

## Fluctuation of a Mountaineer's Speed

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**Abstract.** Using a portable navigator for Global Positioning System, the position and the altitude of a mountaineer hiking in the area of Tanzawa-Oyama Quasi-National Park are measured. The time series of average speed of a mountaineer is obtained. Fluctuation of average speed is analyzed in terms of autocorrelation function and  $f(\alpha)$ -spectrum. It depends on a style of mountaineering.

### 1. Introduction

A ridge line and a valley in mountain area have a beautiful fractal structure. A mountain trail has a fractal structure. An ordinary mountaineer hikes along a mountain trail. A mountaineer climbs up and down on a trail with fractal structure so long time and adjusts his/her speed so that the fatigue may be lessened if possible. Mountaineer's speed strongly depends on a slope and a condition of trail. We are interested in fluctuation of the average speed during the short time interval, for example, 20 seconds. This average speed is reflected both by conditions of trail and of mountaineer.

The author uses *eTrex Legend* (GARMIN Co., 2002) which is a portable navigator for Global Positioning System (GPS). The official accuracy of GPS is 15 m. However this navigator distinguishes the right and left sides of 6 m-road in city. Then the accuracy is about 3 m. This accuracy is enough to study fluctuation of average speed for a mountaineer. The area where the author hiked is Tanzawa-Oyama Quasi-National Park (abbreviate to Tanzawa) mainly located in Kanagawa prefecture, Japan (Appendix A) (FLORENCE *et al.*, 2001). The illustration of trails in Tanzawa is displayed in Fig. 1. Without a companion, author went climbing to Tanzawa in spring, early summer and autumn. These seasons are known as Tanzawa's best seasons for mountaineering.

The styles of mountaineering are classified into three categories, that is, "climb up (CU)", "traverse (T)" and "climb down (CD)". The first style is the initial stage of mountaineering. A mountaineer climbs up about 1000 m in Tanzawa. The second style is the middle stage which a mountaineer traverses from the peak of a certain mountain to that of another one. The third one is the final stage.

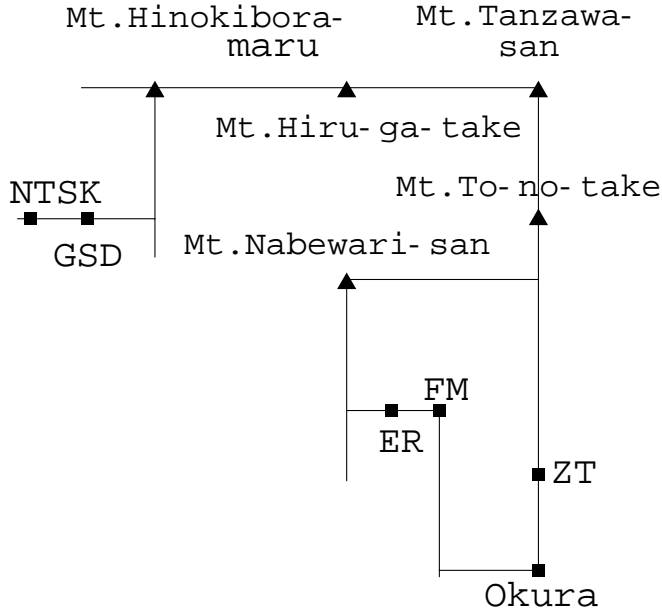


Fig. 1. Illustration of trails in Tanzawa where author hiked. Full names of abbreviations are following: Nishitanzawa-shizen-kyoshitsu (NTSK), Gora-sawa-no-deai (GSD), Zojiba-no-taira (ZT), Futamata (FM) and End of roadway (ER). See also maps in Appendix.

## 2. Procedure

We show the procedures of measurement and analysis.

(1) Measurement interval of a position and an altitude is 20 seconds. In order to calculate autocorrelation function, we use only a continuous data measured in fine or cloudy days. The signals from several satellites are frequently lost in the forest abounding in trees. The data in such areas is omitted. In Tanzawa, the receiving condition of signals is good in areas where the altitude is over 600 m.

(2) Data in a navigator is transferred to a computer and altitude data is revised by using the data of 1:50000 map stored in Kashmir3D (SUGIMOTO, 2002).

(3) Average speed during 20 seconds is calculated and thus a time series is obtained. Figure 2 displays an example constructed by the data for traverse from Mt. Hinokiboramaru to Mt. Hiru-ga-take.

(4) For the time series  $\{v_i\}$  ( $1 \leq i \leq N$ ), autocorrelation function (ACF)  $S(\tau)$  is calculated. ACF is defined by

$$S(\tau) = \frac{1}{N-\tau} \sum_{i=1}^{N-\tau} (v_{i+\tau} - \bar{v})(v_i - \bar{v}) \quad (1)$$

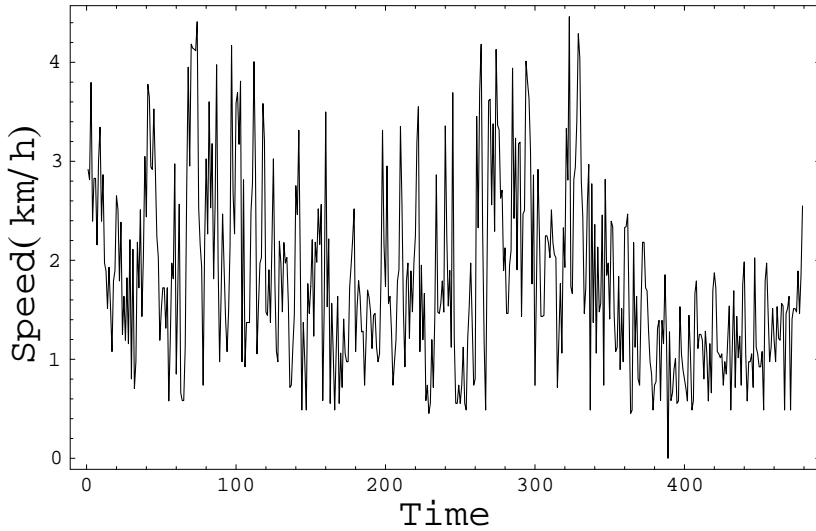


Fig. 2. A time series of average speed for traverse from Mt. Hinokibora-maru to Mt. Hiru-ga-take. Unit of time is 20 seconds.

where  $\bar{v}$  is the average speed and  $\tau$  is a lag of time. If  $S(\tau)$  decreases as  $\exp(-\alpha\tau)$  ( $\alpha > 0$ ), we say it “exponential decay” of ACF. If  $S(\tau)$  decreases as  $\tau^{-\beta}$  ( $\beta > 0$ ), we say it “power decay”. If the decay of  $S(\tau)$  is similar to that of random process, we say it “rapid decay”. ACF determines the local similarity of time series. We do not need so many data to calculate AFC. This is a merit of AFC. If ACF decays as the power law, the original data has a fractal property. However the inverse relation does not hold. Thus we need  $f(\alpha)$ -spectrum to discuss the fractal property of observed data series.

Next, using the distribution function  $p_i$  for the time series, we calculate  $f(\alpha)$ -spectrum defined by

$$\tau(q) \equiv (q-1)D(q) = \lim_{\varepsilon \rightarrow 0} \frac{\ln \sum p_i^q}{\ln \varepsilon}, \quad (2)$$

$$\alpha(q) = \frac{d\tau(q)}{dq}, \quad (3)$$

$$f(\alpha) = \alpha q - \tau(q). \quad (4)$$

Here  $\sum p_i = 1$  holds and the minimum value of  $\varepsilon$  is  $\varepsilon_0 = v_{\max}/32$  where  $v_{\max}$  is the maximum average speed. In order to estimate  $D(q)$  and  $\alpha(q)$ , we use  $\varepsilon_0, 2\varepsilon_0, 4\varepsilon_0$  and  $8\varepsilon_0$ .  $f(\alpha)$ -spectrum gives us the information on the complexity of time series and on the singular structure of

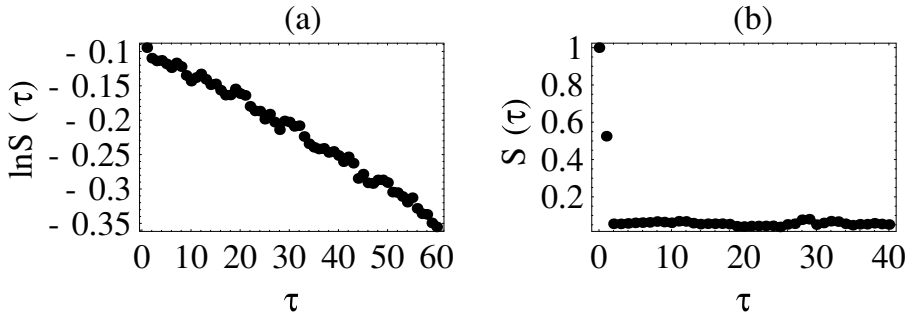


Fig. 3. ACFs for Climb up (a) from Gora-sawa-no-deai (GSD) to Mt. Hinokibora-maru and (b) from Zojiba-no-taira (ZT) to Mt. To-no-take.

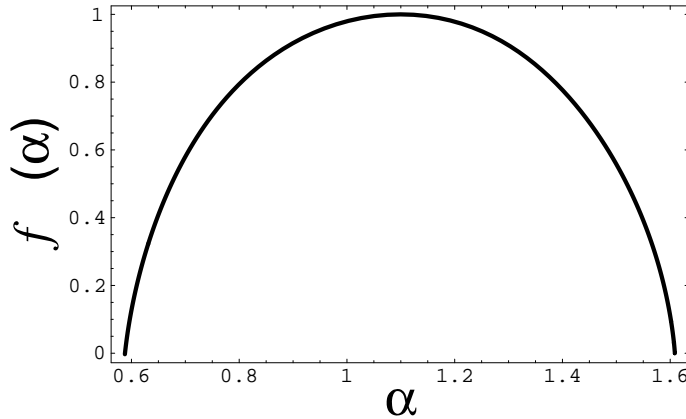


Fig. 4.  $f(\alpha)$ -spectrum for Climb up.

distribution function. However we need many data to calculate  $f(\alpha)$ -spectrum. Thus the author mounted to Tanzawa ten times in the year 2003.

### 3. Climb Up

The exponential decay of ACF is obtained for the data (A) from Gora-sawa-no-deai to Mt. Hinokibora-maru (Fig. 3a) and (B) from End of roadway (over Futamata) to Mt. Nabewari-san. On the other hand, the rapid decay is obtained for the data (C) from Zojiba-no-taira (over Okura) to Mt. To-no-take (Fig. 3b). The rapid decay is caused by the particular condition of the trail of (C), where numerous steps exist. If the trail is ordinal one at which steps exist sparsely, ACF for CU has the exponential decay. This fact means the existence of the brake effect originated by the slope of trail. If the brake effect due to steps is so strong, ACF rapidly decays as ACF for (C). For mountaineers, climbing up steps in progression is laborious. Our result is a corroboration of this fact.

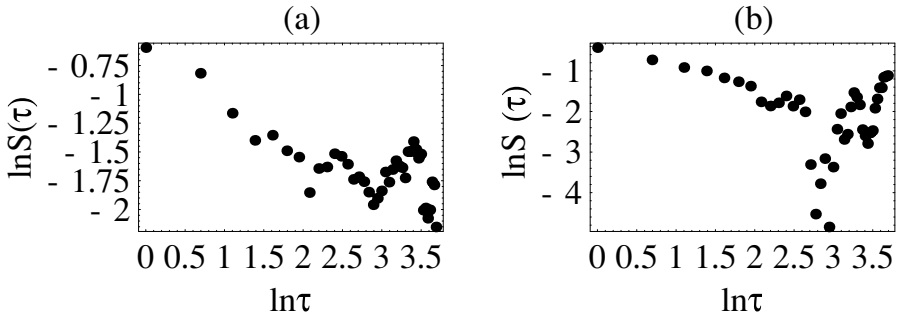


Fig. 5. ACFs for Traverse (a) from Mt. Hinokibora-maru to Mt. Hiru-ga-take and (b) from Mt. Hiru-ga-take to Mt. Tanzawa-san.

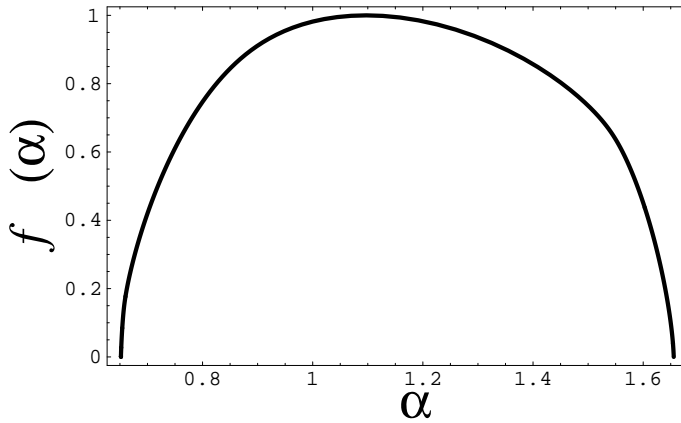


Fig. 6.  $f(\alpha)$ -spectrum for Traverse.

Next we display  $f(\alpha)$ -spectrum for CU in Fig. 4. To calculate it, we use all data for CUs. The minimum value of the fractal dimension is  $D_{\min}^{\text{CU}} = 0.6$  and the maximum one is  $D_{\max}^{\text{CU}} = 1.6$ .

#### 4. Traverse

We display ACFs for the data from Mt. Hinokibora-maru to Mt. Hiru-ga-take (Fig. 5a) and from Mt. Nabewari-san to Mt. To-no-take (Fig. 5b). For all traverse routes, the power decay is observed. Mountaineer makes an effort on controlling and recovering from his/her fatigue. This influences a mountaineer's speed. For example, in the interval whose slope is flat, a mountaineer controls his/her speed in order to keep his/her physical power for next climb up or down.

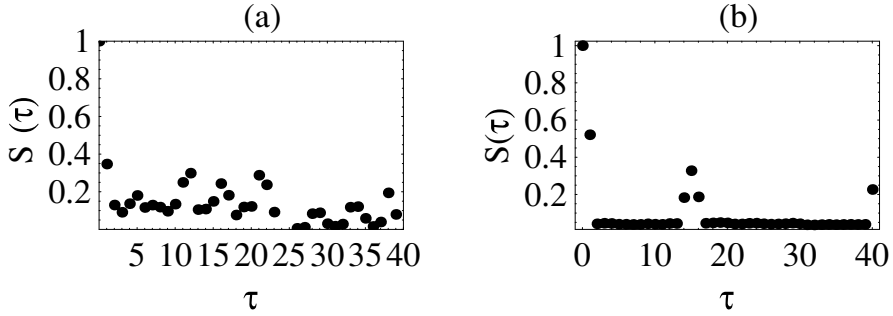


Fig. 7. ACFs for Climb down (a) from Mt. Nabewari-san to End of roadway (ER) and (b) from Mt. To-no-take to Zojiba-no-taira (ZT).

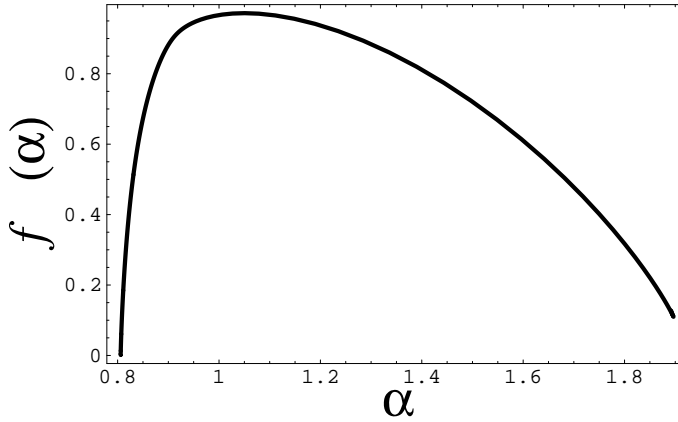


Fig. 8.  $f(\alpha)$ -spectrum for Climb down.

In Fig. 6,  $f(\alpha)$ -spectrum for T is shown. To calculate it, we use all data for Ts. The minimum value of the fractal dimension is  $D_{\min}^T = 0.65$  and the maximum one is  $D_{\max}^T = 1.65$ .

## 5. Climb Down

The rapid decay is obtained for the data (A') from Mt. Hinokibora-maru to Gora-sawano-deai, (B') from Mt. Nabewari-san to End of roadway through a forest (over Futamata) (Fig. 7a) and (C') from Mt. To-no-take to Zojiba-no-taira (over Okura) (Fig. 7b). Therefore we can conclude that the decay of ACF for CD is the rapid one. Since speed for CD is fast compared with that for CU, main effect to decide a mountaineer's speed is the trail condition changing randomly. This causes the rapid decay of ACF. However this is not a

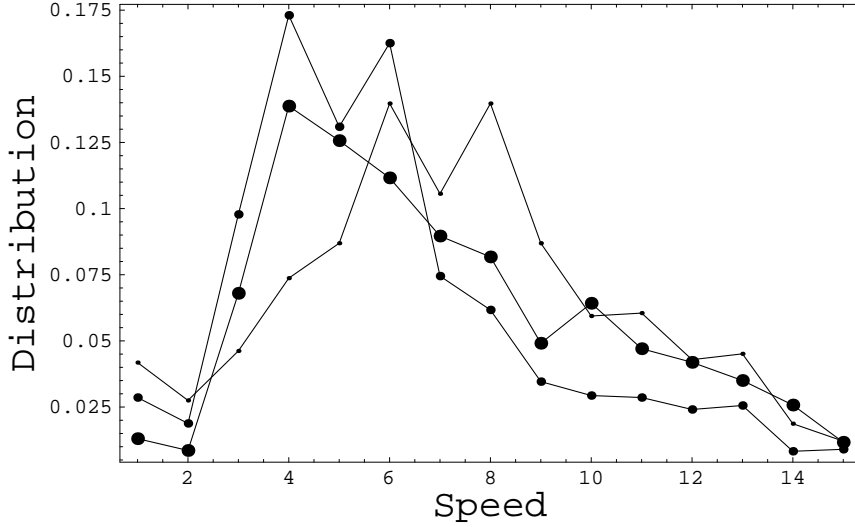


Fig. 9. Largest disks display the distribution function for T, the middle ones show that for CU and the smallest ones shows that for CD. A unit of horizontal axis is  $2\varepsilon_0 (=v_{\max}/16)$ .

random process since  $f(\alpha)$ -spectrum shown in Fig. 8 has the same structure for the time series with multifractal spectrum. To calculate  $f(\alpha)$ -spectrum, we use all data for CDs. The minimum value of the fractal dimension is  $D_{\min}^{\text{CD}} = 0.8$  and the maximum one  $D_{\max}^{\text{CD}}$  is larger than 1.9.

## 6. Summary

According to the facts mentioned above, we can conclude that the distribution functions of all time series for average speed have a fractal structure and the following relations hold.

$$D_{\min}^{\text{CU}} < D_{\min}^{\text{T}} < D_{\min}^{\text{CD}}, \quad (5)$$

$$D_{\max}^{\text{CU}} < D_{\max}^{\text{T}} < D_{\max}^{\text{CD}}. \quad (6)$$

In Fig. 9, three distribution functions are displayed. The peak of distribution function for CD is shifted in the large speed region. The decay of distribution function for T is slow compared with those for CU and CD. If we see these motions embedded in a suitable phase space, we observe that the motions for CU and T are separated into two, namely, a somewhat localized motion and an itinerant motion, and the motion for CD is widely extended itinerancy.

Though velocity of mountaineer fluctuates, we can know the local dynamical property



Fig. A1. Tanzawa in Japan.

of mountaineering from ACF and obtain the singular structure of distribution function from  $f(\alpha)$  spectrum. However our results are primitive. We have to make clear the several problems. Our results do not hold for the beginners since the author has a very long career of mountaineering and for the mountaineers who climb with many persons since their motions are restricted and controlled by a leader. We also consider the difference of mountains. We hope the advanced analysis for fluctuation of a mountaineer's speed.

#### Appendix. Trails in Tanzawa

Tanzawa is a name of mountains located in Kanagawa, Yamanashi and Shizuoka prefectures (Figs. A1 and A2) in Japan. The highest mountain in the Tanzawa range is Mt. Hiru-ga-take (1673 m) located at (139°08'31" E, 35°28'59" N). Mt. To-no-take (1491 m), Mt. Tanzawa-san (1567 m), Mt. Hinokibora-maru (1601 m) and Mt. Nabewari-san (1273 m) are famous mountains. The altitudes of these mountains are not so high. But we need about 1000 m climb before getting to the top of the mountain from the place from which a mountaineer starts to climb. The routes climbed by the author are introduced. In the following, the altitude of the position A is expressed as A(500 m) where 500 m means 500 meters above sea level. The standard course time (YAMA-TO-KEIKOKU SHA, 1997) is expressed as  $A \leftarrow (2h05m, 3h10m) \rightarrow B$  where 2h05m is the course time from B to A and 3h10m is that from A to B.



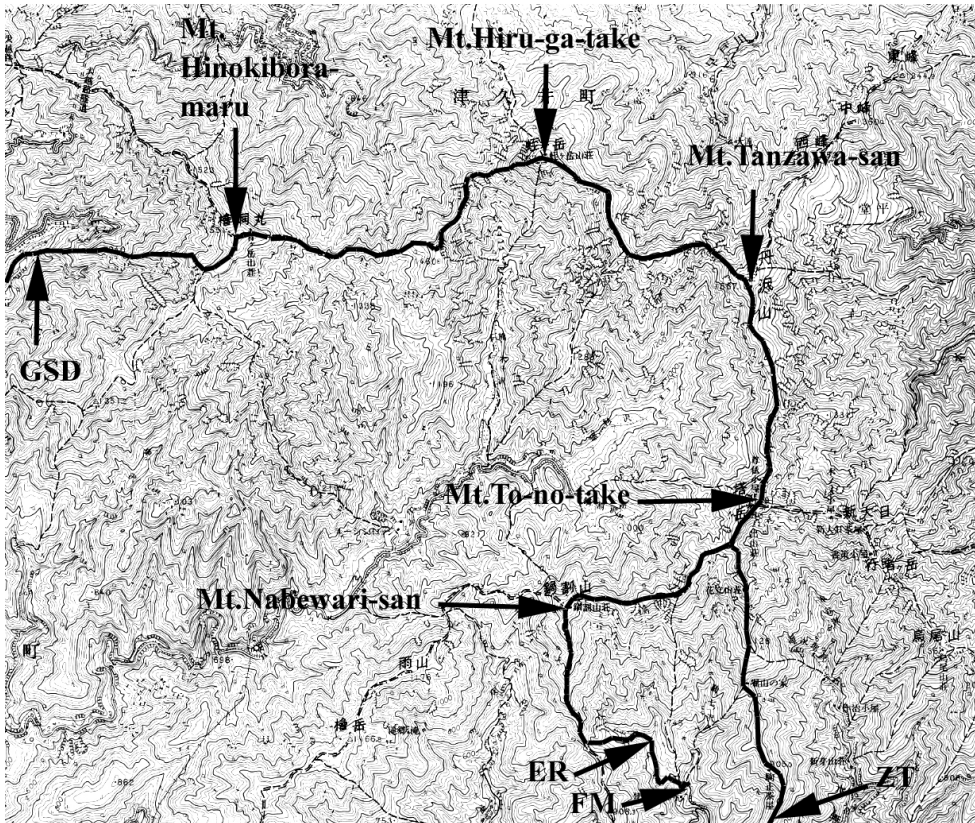


Fig. A2. Middle of Tanzawa (scale 1:50000). Thick line displays the trail that the author hiked. Two bus terminals, Okura and Nishitanzawa-shizen-kyoshitsu, are not included. The same abbreviations in Fig. 1 are used.

(1) Okura (290 m) ← (2h05m, 3h10m) → Mt. To-no-take (1491 m) ← (45m, 1h) → Mt. Tanzawa-san (1567m) ← (1h10m, 1h20m) → Mt. Hiru-ga-take (1673 m) ← (3h20m, 3h05m) → Mt. Hinokibora-maru (1601 m) ← (2h45m, 1h50m) → Nishitanzawa-shizen-kyoshitsu (540 m).

“Climb up and down”

Okura ↔ Mt. To-no-take and Mt. Hinokibora-maru ↔ Nishitanzawa-shizen-kyoshitsu.

The altitude difference between Okura and Mt. To-no-take is about 1200 m. Numerous steps exist in this trail. Many mountaineers use this trail since this is the shortest way to Mt. To-no-take. The receiving condition of signals from the artificial satellites is good in area over Zojiba-no-taira (600 m). The altitude difference between Nishitanzawa-shizen-kyoshitsu and Mt. Hinokibora-maru is about 1060 m. The condition of trail is good for climb up and down. The receiving condition of signals is good in the interval between Gora-sawano-deai (740 m) and Mt. Hinokibora-maru.

“Traverse”

Mt. To-no-take ↔ Mt. Tanzawa-san ↔ Mt. Hiru-ga-take ↔ Mt. Hinokibora-maru.

This traverse is called “Tanzawa main ridge”. There exist a trail with steep up and down and some rocky sections. This course is not for the beginners. The receiving condition of signals is good.

(2) Okura (290 m) ← (1h, 1h10m) → Futamata (600 m) ← (1h10 m, 1h50m) → Mt. Nabewari-san (1273 m) ← (1h10 m, 1h20m) → Mt. To-no-take (1491 m).

“Climb up and down”

Futamata ↔ End of roadway (670 m) ↔ Mt. Nabewari-san (1273 m).

The receiving condition of signals for this interval is good. This trail is well maintained.

“Traverse”

Mt. Nabewari-san ↔ Mt. To-no-take.

The trail is in wood of old beech trees. The receiving condition of signals is good.

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