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The Impact of Climate Changes on Ski Industries in South Korea - In the Case of the Yongpyong Ski Resort -*

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기후변화가 우리나라의 스키 산업에 미치는 영향 -용평 스키장을 사례로-*

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Abstract : This study analyzed changes on the best condition of temperature and relative humidity for making artificial snows in the Yongpyong Ski Resort using data from Daegwallyeong. Depth of snowfall and snowfall days have decrease since 1990s. If the Yongpyong Ski Resort has only to depend on natural snows, it would be difficult to make and maintain ski slope. There are two times of snowmaking during ski seasons: one is the first snowmaking (October-November) for opening ski slopes and the other is the reinforcement of snowmaking (December-March) for maintaining snow quality during the seasons. Days having the best condition for the first snowmaking (daily minimum temperature below -1°C and daily average relative humidity 60 to 80 percent) decreased after 1970s. Days having the best condition for the reinforcement of snowmaking also decreased. While temperature changes are more evident than humidity changes for the first snowmaking, humidity changes are more obvious than change of temperature for the reinforcement of snowmaking. In the future climate projection by A1B scenarios, the length of ski seasons projected to decrease a 10 to 40 percent against the period of 1973-2008. The climate condition for the snowmaking projected to be poor, especially the due to increase of temperature.

Key Words : first snowmaking, reinforcement of snowmaking, change of ski season, temperature changes, humidity changes

요약 : 본 논문에서는 용평스키장을 사례로 인접한 대관령 기상관측지점의 기후자료를 이용하여 스키장 제설(製雪)작업에 영향을 미칠 수 있는 기후요소의 변화를 파악하였다. 신적설량과 신적설일수는 1990년대 이후 감소하는 경향으로 자연설만을 의존할 경우 스키장 관리에 어려움이 야기된다. 제설작업은 스키장 개장시기에 영향을 미치는 10-11월의 초기제설과 스키 시즌의 설질을 유지시키는 12-3월의 보강제설로 구분한다. 초기제설 작업을 위한 유리한 기후 조건인 일최저기온 -1℃ 이하, 일평균 상대습도 60-80%에 해당하는 경우는 분석 기간인 1970년대부터 최근까지 감소하는 경향이다. 보강제설의 기후 조건인 일최저기온 -3℃ 이하, 일평균 상대습도 60-80%에 해당하것는 경우도 각각 감소하는 경향이다. 초기제설 기간은 상대습도보다 기온의 변화가 뚜렷하고 보강제설 기간은 기온보다 상대습도의 변화 경향이 뚜렷하다. A1B 시나리오를 이용한 미래 시나리오 자료에서도 스키시즌이 오늘날보다 10-40% 정도 감소하는 것으로 전망되고 제설을 위한 기온 조건이 더욱 불리해질 수 있다. 초기제설 기간에 비하여 보강제설 기간인 12-3월의 기온변화가 더 뚜렷하다.

주요어 : 초기제설, 보강제설, 스키시즌 변화, 기온변화, 습도변화

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1. Introduction

Climate has a strong influence on the tourism and recreation, including the physical resources that are foundation of the length and quality of tourism season. These days, the growth of tourism industry is worldwide and also, local residents in South Korea make an effort in order to induce tourists for the regional income enlargement. Coastal and mountain regions, in particular, have developed tourism industries using favorable climate conditions (World Tourism Organization, 2003).

Recently it has been demonstrated that the global warming has negatively effected on the tourism industries at coast and mountain regions because of sea level rising, snow line receding by decrease of snowfall and frequent extreme weather events. Nonetheless, the impact of climate change on tourism has less discussed comparing with agriculture, forestry and fisheries and so on (Scott *et al.*, 2004). Relationships between climate changes and the vulnerabilities of winter tourism industry have been partially studied because winter is the most distinct season of temperature rising (Wall, 1992; ACACIA, 2000; IPCC, 2001).

Ski was regarded as a high class sports in South Korea, but has been a winter popular sports by rapid popularization since the late 1990s. Ski industries are very vulnerable due to the variability of snowfalls. Recently, as the winter temperature rising in South Korea due to the global warming changes snowfall days and snowfall period, it is difficult to make and maintain optimum slope conditions. That makes ski industries be pressured on the economic management due to shortened ski seasons and increasing number of snowmaking (World Tourism Organization, 2003).

Early studies for the potential impact of climate change on the ski industries were about the generalized economic extrapolation such as Cline (1992) and he estimated that a 2.5°C warming would reduce the length of the ski seasons by 60 percent across the United States, which was assumed to reduce skier visits nationally by an equal proportion and caused economic losses of approximately US$ 1.7 billion annually. Harrison *et al.* (1986) estimated that the ski season in the southern Ontario would substantially or possibly be reduced 40 to 100 percent under a doubled atmospheric CO_2 climate change scenario by the 2050s. Using similar methodologies and climate change scenarios, McBoyle and Wall (1987, 1992) projected a 40 to 89 percent reduction in the ski season in the Lower Laurential region of Quebec. However, many studies did not discussed about snowmaking adaptation strategy to respond to climate change, but did snowfall reduction due climate change (Galloway, 1988; Konig and Abegg, 1997; Harrison *et al.*, 1999; Elsasser and Bürki, 2002).

Recently, as snowfalls have reduced due to climate changes, it is difficult to maintain ski slopes using only natural snows (Koenig and Abegg, 1997; Scott *et al.*, 2002, 2003; Scott and McBoyle, 2007). Most studies about ski industries in South Korea are about ski resort managements and conditions (Shin and Lee, 2001; Ryu and Park, 2002; Park *et al.*, 2006) except for Heo and Lee(2008). They examined changes of best condition days for first snowmaking in South Korea. Considering unfavorable climate conditions by temperature rising, Heo and Lee (2008) suggested to the snowmaking machine by fan type for making earlier opening of the ski resort.

The Yongpyong Ski Resort was the first ski resort in South Korea opened in 1975 and has been popular. That locates over 800m at high altitudes in mountain regions which is higher than the neighboring ski resorts near Seoul

Metropolitan Area. That higher altitude of the resort has been favorable for making slopes due to abundant snows and lower temperature. The objective of this study is to examine the impacts of climate change in ski industries analyzing relationship between climate and snowmaking conditions for the Yongpyong Ski Resort.

2. Data and Methodology

Data for in this study are climatic data, ski resort management data and interviewed data from ski slope administrators. Climate data are from Daegwallyeong and the selection of the weather station was based on two criteria: the proximity to the Yongpyong Ski Resort (both in terms of distance and elevation) and the availability of a complete climate data set, daily - maximum, minimum and mean temperature, daily precipitation - rainfall and snowfall and daily snow depths for the period of 1973-2008 (Fig. 1). There are high correlations over 95 percent about data (temperature, rainfall, relative humidity) between Auto Weather System (AWS) in Yongpyong Ski Resort and Daegwallyeong weather station. Therefore longer climatic data from Daegwallyeong are used in this study.

The A1B scenario has been used in accordance with the recommendations of the Intergovernmental Panel on Climate Change (IPCC) Task Group on Climate Impact Assessment. A1B scenario most coincides with the reality, a present CO_2 emission continuously increases to 2050, after a little decreases (Kwon *et al.*, 2007). Covered area and duration of future scenario are 37.59° N-38.08° N and 128.53° E-128.77° E, 90 years between 2011 and 2100.

The ski resort management data were collected by various ways. Ski opening date was collected from newspaper (1975-2008), ski tourist data from the Korean Ski Management Society (1990-2008), snowmaking data (hours, quantity, start days, etc.) from the Yongpyong Ski Resort (2002-2008), respectively.

In order to examine the impact of snowfall change on the slope making, trends of snowfall and snowfall days were analyzed. Analyses for the depth of snowfall available for slope opening

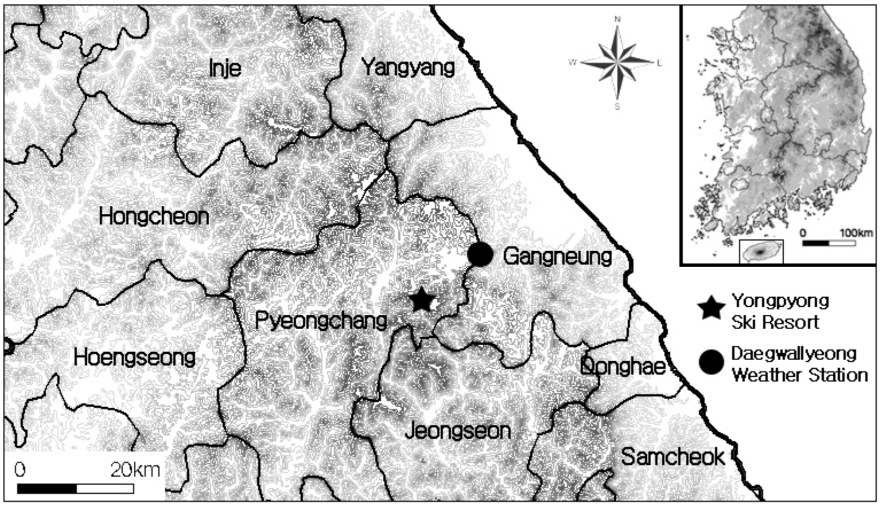

Figure 1. Study area and the location of weather station

help to evaluate the location suitability of the Yongpyong Ski Resort. A long period changes of climate condition for the first snowmaking and the reinforcement of snowmaking have been estimated using a linear regression. To assess the projection of ski resort management in the future climate condition, changes of ski seasons and climate condition related snowmaking were analyzed.

3. The Change of Climate Conditions Affecting for Snowmaking

1) Changes of snowfall

The air temperature rising in winter season can affect on the depth of snowfall and snow days. Fig. 2 shows the variation of snowfall depth and snowfall days from October to March at Daegwallyeong. Both depth of snowfall and snowfall days increased in the early 1990s, but since then they have been decreasing. They were 236.8cm and 51.8 days in the 1970s, 270.0cm and 54.7 days in the 1990s respectively. They increased up to 14 and 5 percent, respectively. However the decreasing trend of snowfall depth and snowfall days is considerable from the mid 1990s. Depth of snowfall and snowfall days in the 2000s were 227.4cm and 52.9 days respectively, that is decrease of 16 and 4 percent from the 1990s. It means that there are difficulties in the management of ski slopes by only natural snowfalls. As the suitable condition for ski slop is 50cm in the depth of snow cover, it is impossible to open ski slopes below 30cm of that (Scott *et al.*, 2003). The day over 50cm and 30cm in the depth of snow from October to March at Daegwallyeong is 19.4 and 32.9 days, respectively. Such facts show that best condition days for ski by natural snows are below 20 days, and the manageable days of ski slope by natural snows are about 30 days.

The manageable minimum condition for ski slopes is 30cm in the depth of snow on mentioned earlier. Bürki *et al.* (2005) suggested that the year having 100 days of 30cm or higher in the depth of snowfall is suitable to open ski resort while the year having below 40 days of that is not. The assessment of location condition as a ski resort for the Yongpyong Resort by natural snows is showed in Fig. 3. The year having below 40 days with 30cm or higher in the depth of snow is 63.9 percent and for that period, Yongpyong Resort is not appropriate as a ski resort. The lower latitude and lower altitude of Yongpyong is unfavorable compared to the more developed countries in ski industries such as Switzerland, Canada and Australia. However,

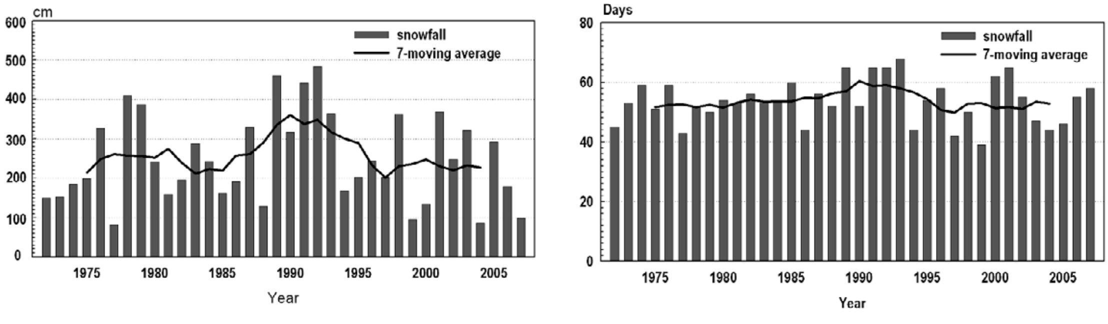

Figure 2. Change of annual snowfall depth (left) and snowfall days (right) for Daegwallyeong (October-March)

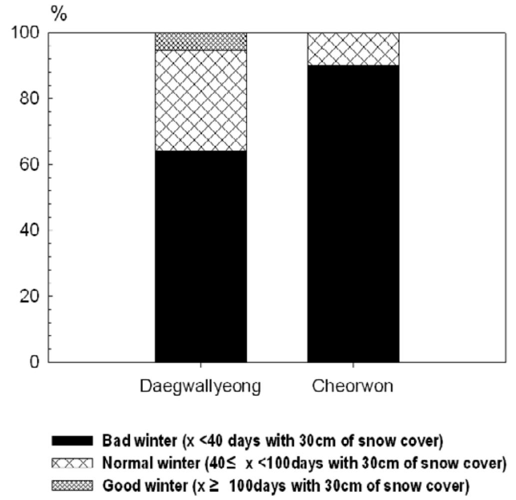

Figure 3. Natural snow-reliability for the Yongpyong Ski Resort and the Pochon ski resort (Yongpyong data derive from Daegwallyeong and Pochon data does from Cheorwon)

Yongpyong is the best ski resort located in the highest site in South Korea. That is relatively stable site to manage ski slope in South Korea.

The dependence on natural snow covers is higher in Yongpyong than in the Pochon Resort near Seoul Metropolitans Area in Fig. 3. Therefore, it might demonstrate that Yongpyong is unsuitable site for ski resort when considering climate conditions only, but economically that can be the site of best condition deciding the location for a ski resort in South Korea when considering snowmaking. The snowmaking is the most important factor for a ski resort in South Korea. In the case of the rise of air temperature, importance of the snowmaking is getting bigger by the time being.

2) Climate condition for the first snowmaking

The suitable snow cover is the most important factor to open ski resort. It is possible to open ski resort when it is over 50cm in the depth of snow cover on slope by snow grooming (Seo, 2008). The technique of snowmaking is essential to make earlier the opening date regardless of recent decreasing snowfalls.

Machines of snowmaking are two types: one is a gun type, and the other is a fan type. The gun type machine is cheap while the fan type machine is more efficient to make abundant snows for the same weather condition comparing with the gun type. During an early stage of opening, the ski slope is covered by artificial snows with a high density and efficient compactness comparing with natural snows. If the ski slop is covered by the natural snows in the first snowmaking, it can be dangerous due to snow avalanches. Therefore, the timing of opening is determined by the condition of snowmaking controlled by air temperature and relative humidity. The best condition in air temperature is below -5°C daily minimum temperature under present technique (Scott and McBoyle, 2007). However, it can be operated when it is -1°C daily minimum temperature in the Yongpyong Resort because it is important to open the ski slope earlier.[1)]

Usually, as the first snowmaking date in the Yongpyong Resort is the end of October and the latest date is 14th December, therefore it is indicated that the period of snowmaking can be for the three months from the first of October to the first of December. Fig. 4 shows the change of days below -1°C daily minimum temperature at Daegwallyeong, the possible days for the first snowmaking in Yongpyong. That shows a decreasing trend by 2.0 days per a decade from the first of October to the first of Decemberand and that change is statistically significant at 95 percent level. However, the first snowmaking date happens from October to November in these days, and the change of the days below -1°C daily minimum temperature in the months showed in Fig. 4. The possible period has a decreasing trend by 2.2 days per a decade.

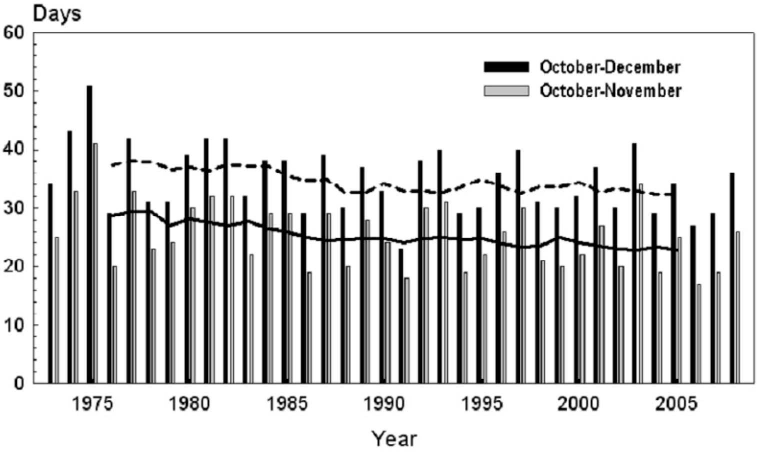

Figure 4. Change in the frequency of days below -1°C minimum temperature (dash line: 7 years moving average from October to December, bold line: 7 years moving average from October to November), after Heo and Lee (2008)

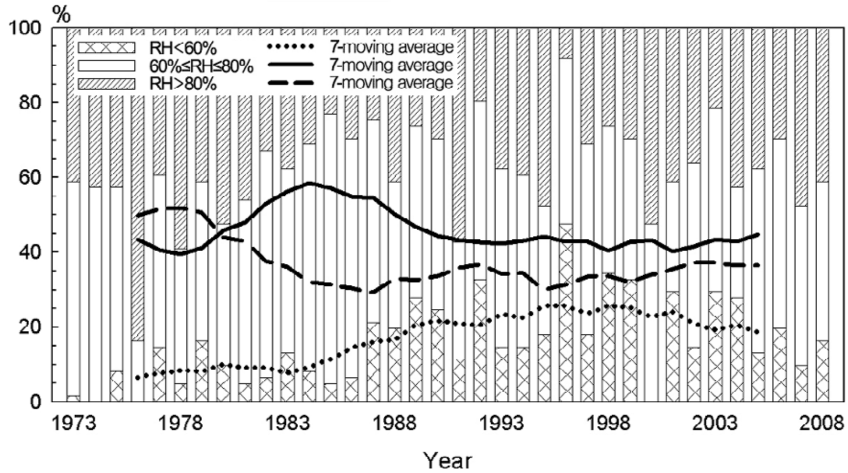

Figure 5. Changes of relative humidity (October-November)

Moreover, the opening time of ski slope is affected humidity with air temperature. The suitable relative humidity to make artificial snows is 60 to 80 percent (Seo, 2008) as it mentioned earlier. Therefore, the best condition for snowmaking is that minimum temperature is below -1°C and the range of relative humidity is 60 to 80 percent.

To examine the change of relative humidity which affects the first snowmaking, the days with relative humidity 60 to 80 percent from October to November analyzed and showed in Fig. 5. The days decrease 1.1 days per a decade, showing 33.0 days in the 1970s and 26.1 days in the 1990s. This resulted from increases of the days below 60 percent of relative humidity due to the air temperature rising after the 1980s in South Korea.

Fig. 6 shows the change of the first snowmaking condition considering the air temperature and relative humidity, it indicates a

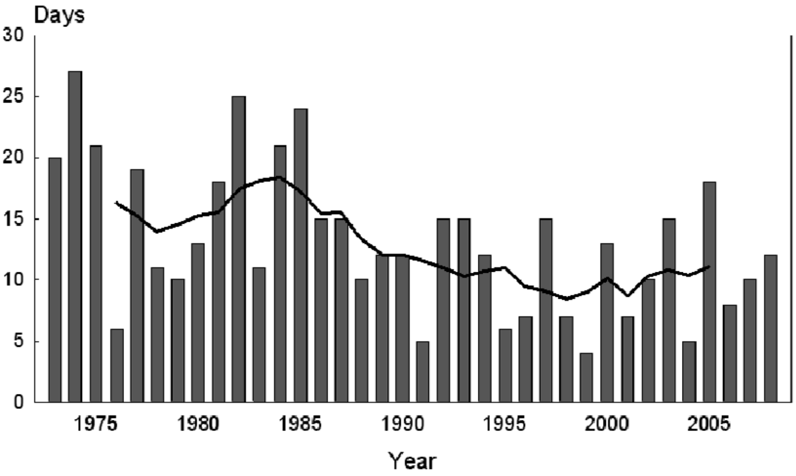

Figure 6. Change in the frequency of days below -1°C minimum temperature and relative humidity 60-80% days (October-November bold line: 7 years moving average from October to November), after Heo and Lee (2008)

distinct decreasing trend. The suitable duration of the first snowmaking decreases 2.8 days per a decade considering the air temperature and relative humidity and that change is statistically significant at 99 percent level. That is, the suitable condition of snowmaking is less frequent and it makes difficult for ski resort administrators who want to open the ski slope early.

3) The reinforcement of snowmaking

At the opening time of ski slopes, only 2 or 3 ski slopes are opened. To make the opening date of ski resort earlier, it must be below the freezing point of minimum temperature, and then opening time of ski slope is available from October to November. In December when opening all the ski slopes in the resort, the temperature condition is critical for artificial snows. For the Yongpyong Resort, it is below -3°C daily minimum temperature when the reinforcement of snowmaking needs.

Fig. 7 shows the change of days below -3°C daily minimum temperature at Daegwallyeong. The trend is decreasing with 1.6 days per a decade, which is less than the first snowmaking for this study period. The average of the day is 104.9 days from 1970s to 1990s, 100.9 days for 2000s. In the same period, the regression coefficient of daily minimum temperature is 0.66 both seasons in the first snowmaking and season in the reinforcement of snowmaking, the air temperature does not more change in critical season. That is coincided with the result of Heo and Lee (2006) which analyzed the change of extreme temperature by intensity in winter season.

The change of days with 60 to 80 percent in relative humidity from December to March is showed in Fig. 8. The day of suitable condition in humidity decreased 1.1 days per a decade for an early stage of slope opening from 1980s, and that is decreasing 7.3 days per a decade for the mid ski season. According to analyses of monthly relative humidity, it decreases 1.7 percent per a decade from October to November, and decreased 2.5 percent per a decade from December to March temperature at Daegwallyeong. It indicates that temperature condition is important for the first snowmaking

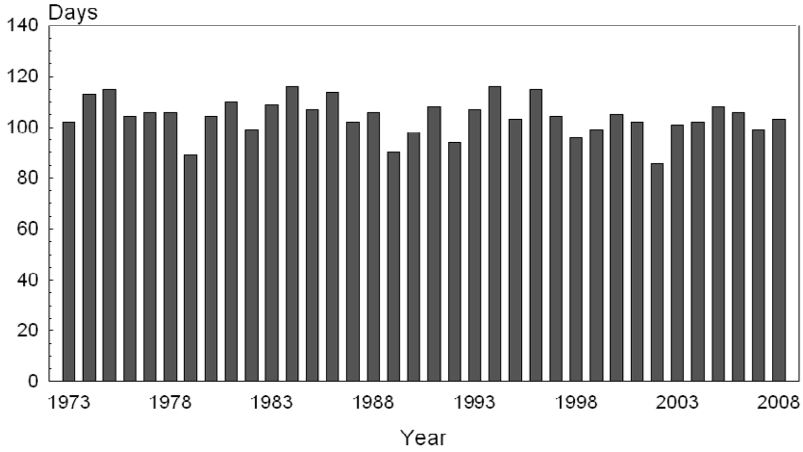

Figure 7. Change in the frequency of days below -3°C minimum temperature (December-March)

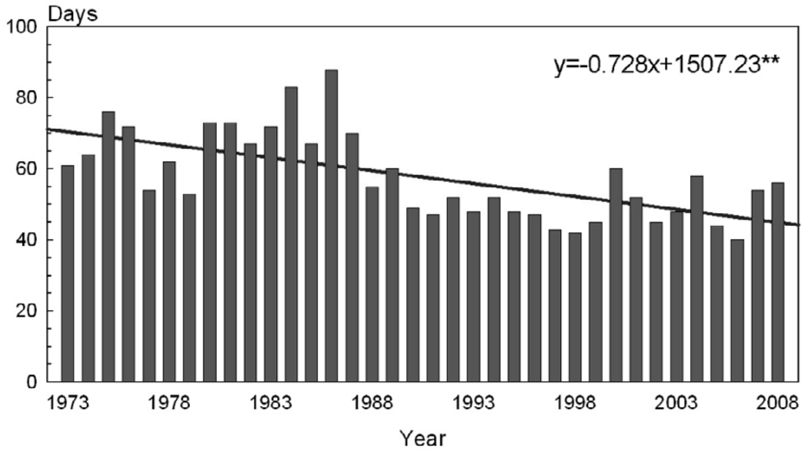

Figure 8. Change in the frequency of relative humidity 60-80% days (December-March, **: significant at 99 percent level)

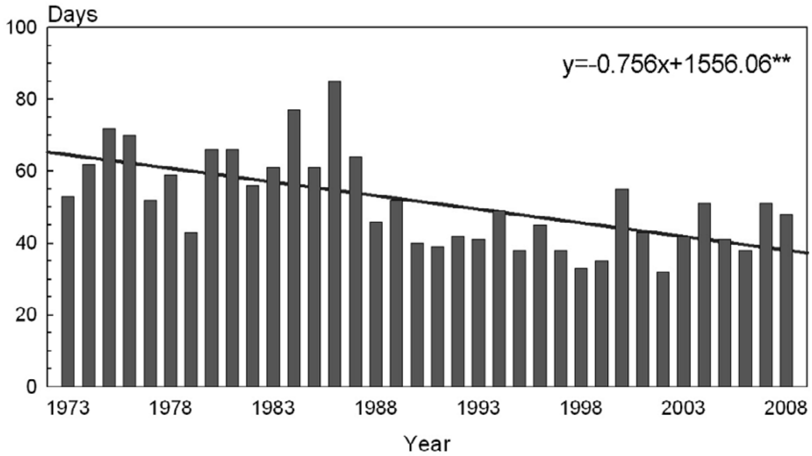

Figure 9. Change in the frequency of days below -3°C minimum temperature and relative humidity 60-80% days
(December-March, **: significant at 99 percent level)

while humidity condition is important for the reinforcement of snowmaking.

Fig. 9 shows the change of the suitable weather condition for the reinforcement of snowmaking under considered temperature and humidity. It shows a obvious decreasing trend about 7.6 days per a decade, while the decreasing trend of the first snowmaking day is only 2.8 days per a decade. Therefore, it is necessary to reinforce snowmaking to maintain the best condition for ski slopes because it can cause a serious economical damage.

4. The Projection of Ski Resort Management due to Climate Changes

1) The projection of ski season change

Scott *et al*. (2003) suggested that the first snowmaking be required 50-75cm in the depth of snow cover to prepare for the temperature rising and rainfall after snowmaking. To estimate future possible ski season length for the ski resort, it needs to predict future snow conditions. However, A1B scenario data can only provide air temperature, precipitation, relative humidity, and so on. Therefore, possible ski seasons has to be estimated using air temperature and precipitation. Scott *et al*. (2003) assumed ski slopes should be closed if any of the following climatic conditions occurred: maximum temperature is 10°C or higher for 2 consecutive days accompanied by rainfall; 2 days of rainfall is 20mm or more.

In A1B scenario, there are few days which both having 2 consecutive rainfall days and 20mm or more rainfall for the months of possible closing dates for the ski resort. Therefore, for this study, ski resort closing dates are assumed as those having mean temperature 4°C or higher and accompanied by rainfall. These criteria are the snow melting index suggested by Fukushima *et al*. (2002). In fact, slopes administrators of the Yongpyong Ski Resort would decide at the discretion of closing date considering the condition of slope snows melted after winter ski seasons.

Table 1. Estimating ski season length in the future by 30-year period (unit: days)

period	ski season length
2010s-2030s	105.6
2040s-2060s	84.4
2070s-2090s	61.6

Table 1 shows an outlook of future ski season length by A1B scenario by 30-year period. Ski season length drastically decreased. As an average ski season lengths is 105.6 days in the period of 2010s to 2030s and 61.6 days from 2070s to 2090s. That indicates a decrease of 41.7 percent after 2070s against the period of 2010s-2030s. In the future, ski resort management has a difficulty because ski season length remains very short (about -10 to -40 percent) comparing with the present (average 120.0 days).

2) The projection of changes in temperature and humidity

The changes of air temperature impact on the snowmaking during 2011-2100 using future climate scenario data is showed in Table 2. Days of below -1°C daily minimum temperature for the first snowmaking season is average 25.5 days from 1973 to 2008, but the period of 2010s to 2030s has decrease into an average 6.9 days and 0.2 days after 2070s. If snowmaking technology advances in future, a minimum criterion of temperature is -2°C for the economic management in the outside (Scott *et al*., 2003).

When analyzing the snowmaking criterion of below -1°C daily minimum temperature accordance with A1B scenario, future projection of climate changes for the first snowmaking would be in negative.

The reinforcement of snowmaking carrying out from December to March would be also negatively effected by future temperature change. Suitable days of the reinforcement of snowmaking from observation data (1973-2008) is 121.0 days in average, but 103.8 days for the period of 2010s to 2030s, and 74.0 days for the period of 2070s to 2090s decreasing 28.7 percent. Days of below -3°C daily minimum temperature for the reinforcement of snowmaking after 2070s would decrease 38.8 percent comparing with period of 1973 to 2008.

Change of future relative humidity in A1B scenario might not be distinct. There is an insignificant change of relative humidity from October to November and there has been no distinct change from December to March. From 1973 to 2008, relative humidity which impacts on snowmaking has decreased since 1980, but there is little impact on snowmaking in the future.

The change of best climate conditions for snowmaking with considering both temperature and humidity is showed in Table 3. The best condition days of the first snowmaking is 13.2 days in average from 1973 to 2008, but the first 30 years (2010s-2030s) and the second 30 years (2040s-2060s) of future climatic data have only 2.5 days and 0.9 days, respectively. Even there would be none of best condition from 2070s to 2090s. The best condition days for the reinforcement of snowmaking is 40.0 days in the first 30 years (2010s-2030s) and 30.2 days in the third 30 years (2070s-2090s), with drastic decrease comparing with a present observation data (51.3 days).

The change of relative humidity in the observation data is more evident than temperature for the reinforcement of snowmaking. This result is owing to differences (22.6 days) of days including daily relative humidity 60 to 80 percent between observational data and scenario data during 1973-1990, but 2.9 days since 1990. In consequence, the difference

Table 2. Changes of suitable snowmaking days by air temperature (first snowmaking: below -1°C minimum temperature, reinforcement of snowmaking: below -3°C minimum temperature)

(unit: days)

season / period	first snowmaking (October-November)	reinforcement of snowmaking (December-March)
2010s-2030s	6.9	103.8
2040s-2060s	2.2	90.0
2070s-2090s	0.2	74.0

Table 3. Changes of suitable snowmaking days by air temperature and relative humidity 60-80% (first snowmaking: below -1°C minimum temperature, reinforcement of snowmaking: below -3°C minimum temperature)

(unit: days)

season / period	first snowmaking (October-November)	reinforcement of snowmaking (December-March)
2010s-2030s	2.5	40.0
2040s-2060s	0.9	34.0
2070s-2090s	0.0	30.2

of relative humidity between observational data and future scenario data must study by comparison between multiple climate change models in the future.

5. Summary and Conclusion

This study analyzed changes on the best condition of temperature and relative humidity for making artificial snows in the Yongpyong Ski Resort using data from Daegwallyeong.

Depth of snowfall and snowfall days of Daegwallyong is decreasing trend since 1990s. If the Yongpyong Ski Resort has only to depend on natural snows, it would be difficult to maintain and manage it. Therefore, Yongpyong is dependent region of artificial snow by snowmaking. Snowmaking has affected to air temperature and humidity. The suitable relative humidity to make artificial snow is 60 to 80 percent. Temperature standards of the best condition for the first snowmaking and the reinforcement of snowmaking are below -1°C and -3°C, respectively. Days of below -1°C daily minimum temperature for the first snowmaking have decreased 2.2 days per a decade and suitable relative humidity have also decreased 1.1 days per a decade including with clearly decrease after mid 1980s. Days of below -3°C daily minimum temperature and suitable relative humidity for the reinforcement of snowmaking have decreased 1.6 days and 7.3 days per a decade, respectively. So that season of the first snowmaking (October-November) have a damage owing to changes of temperature than changes of humidity. The other side, the reinforcement of snowmaking (December-March) suffers from changes of humidity than changes of temperature.

The ski season Length in future will decrease over 10 to 40 percent comparing with ski season of the Yongpyong Ski Resort in these days. It is also obvious that days of the best temperature condition are decreased considering that the climate has changed for snowmaking in the future. The best temperature condition days for the first snowmaking don't exist and the reinforcement of snowmaking have decreased 38.8 percent of the period from 2070s to 2090s comparing with today. Decreasing trend of Suitable days in the reinforcement of snowmaking by temperature rising during December to March is evident against observation data.

This study has provided the understanding of relationships between climate changes and snowmaking, which is analyzed conditions of temperature and humidity for snowmaking have been continuously negative. After 1990, the flow of tourists has been continuously increased towards the ski resorts except for the IMF crisis because the cognition for ski changes from high class sport to popular sport. If ski resort tourists increase, preparation of climate change would be demanded for ski industries activity. Because it can't provide suitable physical environment in ski resort.

Note

1) This climate conditions for snowmaking in the Yongpyong Ski Resort result from interview with Byoungsun Ahn, Myoungrae Kim, Jongju Lee and Jounghoon Choi in charge of snowmaking management.

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