300 m- 1 900 m | --- | Subalpine/alpine frigid temperate kurmmholz belt | 4000 m- 4200 m | --- |
| Evergreen broad-leaved forest | 1 600 m - 3100 m | 1400 m - 3200 m | Montane evergreen sclerophyllous shrub belt | 3700 m- 4000 m | 3700 m- 4000 m |
| Semi-evergreen broad-leaved forest | 1900 m - 2800 m | --- | Subalpine/alpine evergreen shrub belt | 2800 m- 3300 m | 2800 m- 3300 m |
| Evergreen sclerophyllous & broad-leaved forest | 2500 m - 3100 m | 2800 m- 4300m | Subalpine/alpine deciduous shrub belt | --- | 3680 m- 4280 m |
| Evergreen & deciduous broad-leaved forest | 1600 m - 2400 m | --- | Subalpine/alpine bush & meadow belt | 3800 m- 4600 m | 3800 m- 4200 m |
| Evergreen & deciduous broad-leaved & coniferous mixed forest | 2700 m - 3000 m | 2700 m- 3000m | Alpine evergreen Leather-leaved shrub | 3500 m- 4800 m | 3500 m- 4700 m |
| Deciduous broad-leaved forest | --- | 2300 m- 2500m | Alpine deciduous shrub belt | 3500 m -4100 m | 3500 m- 4700 m |
| Broad-leaved & coniferous mixed forest | 1600 m - 3300 m | 2000 m- 3500m | Alpine shrub & meadow belt | 3500 m- 4500 m | 3800 m- 4800 m |
| Warm evergreen coniferous forest | 2200 m - 3200 m | 2400 m- 3450 m | Alpine meadow | 3700 m- 4600 m | 3500 m- 4900 m |
| Temperate coniferous forest | 2500 m- 36000 m | 2500 m- 3700 m | Alpine desert | 4200 m- 5000 m | --- |
| Bright coniferous forest | 3000 m- 3800 m | 2700 m- 3600 m | Alpine desert-steppe | 3800 m- 4500 m | --- |
| Dark coniferous forest | 2500 m- 4500 m | 3000 m- 4500 m | Sub-nival belt | 4000 m- 5000 m | 4200 m- 5100 m |
| Subalpine / alpine krummholz belt | 2800 m - 2900m | 2800 m- 2900 m | Nival belt | Above 4500m | Above 4600m |

distributes in the northern part of the Hengduan Mountains, at an elevation ranging from 3000 m to 4000 m.

Diverse altitudinal belts have been developed in the Hengduan Mountains, and they show quite different on different flanks (Table 2). Montane dark coniferous forest appears in most of the altitudinal spectra and serves as the dominant belt of the study region.

## 2 Spatial Pattern of Altitudinal Belts in the Hengduan Mountains

(1) Spatial pattern of forest line

After analyzing the data of altitude, latitude and longitude of altitudinal belts on different sides with SPSS software, we obtained the following results: the elevations ($E$) of the forest line on the west and the east flanks were closely related to longitude ($x$) and latitude ($y$), as shown in Figure 2 and Figure 3. The latitudinal forest line patterns on the west and east flanks are similar, both an arched quadratic curve model, with differences only in coefficient. In other words, the forest line in the west and east flanks firstly rises and then falls with latitude, and the highest forest line appears between 30° - 31° N on the east flanks, but between 31° - 32° N on the west flanks.

To properly analyze the spatial pattern of forest line along longitudinal direction, we need to rule out the disturbance of latitude by choosing the data between 28° - 29° N. The results show that the longitudinal forest line patterns for both the west and the east flanks are also similar and can be described by a concave quadratic curve. In other words, the elevation of forest line falls from east and from west, reaching the lowest point between 99.5° - 101° E (Figure 3).

(2) Spatial pattern of montane dark coniferous forest

Totally 36 data of dark coniferous forest line elevation (15 data on the east flanks and 21 on the west flanks) are used to conduct correlation analysis for revealing their spatial pattern along longitude and latitude. The results show that the distribution of dark coniferous forest is closely related to longitude ($x$) and latitude ($y$), and has similar latitudinal and longitudinal spatial patterns with forest line (Figure 4 and Figure 5). From south to north, the elevation of the upper limit of dark coniferous forest rises firstly, reaches the highest position (about 30°N for east flank and 32°N for west flank), and then begins to fall with latitude (Figure 4). From west to east, the elevation of the upper limit of dark coniferous forest falls firstly, reaches the lowest position between 99.5°-101° E, then rises with longitude (Figure 5).

(3) Spatial pattern of snowline

The spatial distribution of snowline is closely related to latitude ($y$) as shown in Figure 6. An arched quadratic curve can best describe the latitudinal pattern of snowline on the Hengduan Mountains ($R^2$=0.879). At about 30° N, the snowline reaches its highest position (5100 m). The

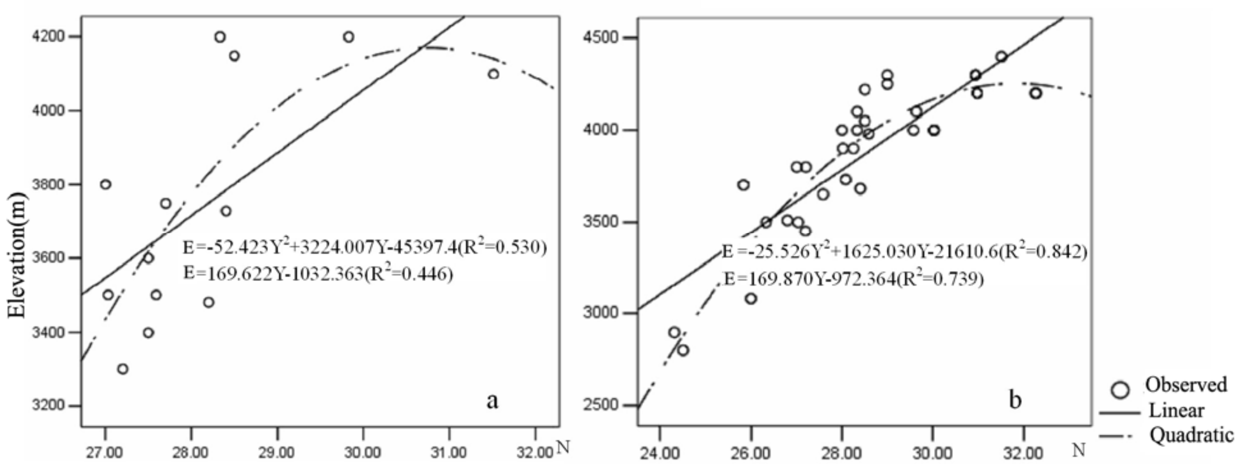


**Figure 2** Latitudinal patterns of forest line for the east flank and west flank of the Hengduan Mountains (a - east flank at 98°-99°E, b - west flank)

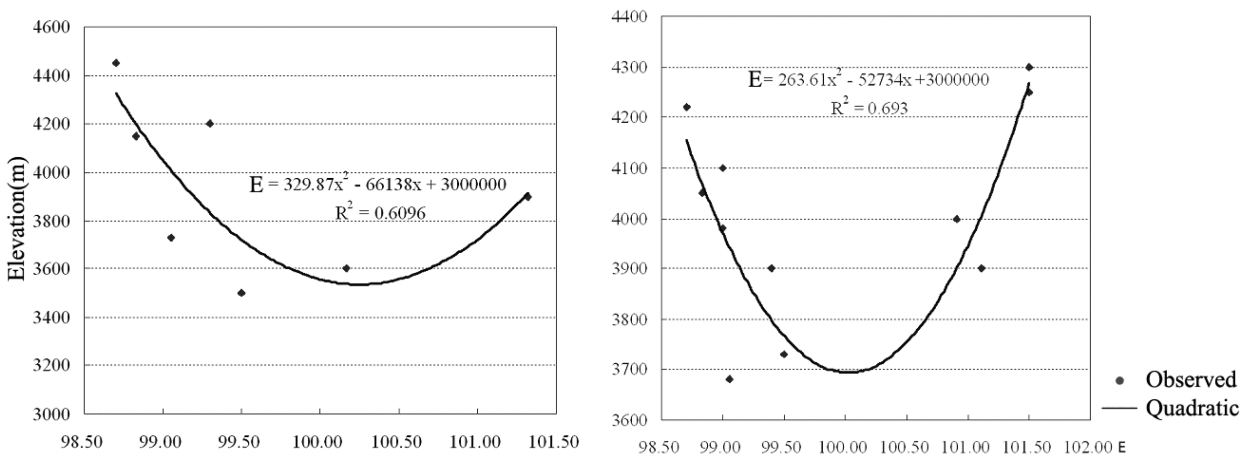


**Figure 3** Longitudinal patterns of forest line for the east flank and west flank of the Hengduan Mountains (Left: east flank; Right: west flank. Data between 28 ° - 29 ° N)

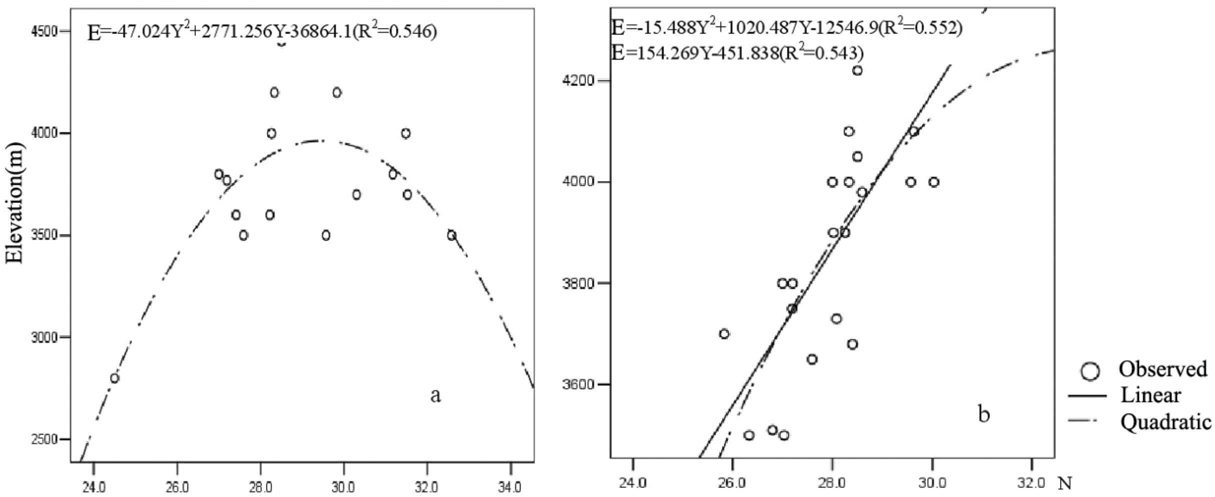


**Figure 4** Latitudinal patterns of dark coniferous forest for the east flank and west flank of the Hengduan Mountains (a: east flank; b: west flank)

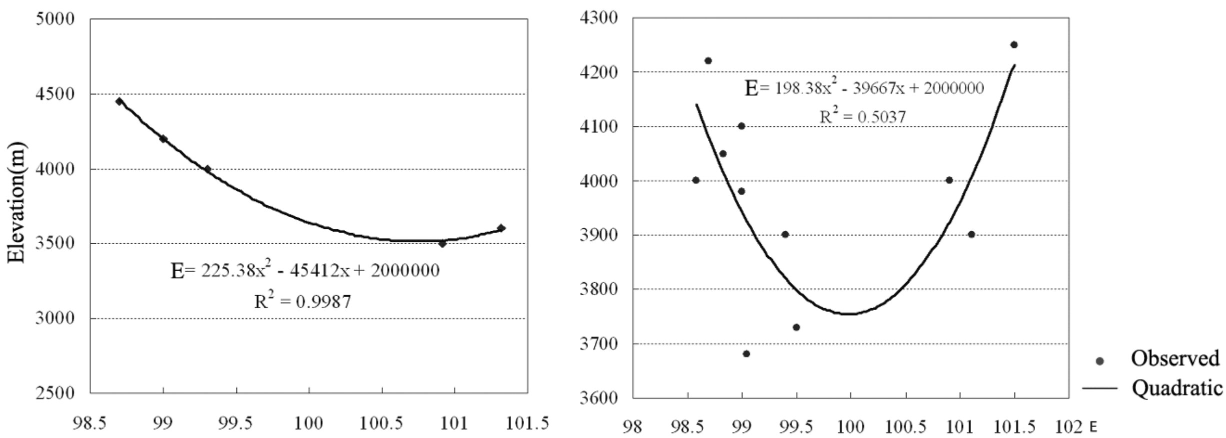


**Figure 5** Longitudinal patterns of dark coniferous forest for the east slope and west slope of the Hengduan Mountains (Left: east slope; Right: west slope. Data between 28 ° - 29 ° N)

longitudinal pattern of snowline was not been analyzed owing to limited data.

The analysis above shows that the main altitudinal belt lines (forest line, the upper limits of dark coniferous forest and snowline) of the Hengduan Mountains have similar latitudinal and longitudinal patterns, namely, the arched quadratic curve with changing latitudes (Figures 2, 4 and 6) and concave quadratic curve along longitudinal direction (Figures 3, 5). In longitudinal direction, the lowest value area of the main altitudinal belts appears between 99.5°-101° E, namely, between the Lancang and Jinsha rivers. These patterns can be together called "Hyperbolic-paraboloid model," revealing the complexity and speciality of the environment and ecology in the study region. This result further validates the hypnosis of a common quadratic model for spatial pattern of mountain altitudinal belts proposed by the authors (YAO et al. 2009, ZHANG et al. 2003, 2006, 2006, ZHANG 2008).

## 3 Exposure-related Area Differentiation of Altitudinal and Base Belts

Climatically, the Hengduan Mountains are mainly located in sub-tropical humid monsoon regions, and affected by the southwestern monsoon

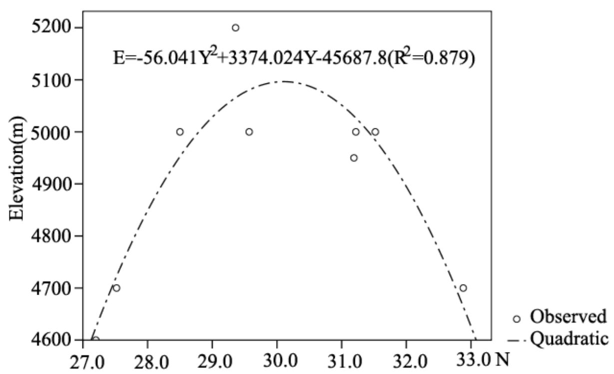


**Figure 6** Latitudinal patterns of snow line in the Hengduan Mountains

from the Bay of Bengal (Indian Ocean) and the southeastern monsoon from the Pacific Ocean. The parallel mountain ranges of the study region act as barriers to the moisture-laden air masses from southeast and southwest. Theoretically, there should be a trend toward less rainfall from eastern and western borders to the central part of the study region. As a result, the base and altitudinal belts and their distribution show quite different.

(1) Base belts on different flanks

As for the mountains south of 28° N and west of 101° E, their west slopes are windward flanks and accordingly the base belts are found with humid evergreen broad-leaved forest such as subtropical monsoon evergreen broad-leaved forest and subtropical evergreen broad-leaved forest, while the east flanks are leeward and the base belts consist of relatively drier types such as subtropical evergreen coniferous forest. South of 28°N and east of 101°E, the eastern flanks are windward and west flanks are leeward, and, therefore, the base belts in the east flanks are more humid than those in the west flanks. Between 28°N and 29° N, hot and dry climate (annual rainfall about 300 mm) and vegetation (bush and steppe) develop in the valley bottoms between mountain ranges. North of 29° N, the mountains gradually merge into the Tibetan Plateau proper, the relative height of mountains decreases and continental climate builds up. The difference in base belts between east and west flanks wears off, replaced by the sharp contrast between north and south flanks.

(2) Altitudinal belts on different flanks

Altitudinal belts show differently in several aspects in the eastern and western flanks. Generally, the structure of altitudinal belt spectra is more complex on the east flanks than in the west flanks. For example, normally 7-9 belts develop on the east flanks, while 5-7 belts on the west flanks. West of the Jinsha River, the upper limit of the same type of altitudinal belt on east flanks is higher than that on west flanks; However, this is reversed for the mountains east of the Jinsha River (Figure 7). In addition, montane coniferous & broad-leaved mixed forest is more common in the east flanks west of the Lancang River or east of the Jinsha River, but montane evergreen leather-leaved shrub belt and montane temperate coniferous forest are more common between the Lancang and Yalong rivers. Montane shrub & meadow belt is common in the west flanks east of the Jinsha River, while montane evergreen leather-leaved shrub belt is more common west of the Jinsha River; montane evergreen broad-leaved forest is common in the west flanks west of the Lancang River; montane coniferous & broad-leaved mixed forest and montane temperate coniferous forest in the west flanks have the same vertical ranges as that on the east flanks. Montane dark coniferous forest widely occurs and serves as the dominant belt in the altitudinal belt spectra of the Hengduan Mountains. For the mountains east of the Jinsha River, the lower and the upper limits of dark coniferous forest in west flanks are higher than those in the east flanks.

(3) Forest line on different flanks

Near 28° northern latitude, forest line is lower in west flanks than in the east flanks west of the Jinsha River; while east of the Jinsha River, forest line is higher in the west flanks than in the east flanks. The plant species near forest line are different in west flanks and east flanks. Normally, dry and cold resistant plants (e.g., *Abies*, *Picea* and *Larix*) distribute on leeward flanks, and wet and cold resistant plants on windward flanks.

From the analysis above, it can be seen that base belts and altitudinal belt spectra in windward flanks are more humid than those on the leeward flanks, and the structures of altitudinal belt spectra are more complex in windward flanks than in leeward. From the westernmost and easternmost sides of the study region to the central part, the structures of altitudinal belt spectra change from complex to simple. In short, altitudinal belt spectra are closely related with moisture-related exposure

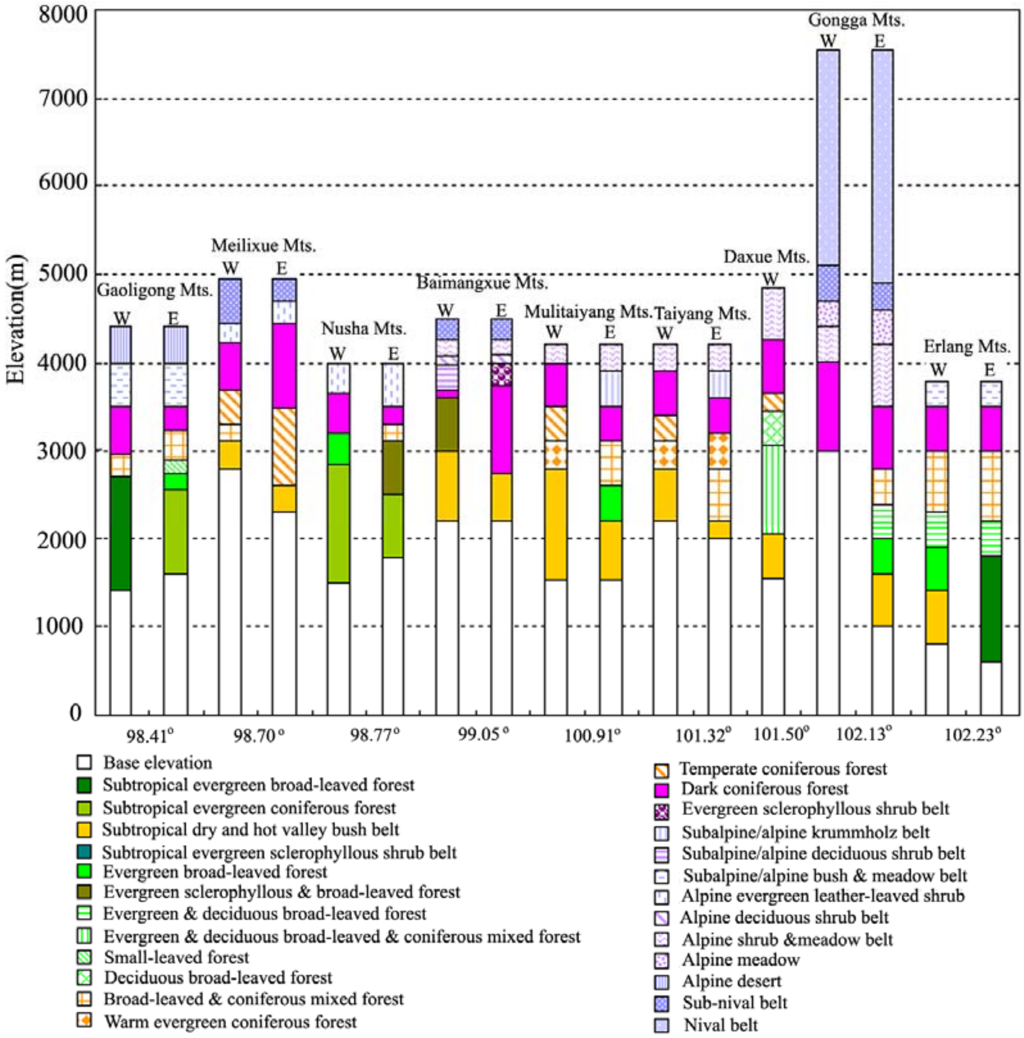


**Figure 7** Comparison of altitudinal belts between the east slope (E) and west slope (W) of the Hengduan Mountains

effect in the Hengduan Mountains. But, their quantitative relationship has been missing. Future research should be focused on this issue — how parallel mountain ranges barrier the movement of moisture-laden air masses and re-shape the distribution of altitudinal belts. It is undoubtedly a great challenge but we must face it in the future.

## 4 Conclusion and Discussion

The altitudinal belts of the Hengduan Mountains are very complex and diverse, and it is very difficult to use a simple model to describe them. Through this study, the following conclusions can be drawn and need further discussions:

(1) The main altitudinal belt lines, such as forest line, the upper limit of dark-coniferous forest and snow line, have similar latitudinal and longitudinal distribution patterns, namely, an arched quadratic curve along latitudes and a concave quadratic curve along longitudes. This pattern can be comprehensively called “Hyperbolic-paraboloid model,” revealing the complexity and specialty of environment and ecology of the study region. The spatial pattern of altitudinal belt limits also clearly shows that the area between the Lancang River and the Yalong River (28°- 29° N and 99°-101° E) is dry and hot in the study region.

(2) The spatial pattern of altitudinal belt spectra is closely related with moisture-related exposure effect in the Hengduan Mountains. Different combinations (spectra) of altitudinal belts and different base belt types appear on the windward and leeward flanks, and even in the same flanks of different ranges. This is closely related with the parallel mountain ranges of the Hengduan Mountains, which, at nearly right angle with the moving direction of prevailing moisture-laden air masses from west and east, hold up the warm and humid monsoon wind from moving into the core region and result in different moisture conditions in windward and leeward flanks. However, how to quantitatively describe the moisture-related exposure effect needs further study.

(3) Although the "hyperbolic paraboloid" model for altitudinal belt distribution is proposed, its mechanism is not still very clear. Especially, the phenomenon that the limits of altitudinal belts fall rather than rise from the easternmost and westernmost parts to the central part of the study region is really hard to understand. It has been thought that they should rise in line with inward decreased moisture conditions.

(4) The quantitative modeling carried out could be improved with RS/GIS. Although this study collected the data covering 109 complete altitudinal belt spectra of the Hengduan Mountains, only 76 of them have clear-cut location and can be used. Moreover, these data are not evenly distributed throughout the study area. Some data are found without accurate positions, and so the coordinates of the center of the mountains or the locations described in literature are used roughly as their location. This affects to some extent the results of simulating the latitudinal or longitudinal spatial pattern. Finally, the current data of altitudinal belts have an accuracy of only 100 m and spatially discrete, without high-precision and continuous belt data for modeling. Therefore, it is significant to obtain continuous, multi-directional data of altitudinal belts by using remote sensing and GIS technology (SUN et al. 2008) for high-precision modeling.

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