A study of snow climates in The Japan Alps

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ABSTRACT: The Japan Alps on Japan's main island of Honshu consist of 3 mountainous areas broken into the North, Central and South Alps that are located between 35°to 37°N, 136°to 140°E. It is known experientially that the amount of snow differs dramatically in these areas due to the varying influences of the winter monsoons across these mountain ranges. In this study we analyzed the meteorological data and the snow-pack data of two of these areas; the northern North Alps known for it's heavy snow fall, the Central Alps known for it's low snow fall. A distance of approximately 100 km separates these two areas. Based on the processes used by Mock and Birkeland (2000), the results of snow climate classification are as follows; northern North Alps (10 year Ave.: Coastal, 10/10 winters: Coastal), Central Alps (10 year Ave.: Continental, 6/10 winters: Continental, 4/10 winter: Coastal).
The snow-pack data of the northern North Alps over 5 winters showed the characteristics of Coastal climate. On the other hand, Snow-pack characteristic of the Central Alps is similar to Continental characteristic but differs in the high predominance of wet-grain. These results show that the snow climate classification to have attention for the rainfall more than the classifications used in the North America is needed in the Japan Alps.

KEYWORDS: Snow Climate, The Japan Alps, Snow-pack structure, Snow grain type, Weak layer

1. INTRODUCTION

The Japan Alps on Japan's main island of Honshu consist of 3 mountainous areas broken into the North, Central and South Alps that are located between 35°to 37°N, 136°to 140°E. The Japan Alps is one of the most popular area for the snow activity of the ski and the mountaineering in Japan, because it has many peaks of around 3000 m and there is rich snow in the winter season. Therefore, every winter some recreationists are killed by avalanches. Fore example, seven recreationists were killed by avalanches in the 08 winter.

When dividing roughly, the snowfall systems in The Japan Alps are divided into two types, one is the type brought by approaching or passing of low pressure and the other type is the brought by orographic rifting caused by NW winter monsoon which through above the warm Sea of Japan, and the influence of the monsoon is more local than the low pressure. However, amount of snowfall in the area which is strongly influenced in the monsoon is higher than the other area, because their higher frequency of occurrence and longer duration. The region where is strongly influenced by the monsoon is called "The Sea of Japan side region" and the region where is weakly influenced by the monsoon is called "The Pacific Ocean side region", and it is known experientially that the depth of snow cover of each region is very different generally in Japan. It is important to know snow climate which is related with avalanches of the field of activity to reduce avalanche accidents. A lot of researches about snow climate which related with avalanches were done Mainly in North America (i.e., LaChapelle, 1966; Armstrong and Armstrong, 1987; Mock and Birkeland ,2000; Pascal and McClung, 2003).

Though that the various snow characteristics existed in The Japan Alps was empirically known, existing researches of the mountain snow-pack in Japan aimed at the development of the water resources and it focused on the snow water quantity mainly (i.e., Ogasawara, 1964; Nakagawa, 1976).

Therefore, we examined the characteristic of the snow climate which is related with avalanches using the meteorological and snow-pit data which were collected from the two study plots (Pacific Ocean side region: Nishikoma study plot and the Sea of Japan side region: Tugaike study plot) to contribute to avalanche accidents reduction in the Japan Alps.

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2. STUDY SITE

Tsugaike study plot (36°46′N, 137°49′E, 1560 m a.s.l.) is located in the lift top of the Tsugaike highland ski ground which is on the foot of Mt. Hakuba-Norikuradake (2456 m a.s.l.) in the northern part of North Alps, and it belongs to the typical Sea of Japan side region: heavy snow region.

Nishikoma study plot (35°49′N, 137°50′E, 1900 m a.s.l.) is located on the path leading to the top of Mt. Shogi-Gashira-Yama (2730 m a.s.l.) in the northern part of Central Alps, and it belongs to the typical Pacific Ocean side region: little snow region. The tree line of Mt. Hakuba-Norikuradake is 2200 m a.s.l. and Mt. Shogi-Gashira-Yama is 2600 m a.s.l.. Both study plots were located in the sub-alpine forest which consist of fir trees and mountain birches mainly. Study plots were located in the flat locations which have enough space for continuous snow-pit observations and are little influenced by the snow fallen off trees and the snowdrift caused by the wind.

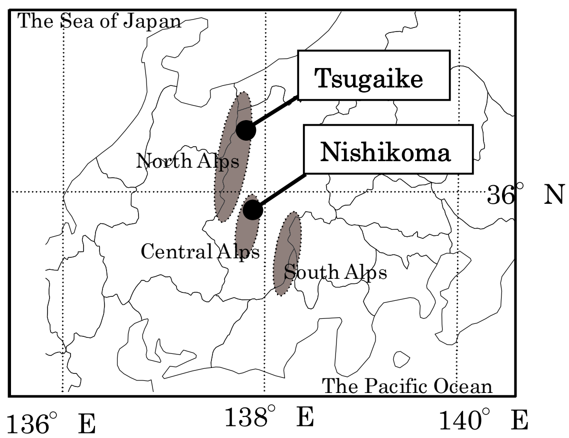

Fig.1 Study site

3. METHOD

First, we collected meteorological data from 2 study plots and examine the general climatic conditions of both of the Sea of Japan side region and the Pacific Ocean side region, using snow climate classification scheme proposed by Mock and Birkeland, 2000. Next, we examined the snow-pack characteristic which is related with avalanches based on the snow-pit observation data. Based on these, we analyze the snow climate which is related with avalanches of the study area.

3.1 WEATHER AND SNOW-PIT DATASETS

We collected a meteorological data and snow-pit data from the study plots and around the study plots. The contents of the collected datasets are shown in Table1. Because we could not collect continuous air temperature data from the study plots, air temperature data of Nishikoma study plot were estimated from the values which were recorded at AMEDAS Ina which is located about 10 km East and air temperature data of Tsugaike study plot were estimated from the values which were recorded at AMEDAS Hakuba which is located about 5 km Northeast. The air temperature lapse rate of 0.6℃/100m:Nishikoma was estimated from 2 winter (00-01-01-02 winters) datasets and 0.5℃/100m:Tugaike was estimated from 1 winter (07-08 winter) datasets. The values of Amount of rainfall were estimated by accumulating the rainfall values recorded in AMEDAS when the estimated air temperature of study plots becomes equal to or more than 0℃. Each pit was dug to 150cm from the snow surface to the ground. Grain type, size, hand hardness and snow temperature (every 10 cm) values were taken. In Tsugaike Shovel compression test was used to measure layer and interface strength. CAA Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches were used.

3.2 SNOW CLIMATE CLASSIFICATION

We used snow climate classification scheme proposed by Mock and Birkeland, 2000. The sche me uses the meteorological data of December to March (the mean air temperature, the amount of to tal rain fall, the amount of total snow water equival

Table 1 The contents of the collected weather and Snow-pit observation datasets

Study site	elements	Observation Site	Observer	period	interval
Nishikoma	Air temperature	AMEDAS Ina (674m a.s.l.)	Japan meteorological Agency	95-96～04-05	1/hour
	Rainfall				1/hour
	Air temperature	Nishikoma (1900m a.s.l.)	Authors	00-01～01-02	1/hour
	Snow depth		Authors	95-96～05-06	1/month
	Snow-pit		Authors		
Tsugaike	Air temperature	AMEDAS Hakuba (703m a.s.l.)	Japan meteorological Agency	96-97～05-06, 07-08	1/hour
	Precipitation			96-97～05-06	1/hour
	Air temperature	Tsugaike (1600m a.s.l.)	Authors	07-08	1/hour
	Snow depth		Tsugaike Ski patrol	96-97～05-06	2/day
	Snow-pit		Authors	99-00～05-06	2-4/month

ent, the amount of total snow fall and the Decemb er temperature gradient) to divide into Coastal, Int ermountain and Continental three class (Fig.2).
It was difficult to consider that this classification is suitable just as it is for The Japan Alps, but we tried to use the scheme to compare the snow climate of The Japan Alps and the snow climate of North America. Specifically, in Japan, the term, Continental, isn't suitable but in this paper we use it. Some values which did not have measurements were substituted by the method which is shown below. The values of snow water equivalent which estimated from the maximum snow depth were used instead of the value of total snow water equivalent. The value of snow water equivalent was estimated from the maximum snow depth, on the assumption that the value of mean snow density is 300kg/m^3. The assumed new snow density of 100kg/m^3 were used to estimate the amount of snow fall from the value of snow water equivalent which estimated from the maximum snow depth. The values which divided the snow depth of the end of December by mean air temperature of December was used instead of The December average temperature gradient.

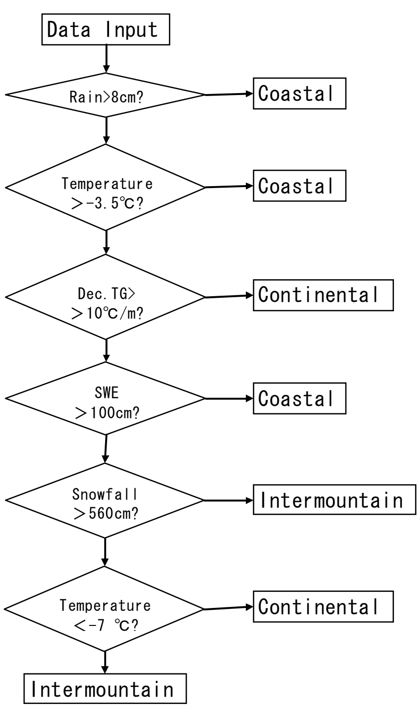

Fig2 Flowchart illustrating the classification procedure for the snow climate (Mock and Birkeland ,2000).

3. RESULTS AND DISCUSSION

3.1 METEOROLOGICAL CONDITION AND SNOW CLIMATE CLASSIFICATION

The monthly mean meteorological values of each study plot are shown in Fig.3.
Snow depth of each study plot are very different (T he 10 year mean values of Nishikoma: 113 cm an d Tsugaike: 384 cm), but the difference of air temp erature values is very little (The 10 year mean valu es of Nishikoma: -6.6℃ and Tsugaike: -5.6℃) whe n considering the vertical gaps of 300m of each sit e.
When focused on the change of the snow depth, though the snow depth of Tsugaike was decreased in March, the snow depth of Nishikoma reached maximum in March, and in Nishikoma quite much amount of rainfall was observed in March. This is because the frequency that the low pressure passes becomes high when becoming in March, and it bring the increase of precipitation (snow and rain) to Nishikoma which is influenced by the low pressure strongly.
When comparing with the meteorological value of these study plots and the value of North America which was reported in Mock and Birkeland, 2000, the snow depth of Nishikoma corresponds to the range of Continental climate and the temperature corresponds to Intermountain climate. The snow depth of Tugaike corresponds to the range of Coastal climate and the temperature corresponds to Intermountain climate.

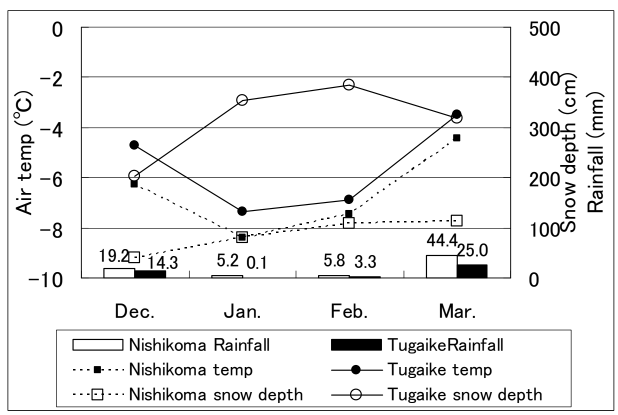

Fig.3 10 year mean value of Rainfall, Snow-depth and air temperature of each month.

The results of Snow climate classification are shown in Table2: Nishikoma and Table3: Tsugaike. The results of they are as follows; Nishikoma (10 year average: Continental, 6/10 winters: Continental, 4/10 winter: Coastal), Tsugaike (10 year average.: Coastal, 10/10 winters: Coastal). The thresholds which influenced results of the

Table 2 Snow climate classification results of Nishikoma. Gray hatching shows the value of criteria for classification.

	Classification	Rainfall (cm)	Temp (℃)	Dec.TG (℃/m)	SWE (mm)	Snowfall (cm)
95−96	Continental	6.5	-7.2	-	264	264
96−97	Coastal	9.5	-6.6	20.6	508	508
97−98	Continental	7.3	-6.5	15.9	386	386
98−99	Coastal	9.9	-6.3	24.0	436	436
99−00	Continental	1.8	-6.7	26.4	264	264
00−01	Continental	2.6	-7.2	16.4	353	353
01-02	Continental	7.8	-5.8	11.7	594	594
02-03	Continental	1.9	-7.2	-	462	462
03-04	Coastal	8.9	-6.3	12.1	498	498
04-05	Coastal	18.4	-6.5	9.4	267	267
Ave.	Continental	7.5	-6.6	16.1	418.7	418.7

Table 3 Snow climate classification results of Tsugaike. Gray hatching shows the value of criteria for classification.

	Classification	Rainfall (cm)	Temp (℃)	Dec.TG (℃/m)	SWE (mm)	Snowfall (cm)
96−97	Coastal	2.6	-5.4	3.5	1049	1049
97−98	Coastal	9.8	-4.8	7.9	851	851
98−99	Coastal	7.9	-4.9	0.9	1053	1053
99−00	Coastal	1.4	-5.9	2.8	1221	1221
00−01	Coastal	1.6	-5.9	3.8	1307	1307
01-02	Coastal	3.4	-4.9	4.4	1304	1304
02-03	Coastal	0.8	-6.3	3.3	1396	1396
03-04	Coastal	7.4	-5.3	2.7	1214	1214
04-05	Coastal	6.9	-5.5	4.9	1152	1152
05-06	Coastal	0.9	-6.7	3.3	1122	1122
Ave.	Coastal	4.3	-5.6	3.8	1166.9	1166.9

Table 4 Number of cases classified by criteria.

Criteria for classification	Nishikoma	Tugaike
Rain>8 cm	4	1
Temperature>-3.5℃	0	0
Dec.TG>10℃/m	4	0
SWE>1000mm	0	9
Temperature<-7℃	2	0
Temperature>-7℃	0	0

divisions are Continental: 6 (Dec.TG>10℃/m: 4, Temperature<-7℃: 2), Coastal : 4(Rain>8 cm : 4) in Nishikoma and Coastal : 10 (SWE>1000mm : 9, Rain>8 cm : 1) in Tugaike (Table 4). In Tsugaiek, the almost of cases could be divided into Coastal easily with the threshold of SWE. On the other hands, in Nishikoma, Both extreme classification results, the Continental and the Coastal were fitted, on the ratio of 6:4, without the Intermountain.

The difference in these results were brought by the threshold of rainfall (<8cm), but the amount of rain fall is close to the thresholds (<8cm) even in the winter which divided into Continental climate. For that reason, it is divided into the Continental climate or the Coastal climate, by a little difference of amount of rainfall.

The stations which have similar classification results with Nishikoma were not exist in the 48 stations of The United States which were used by Mock and Birkeland, 2000.

3.2 SNOW-PACK CHARACTERISTICS

3.2.1 SNOW-PACK STRUCTURE

In Nishikoma, the predominant snow grain type is depth hoar (include facets) and wet-grain and the structural weakness caused by weak depth hoar exists inside the snow-pack (Fig.4).

Thickness dominance (%) of depth-hoar is 33% and wet-grain is 33% (Fig.5), and the hardness profile type of C (The structural weakness caused by weak depth hoar and facets exists inside the snow-pack) was 56% (Fig.6) within observed snow pits in Nishikoma (10 winter 36 pits). It consider that The high Thickness dominance of wet-grain:33% is brought by the influence of much rainfall. Snow-pack characteristic of Nishikoma is

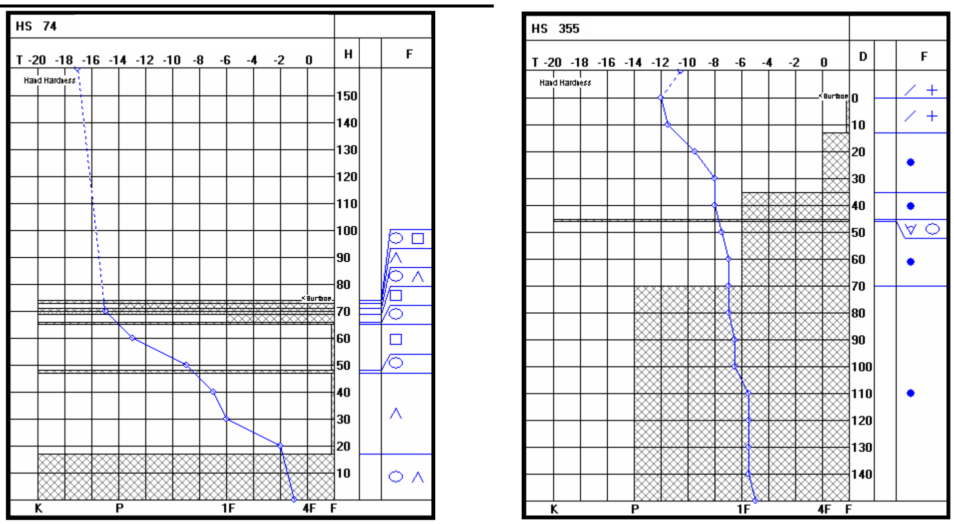

Fig.4 Typical examples of snow-profile in high winter. Left: Nishikoma (99.02.29) and right Tsugaike (01.02.15).

similar to Continental characteristic but differs in the high predominance of wet-grain.
In Tsugaike, the snow-pack shows typical Coastal characteristics, the predominant snow grain type is rounded grains and snow hardness increase progressively from surface to the bottom (Fig.4). Thickness dominance (%) of rounded grain is 80% (Fig.5) and hardness profile type of A (The type of hardness profile as hardness increase progressively from surface to the bottom) and B (Almost as same as A, but include one or multi hard layers of melt-freeze crusts) were 66% (Fig.6) within observed snow pits in Tsugaike (5 winter 47 pits).

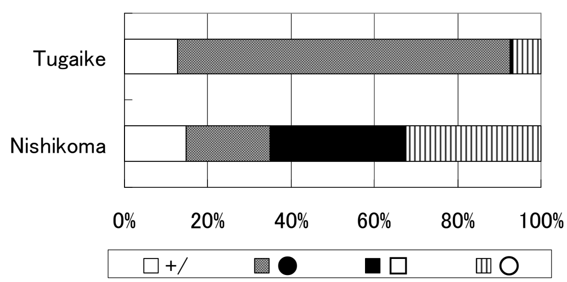

Fig.5. Thickness dominance (%) of each snow-grain type with in observed snow pits (Nishikoma: 10 winter 36 pits, Tsugaike:5 winter 47pits).

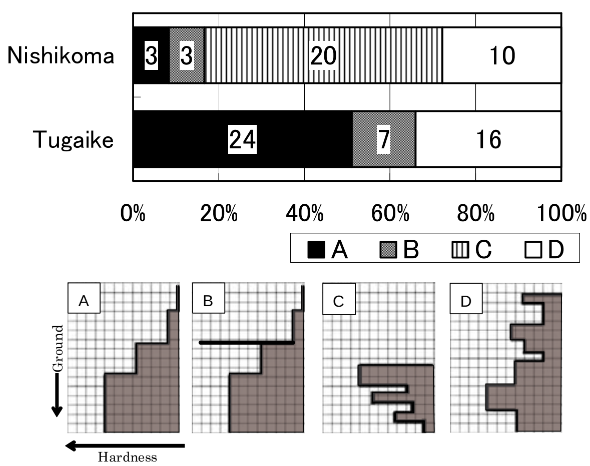

Fig.6. Percentage of observed hardness profiles (Nishikoma: 36 pits, Tsugaike: 47pits). A: The type of hardness profile as hardness increase progressively from surface to the bottom, B: Almost as same as A, but include one or multi hard layers of melt-freeze crust, C: The structural weakness caused by weak depth hoar and facets exists inside the snow-pack, D: other irregular profile.

3.2.3 WEAK LAYERS OBSERVED IN TSUGAIKE

Totally, 75 weak layers were observed at Tsugaike study plot. Observed numbers of every grain types of weak layers are shown in Fig.7. 50 weak layers related to new snow crystals were observed (Precipitation particles: 31、Decomposing: 19) and it accounts for 67 % of the whole observed weak layers. Facets which is formed near the snow surface: 7 and the weak interface: 7 were observed but surface hoar which is popular in Canada and Swiss (Schweizer, J. and J.B. Jamieson, 2001) was observed only one time in 5 winters. Observed numbers of weak layer related with observed depth and the class of strength, are shown in Fig.9. Weaker layers which are judged easy are only near the snow surface. The total number of weak layer is decreased and the proportion of number of the stronger layers which judged moderate or hard is increase with the snow depth. These results suggest that the persistence of weak layers are low in Tsugaike study plot. The characteristics of these weak layers agrees with the characteristics of weak layers in the Coastal climate known generally (i.e., McClung and Schaerer, 2006; Tremper, 2001）

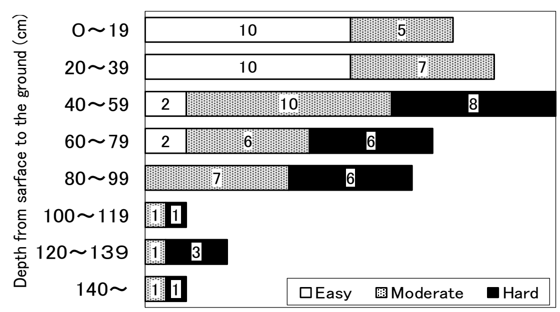

Fig.8 Observed numbers of each strength classes related with observed depth at Tsugaike.

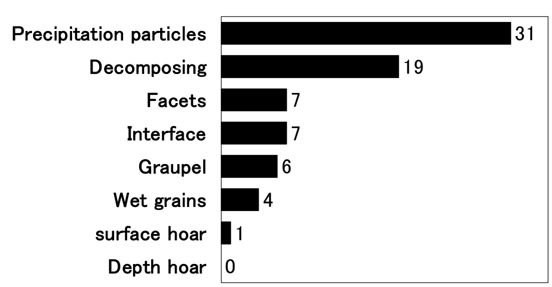

Fig.7 Observed number of each grain types of weak layers at Tsugaike.

4. CONCLUSION

The snow climate of the Japan Alps was examined using the meteorological and snow-pit data to contribute to avalanche safely. It was confirmed that the snow climate of the Tugaike study plot where belongs to Sea of Japan side region is the same as the coastal climate of North America almost. On the other hand, the snow climate of Nishikoma study plot where belongs to the Pacific Ocean side region is similar to the Continental climate of North America, but amount of rain fall and high predominance of wet-grain differs from Continental climate.

The Pacific Ocean side region in The Japan Alps has higher probability of exposure to the rainfall than The Continental climate in North America has. They are brought about by the low elevation range (even the peaks are around 3000 m a.s.l.) and the strong influence of the low pressures passing on the Pacific Ocean to the Pacific Ocean side region in the Japan Alps. For that reason, to examine the snow climate in The Japan Alps, it is necessary to be careful of the evaluation of the rainfall and needs the snow climatic division which is different from North America. In the future, we must make a climatic division which suited the climate of Japan with relating to avalanche activity data and the avalanche accidents cases.

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