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# CHINA'S ANTI-SEASON ICE CAVES AND THEIR MECHANISM

**Abstract**: Jin S., Shu L., Huang S., Zhang Q., Wu Z. & Hu C., *China's anti-season ice caves and their mechanism*. (IT ISSN 0391-9838, 2015).

A dynamic ice cave (DIC) is a natural phenomenon: the ice in the caves freezes in midsummer or late spring rather than in winter. It is created by the unique local geological structure. DICs are important tourism resources; actually, during recent years, they have been developed in varying degrees. Due to tourism exploitation or other unknown factors,

some DICs in China are suffering a recession. To reveal the mechanism of DICs' operation can help with their protection and save them from destructive exploitation. In this paper, the geographical distribution of China's DICs is given in the first part. Then the influencing factors of the nature ventilation of DIC, the transition mechanism between two seasons of DIC, the interesting relation between the temperatures of warm cave and outside air was analyzed.

Key Words: Ice cave, Cave climate, Impact of tourism exploitation, China.

动力冰洞是一种自然现象：这种洞穴会在盛夏或暮春时结冰，是当地特殊的地质及气候条件形成的。动力冰洞是重要的旅游资源，近年来得到不同程度的开发。因为这些开发和其它未知因素，中国的一些动力冰洞处于衰退中。解开动力冰洞的形成机理，可以帮助它们的保护和免于破坏性的开发。本文首先介绍了中国反季节冰洞的分布，接着分析了影响动力冰洞自然通风的因素，两个不同周期的转换机制以及暖洞温度与外界空气温度之间的关系。

## INTRODUCTION

Dynamic ice cave was named by Luetscher based on their origin (Luetscher, 2004). A DIC usually has two or more entrances located at different elevation. The ones with higher altitude blow warm air in winter and usually be called warm caves when the ones with lower altitude blow cold air in winter be called cold caves or ice caves. The cycles of DIC have two different links, cold-cave season and warm-cave season (Byun, 2004). The cold-cave season, usually extending from early April to late September, was named for the cold wind blowing out from cold caves. A warm-cave season locates between two cold-cave seasons. It was named for the characteristic warm air with white steam blowing out from warm caves. In previous works, beside Chimney-effect, many other theories have been proposed to explain DIC including evaporation effect, radiative cooling and the adiabatic expansion theory, the limitations of which were discussed by Byun (2011). In this paper, after a brief introduction of China's dynamic ice caves, the influencing factors of the nature ventilation of DIC were analyzed. The transition mechanism, which had almost not been mentioned in the previous references, was also discussed.

## DISTRIBUTION OF CHINA'S DYNAMIC ICE CAVE

China's DIC distribution is really concentrated: No. 1 to 3 are located in the great Changbai Mountains region, in the northeast of China, No. 4 in the Yan Mountains region and No. 5 in Taihang Mountains region, No. 6 to 9 in a small region beside the Yangtze river; the last one located beside Jinsha River (the name of Yangtze river's upper reaches, as shown in fig. 1 and their Latitudes and Longitudes were shown in table 1). Lack of space forbids the description of every DIC in detail, so only part of them will be introduced below.

Ren ice cave (Li Jinrong, 1992) is located in a slope near a Village Chuanyinggou in the eastern mountainous region of Liaoning Province. This area is about 1,000 meters by 20 meters. Early in the 20th century, a local family named Ren found this strange phenomenon when they built their own house. Taking advan-

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tage of this DIC, they constructed a small storage room, which survives to this day. In summer, outdoor temperature is increased by the warm sunshine; however, ground temperature under the slope falls. According to tests by Ren, the temperature in the small storage room goes down to –10°C in hot summer, and the temperature in the rock crevices is much lower, reaching –15°C. From May to early August, rain water flowing into the storage room freezes into icicles; during the cold winter, the storage room is as warm as spring. The family of Ren also asserted two little land areas around the fumaroles spurting hot air on the hill, and then built a greenhouse with plastic film and branches of fraxinus and oak. The vegetables grew very well in the green house when the minimum temperature of outdoor dived to –30°C; what is more surprising is that even the branches of fraxinus and oak sprouted and foliated. Ren Hongfu tested the temperature in the greenhouse repeatedly: the air temperature maintained at 17 °C, and the ground temperature stayed at 15°C.

The Chengde Miracle Well (Nie, 2006) is located in a little village named Shuanglin in the Wuling Mountain of Chengde. This region was the royal tombs area of the Qing Dynasty, a forbidden place to common people before the end of the Qing Dynasty in 1911. It is a famous sightseeing district for scenic mountains, dense forests, great canyons and clear streams. Due to the changes in climate and geology or other unknown factors, the summer ice recorded by Li Daoyuan in the valley about 15 centuries before is no longer visible. However, a well dug by the local villagers proves his record to a certain extent. The depth of the dry well is 8.6 m, which is ice cold in summer but warm in winter. Cui Shilin (2011) led a geologic survey of the Chengde Miracle Well on June 20, 2011. They found the well is located in a north-south valley, which is high in the north and opens to the south. Caused by the enormous uplift stress fractures of volcanic activity, the layer of dolomite limestone broke into large or small slates. There are a lot of cracks between the slates, from which cold air flows out in summer and warm air is released in winter. The detection results of acoustical frequency electric showed a high underground porosity in this area. The steady burning of the candle proved that the gas flowing out from the crevice had adequate oxygen. It was –6°C at the well bottom while the outdoor temperature was 30.5°C.

Ice Back and Taiji Mountain (Guo, 1985) are both located in Linzhou, Henan Province. I visited Ice back on September 20, 2012. Ice back is located in a slope of Olitic Limestone. The slope is a typical collapse accumulation (in some place, the collapse is still developing). The water from the spring converges into stream. The slope filled with gaps from which cold wind blows every summer. During early summer, the temperature of the cold wind is below zero and water freezes in the gaps. To increase the income from tourism, Ice Back was developed as a beauty spot. The former little cave turned into a deep manmade cave with a door only open when there are some visitors. Such a huge human intervention has a very big risk of weakening the cave. As most tourists are attracted by the Great Taihang Gorge and the famous Hongqi Canal nearby, it is not a crowd interest places.

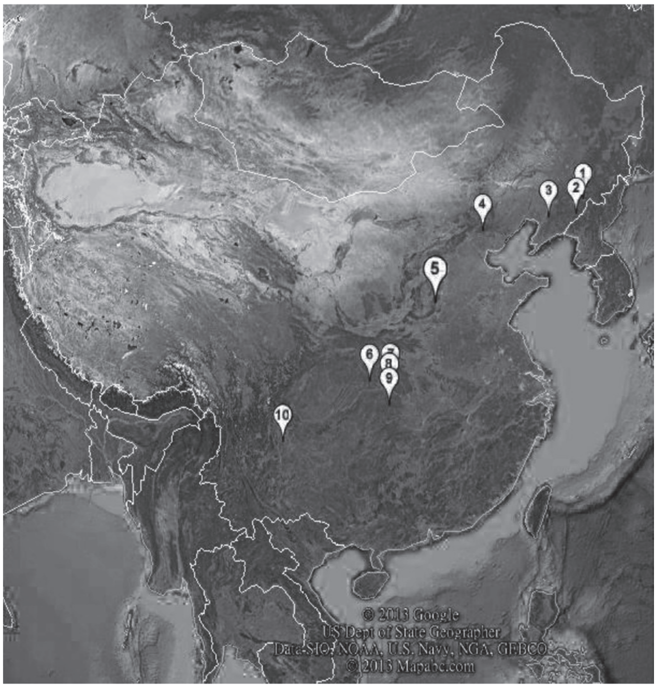


FIG. 1 - Geographical distribution of China'a dynamic ice cave.

Taiji Mountain (Guo, 1985) is located on the side of the Valley of Peach Flower, 10 kilometers south of Ice Back.

In Taiji Mountain, there are thousands of little caves, from which cold wind blows during summer. Therefore, all butterflies fly high above the grass to avoid freezing. In winter, no snow covers the areas around the caves even when there is an accumulation of thick snow nearby.

## THE POWER OF AIR CIRCULATION AND THE TEMPERATURE RESPONDING PHENOMENON

The air circulation of a dynamic cave is the result of the «Chimney-effect» (Thury, 1868). The air flowing in the talus is heated or cooled by convection heat transfer with the rocks. This temperature rise (or drop) changes the air density and generates a natural ventilation by breaking the gravity balance of the inside air and outside air. This natural ventilation usually referred to as «Chimney-effect». The natural ventilation pressure ($P_n$) can be calculated approximately use the fellow equation

$$P_n = \bar{\rho} g \quad z \tag{1}$$

where = $\underline{\rho} = \underline{\rho}_0 - \underline{\rho}_i$ is the equivalent difference between the average density of the outside air and the inside air, g is the acceleration of gravity, $\Delta z$ is the altitude intercept between the entrance and exit. For a DIC, its pipeline characterization can be regarded as invariable. Therefore, the flow velocity ($\mu$) will change with $P_n$.

$$q - u = \frac{1}{2}\ \mu^2 + z + (\frac{P_n}{\rho}) \tag{2}$$

where $q$ is the heat exchange amount of air, $\Delta u$ is its internal energy change.

The heat convection between air and rocks is governed by the Newton cooling law,

$$q = h\ \ t \tag{3}$$

where $\Delta t$ is the temperature between rocks and air, $h$ is convective heat-transfer coefficient and obeys the Dittus-Boelter equation (Winterton, 1998),

$$Nu = 0.023\ \mathrm{Re}^{0.8}\ \mathrm{Pr}^{n} \tag{4}$$

In the warm-cave process n = 0.4; in the cooling process $n = 0.3$.

$$Nu = \frac{hl}{\lambda} \tag{5}$$

$$\mathrm{Re} = \frac{\mu l}{\nu} \tag{6}$$

$$\mathrm{Pr} = \frac{\nu}{a} \tag{7}$$

where $Nu$ is the Nusselt number, $Re$ is the Reynolds number, $Pr$ is the Prandtl number, $\lambda$ is the coefficient of thermal conductivity, $l$ is the qualitative size (in this case, it is the equivalent diameter of the runner in the rocks), $\mu$ is the flowing velocity, $\nu$ is the kinematical viscosity, $a$ is the thermal diffusivity of air.

The equations from (1) to (7) describe the relation between temperatures of outside air and exit (cold cave or warm cave). It can be summarized by fig. 2.

Taking warm-cave season as example, the air sucked from cold cave is heated by the rocks in the talus and blow out from the warm cave. The temperature of outside air ($T_o$) and the temperature of the rocks ($T_{rock}$) are the two most significant affecting factors of $P_n$. For a Korea DIC, Ice Valley in this season, the temperature of cold cave change dramatically with when that of the outside air the temperature of warm cave decreased with a very little rate about 1.3°C per month(Byun, 2011). Therefore the temperature of the rocks ($T_{rock}$) in the talus can be deduced as invariable in the period of one week and $P_n$ is decided by $T_o$.

The temperature responding phenomenon was first recorded by Tanaka at Nakayama Wind-hole (Tanaka, 2000) and reappeared in the field investigations of Ice Valley (Byun, 2004). During the warm-cave season, if the outside air temperature rises, the temperature of wind from warm cave drops. This drop is big when the outer air temperature is above zero and small when it is below zero (as shown in fig. 3, fig. 5 and fig. 7). This temperature responding phenomenon can be explained using the relation schema in fig. 1 with equation (1) to equation (7). During the warmcave season, *Pn* reaches higher in colder weather (equation (1)). As the gas velocity $\mu$ increases with *Pn* (equation (2))

$$\begin{tikzcd}
T_o \arrow[r] & \overline{\rho}_o \arrow[r] & \Delta\overline{\rho} \arrow[r] & P_n \arrow[r] & \nu \arrow[r] & T_c(T_w) \arrow[d, dash] \\
 & & \overline{\rho}_i \arrow[u] & & & {} \arrow[lll]
\end{tikzcd}$$

FIG. 2 - The relation schema between temperature of outside air and exit (cold cave or warm cave)

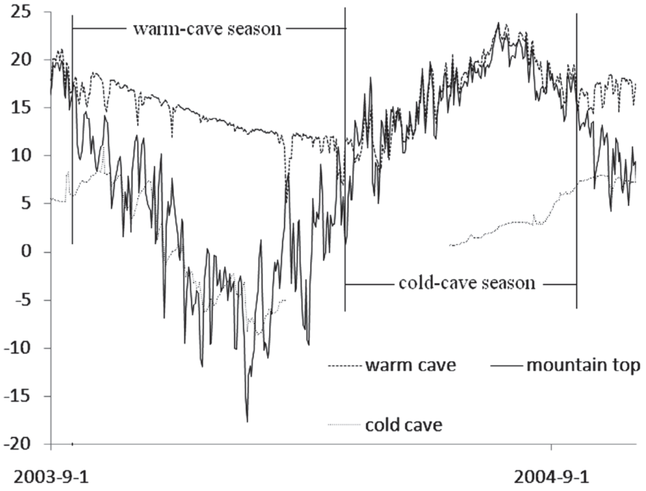


FIG. 3 - The temperature of warm cave ($T_w$), cold cave ($T_c$) and outside air ($T_o$ , rappresented by the measured values at mountain top) of Ice Valley from September 2003 to September 2004 (after Byun, 2011).

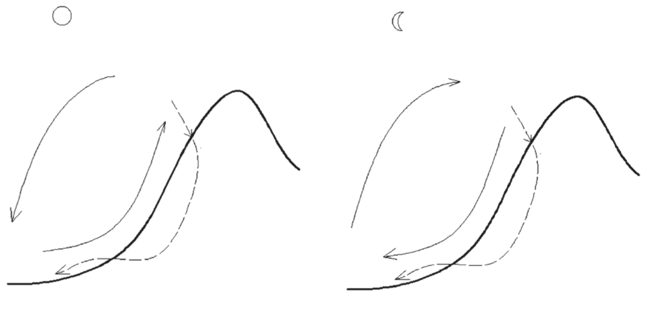


FIG. 4 - The diagram of summer mountain-valley breeze and natural ventilation in the talus: the left one is the valley breeze during the day, the right one is the mountain breeze at night; the dashed line represent the natural ventilation in the talus.

TABLE 1 - China's DICs from high latitude to low

| No. | Name | Latitude and Longitude |
|---|---|---|
| 1 | White Mountain ice cave | 41° 50'N, 126° 20'E |
| 2 | Ren ice cave | 41° 0'N, 125° 29'E |
| 3 | Qianshan ice cave | 40° 59'N, 123° 7'E |
| 4 | Chengde Miracle Well | 40° 21'N, 117° 30'E |
| 5 | Ice Back and Taiji Mountain | 36° 13'N, 113° 43'E |
| 6 | Shennongjia ice cave | 31° 38'N, 110° 34'E |
| 7 | Three Gorges ice cave | 31° 31'N, 109° 04'E |
| 8 | Zigui ice cave | 31° 5'N, 110° 31'E |
| 9 | Wufeng Baiyi ice cave | 30° 15'N, 110° 33'E |
| 10 | Yan Mountain ice cave | 27° 27'N, 103° 13'E |

and the heat transfers by convection will be better under a bigger (equation (3)-equation (7)), so higher $P_n$ means warmer air spurting out from the warm cave. However once the outside air is cold enough to ensure the air flowing in the talus is fully-heated to the temperature of the rocks, a colder outside air can result in a higher $P_n$, a larger $\mu$ but is helplessness to increase $T_w$ (or to decrease $T_c$ during coldcave season). This has been proved by Tanaka and Mizuho's observational study of summertime ice at the Nakayama windhole (Tanaka, 2000). On 30 June 1998, the temperature of outside air reached a maximum at 12:00, and the wind velocity reached its maximum at 16:00, however $T_c$ was almost unchanged all the day.

## THE TRANSITION MECHANISMS BETWEEN COLD-CAVE SEASONS AND WARM-CAVE SEASONS OF DICS

The transition mechanism, which has almost not been mentioned in the previous references, is very important to uncover the secret of DIC. The transition mechanism includes the influence of intrinsic factors and extrinsic factors.

At the end of the cold-cave season, the rocks of the talus lose most of their cooling potential and the temperature of outside air is much lower than that at the height of summer.

These intrinsic factors result in a weakening of $P_n$, which has a marked effect on the cold-cave season. Under the influence of intrinsic factors, the cold-cave season reaches an unstable critical state gradually. Then, the extrinsic factors play their roles in state transition at a vital moment. A similar situation takes place at the end of the warm-cave season.

Large temperature changes, the mountain-valley breeze and rainfall are possible extrinsic factors that may play significant roles in the transition.

Mountain-valley breeze is a localized climate created by the heat budget of valley air: during the day, the valley air is heated by the sun and rises up, causing a warm, upslope valley wind; at night, mountain air cools rapidly and flows down, causing a cold, downslope mountain wind (Christopherson, 1992).

From fig. 4, we can see the effect of mountain-valley breezes on the cycle of DICs in summer.

During the day, the valley breeze is contrary to the direction of the natural ventilation in the talus, so it impedes the suction and discharge of air, weakening the natural ventilation. At night, the mountain breeze is in the same direction as the natural ventilation in the talus, so it makes it easy for air to flow into the talus and has an injection action on the outflow of air, enhancing the natural ventilation. As the temperature difference between the outside air and the talus rock during the day is larger than at night, so from day to night, the natural ventilation is declining. Therefore, the mountain-valley breeze helps the cycle to run more smoothly by reducing the peak and filling the valley.

In summer, the air blowing from the cold cave is cold and heavy; therefore it drops below the outside air to form a stable layered structure, which can protect itself from the disturbance of the valley breeze (Tanaka, 2000). However, when autumn comes, with decreasing temperature of outside air and weakening cooling potential, the air blowing from the cold cave is gradually warmed up. The temperature gradient of layered structure declines subsequently, which destroys the stability of the layered structure. The weakened layered structure can no longer protect itself from the disturbance of the valley breeze, and then the critical moment of transition comes. After the up-slope valley breeze turns the cold-cave season to the warm-cave season, the following down-slope mountain breeze may reverse this action. Because of the seesaw battle between the valley breeze and the mountain breeze, there will be perturbations and oscillation, or even regressions to the former cycle more than

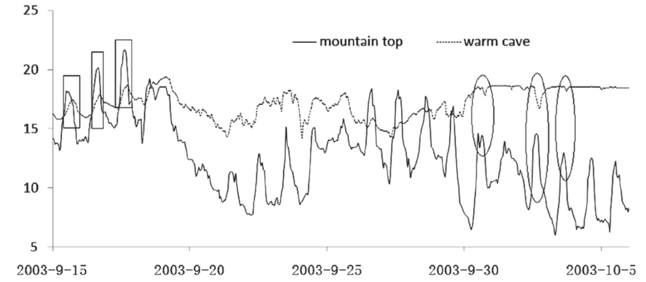


FIG. 5 - The transition from cold-cave season to warm-cave season, typical temperature opposite of warm-cave season in ellipses and temperature follow of cold-cave season in rectangle. (after Byu, 2011)

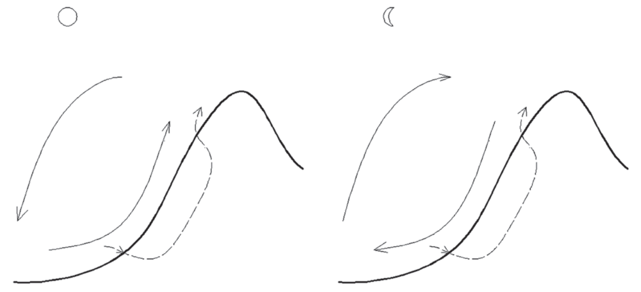
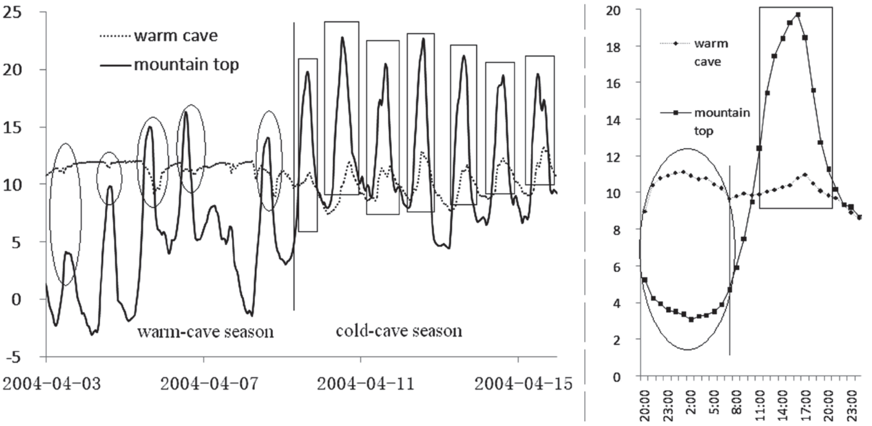


FIG. 6 - The diagram of winter mountain-valley breeze: the left one is valley breeze during the day, the right one is mountain breeze at night; the dashed line represent the natural ventilation in the talus.

Fig. 7 - The successful transition from warm-cave season to coldcave season, typical temperature opposite of warm-cave season in ellipses and temperature follow of cold-cave season in rectangle. The right one is the detail with enlarged scale from 20:00 of April 9 to 23:00 of April 10 (after Byun, 2011).



once before the new cycle is strong enough to maintain its own stability. From September 15 to 17, the temperature of warm cave changed with the outside air but with a much smaller changing scope, which is a typical characteristic of a DIC during warm-cave season. Then a large temperature drop triggered the transition. However, there was no typical characteristic of warm-cave season until September 30. The typical characteristic includes the temperature opposite between warm-cave and outside air and the nearly immutability of the temperature of warm cave when the outside air is cold enough. It took two weeks for Ice Valley to finish the transition from cold-cave season to warm-cave season (as shown in fig. 5).

In winter, as the direction of natural ventilation changes, the roles of valley breeze and mountain breeze also reverse: the valley breeze enhances the natural ventilation and the mountain breeze weakens it (as shown in fig. 6). When the arm-cave season reaches its unstable critical state under the influence of intrinsic factors, the mountain breeze plays an important role in the transition. The situation is similar to the transition from the cold-cave season to the warmcave season.

The transition at February 19 was reversed 3 days later by a dramatic temperature drop of 15°C in 24 hours (as shown in fig. 8). Both the two transition from warm-cave season to cold-cave season took place in night, when the nature ventilation can be weaken by a reverse mountain breeze.

## DISCUSSION AND CONCLUSION

In this work, we give an explanation of the interesting emperature responding phenomenon of DIC during warm-cave season after an comprehensive analysis of the interaction of $T_o$, $T_w$ and $P_n$. Before the air fully-heated to the temperature of the rocks during warm-cave season, a colder outside air means a higher $P_n$, a larger $\mu$, and a warmer air spurting out from the warm cave. However, once the air has been fully-heated, the air spurting out will keep unchanged.

The transition mechanism, which has almost not been mentioned in the previous references, is also discussed. The transition mechanism includes the influence of intrinsic factors and extrinsic factors. At the end of a cold-cave season (or a warm-cave season), the continual decreasing temperature difference between outside air and talus rocks results in a recession of natural ventilation and makes DIC reach an unstable critical state. Two possible extrinsic factors large temperature changes, the mountain-valley breeze was analyzed and compared with the observed temperature of Ice Valley by Byun (2011).

The mechanism of DICs can be used in the buildings of mountain areas. This kind of building can provide air conditioning in summer by taking advantage of unique local geology and climate. However, to describe the cycle of a DIC quantitatively, more in situ observations need to be carried out.

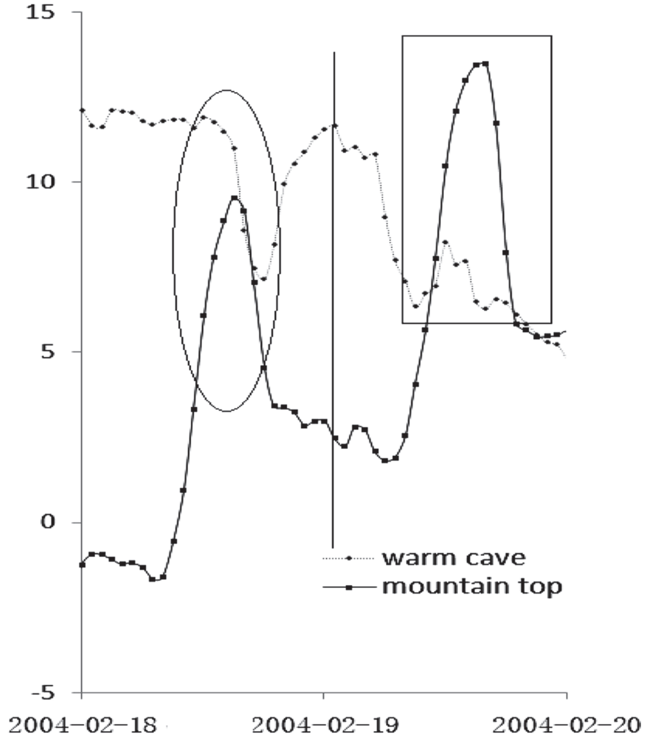


Fig. 8 - A failure transition from warm-cave season to cold-cave season (after Byun, 2011)

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