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EVALUATION OF SNOW COVERED AREA BY USING NOAA-AVHRR DATA AND SNOWMELT RUNOFF ANALYSIS IN THE OKUTADAMI BASIN

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SYNOPSIS

Area of the remaining snow is evaluated by using NOAA-AVHRR data during the snowmelt season from 1988 to 1990 in a river basin of the Tohoku District, Japan. The hydrological data of the basin are also utilized. It is confirmed that a set of NOAA-AVHRR data is useful as a time series data of the remaining snow covered area. The relationship between water equivalent volume and area of remaining snow is discussed. The evaluated remaining snow covered area is used to calculate daily snowmelt in the basin and it is shown that the runoff in the snowmelt season is simulated well.

INTRODUCTION

The usage of satellite data in hydrology may be classified into some categories. Firstly, a group of earth observing satellite data with high resolution such as LANDSAT-MSS,-TM, MOS1-MESSR, and SPOT-HRV may be used to obtain detailed information about a basin. A landcover analysis of the catchment is a typical example of this category. In this category, satellite data is considered independent of time because we can expect to obtain only a few good

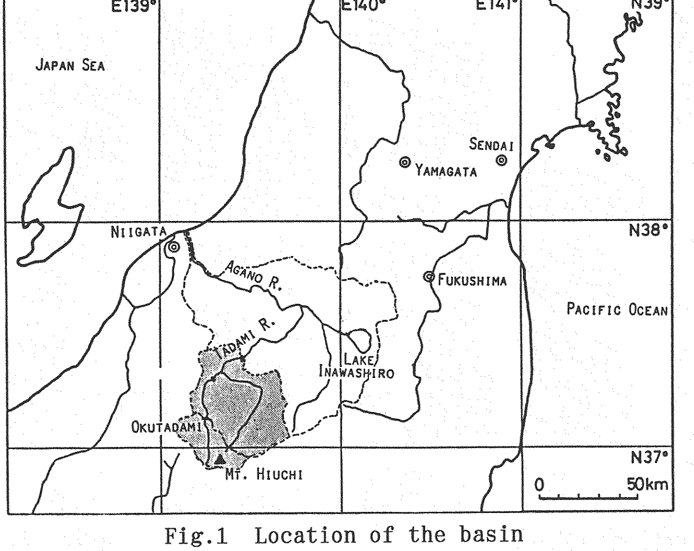

Fig.1 Location of the basin

clear images in a year. Another typical usage of satellite data is a meteorological one which has been necessary for prediction of rainfall distribution. The hourly or daily data of GMS and/or NOAA-AVHRR are useful for this purpose. In the third category, direct evaluation of hydrological characteristics from satellite data may be attempted. A time series data of evaporation, soil moisture and so on could make clear an important link of water circulation if the satellites supplied them.

This paper reports an attempt in the third category. The main purpose is to study the possibility of usage of satellite data as a time series in the research of hydrology. A set of NOAA-AVHRR(National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer) data was utilized to evaluate the remaining snow area in spring. Analysis was applied to the Okutadami basin, which is known as a very heavy snow region where melting snow is highly utilized for electric power generation.

First, the criteria of snow covered area discrimination will be discussed. The scheme is applied to a set of images in each spring of the years 1988 to 1990. The hydrological data on ground were also collected in the basin and melting snow volume was estimated. Comparing the change of the remaining snow area with the accumulation of snowmelt runoff volume, an empirical relationship between the area and the volume of remaining snow is derived. The obtained time series data of the snow area is also used to calculate a daily snowmelt volume and runoff in the snowmelt season is analysed by a tank model.

THE OKUTADAMI BASIN

The Tadami River is a tributary of the Agano River(Fig.1). The catchment of the Taki Dam, 1991.4km^2, was selected to analyse and evaluate the remaining snow

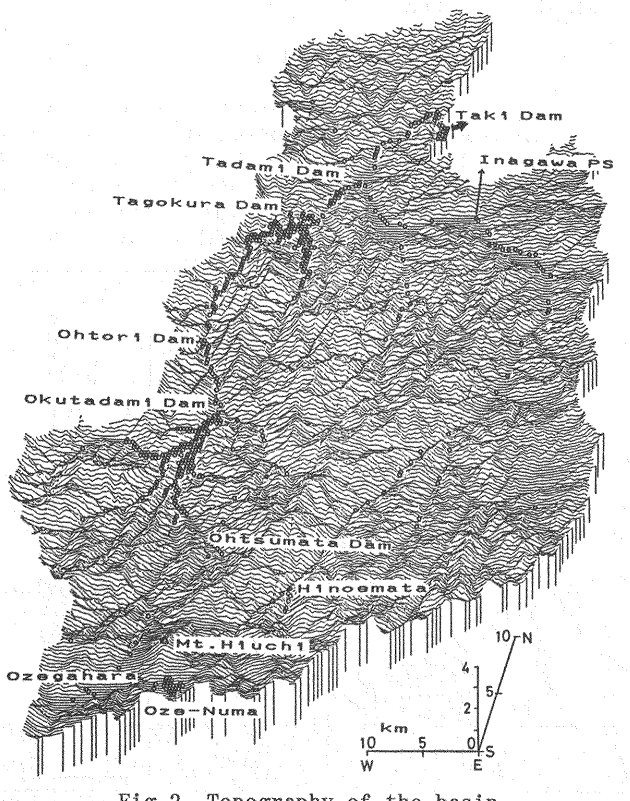

Fig.2 Topography of the basin

area. It is spread over Fukushima, Niigata and Gunma Prefectures and most of its area lies in Fukushima Prefecture. The catchment of the Okutadami Dam, which is the uppermost part of the Taki Dam catchment, was also selected especially for snowmelt runoff simulation.

The general topography is mountainous, as shown in Fig.2, comprising low mountains at the downstream end and high mountains at the upstream end, including some flat areas, such as Ozegahara in the most upstream part of the basin. The elevation of the basin varies from about 300m at the downstream end in the north to over 2,300m above sea level in the south. The basin area is primarily covered by broad-leaved trees(about 89.1%) and also has needle-leaved trees(9.5%) and other types of landcover(1.4%). Soil types of basin are rock at 11.3%, debris at 19.6%, brown forest soil at 46.6%, podzol at 19.2% and others at 3.3% of the total area.

Within the basin there are six dams used for electrical purposes:Taki, Tadami(completed in August, 1989), Tagokura, Ohtori, Okutadami and Ohtsumata Dam, from downstream end to upstream. There are also nine small intake dams, three of which divert water into Ohtsumata Dam through tunnels, five of which divert water into Okutadami Dam and one of which diverts water into the Ina River Power Station, located outside of the basin.

PROCESS OF NOAA-AVHRR DATA

We have been receiving AVHRR data of NOAA-10 and 11 and making an image-database O-TIDAS(Original Tohoku Image Database), in which original images were systematically transformed into Mercator system based on orbit information, at Tohoku University since April, 1988. At first, clear images of the catchment in snowmelt season were looked up from the image database. Ten, fourteen and twelve images were available in 1988, 89 and 90, respectively. Shifting images in some pixels in NS and WE direction, those images were rearranged into a precise system of location by using some GCPs(Ground Control Points) because systematic transformation still contains some errors. By this correction, accuracy of the location of images was confirmed within one pixel(1.1×1.1km). Location of boundary(latitude and longitude) of the catchment was digitalized from a map of 1/200,000 and utilized for the snow area evaluation in the catchment.

If there is no cloud in the basin, the snow areas can easily be discrimi-

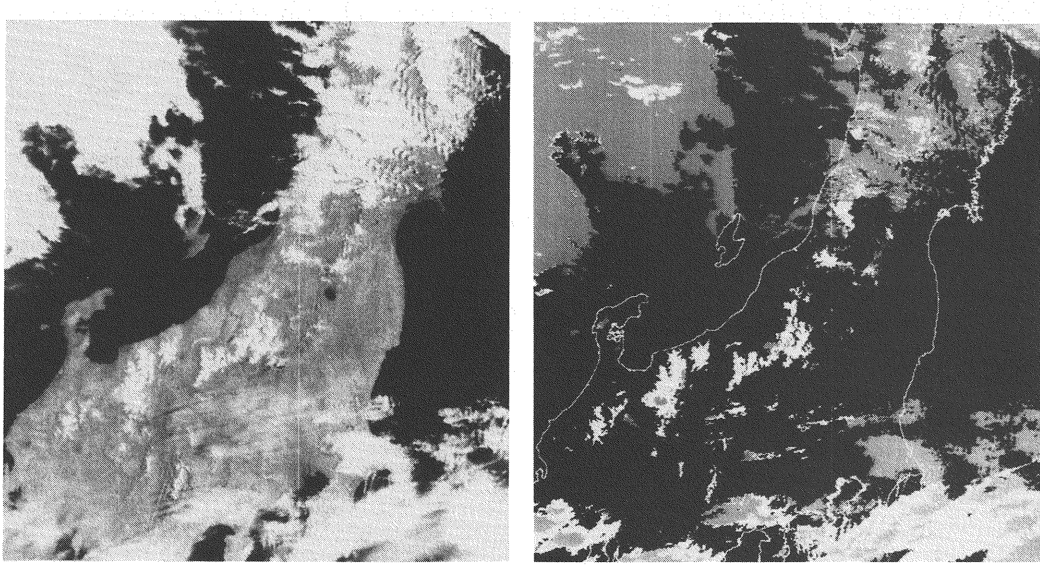

Fig.3 An example of the snow area discrimination April 26, 1989
(a) Channel-2 image, (b) Result(White:Snow, Gray:Cloud)

nated, at glance, both in NOAA-AVHRR Channel-1 (visible:0.58--0.68μm) image and Channel-2(infrared:0.73--1.1μm) image. However, if the image includes some part of cloud, it is difficult to discriminate the snow areas from the clouds by only a single channel image. In this study we adopted the following two steps of criteria of discrimination(Kawamura, Kazama, Edamatsu and Sawamoto(1)):

1) Value of albedo larger than a certain threshold in Channel-1 may be snow cover or clouds.
2) Part where temperature is less than -10°C(Channel-4:10.5--11.5μm) and where there are many water particles in the atmosphere(Channel-3:3.55--3.93μm) may be clouds, and others may be snow cover.

An example of the snow area discrimination is shown in Fig.3. In Fig.3(a), white parts are both snow and clouds. The gray part represents the cloud and the white part the snow in Fig.3(b). Although some parts of the discrimination are incorrect for the area over the sea and along the fringe of cloud where reflection from snow, cloud and shade of cloud is mixed, this method gives rather good results, as shown in the figure. Only images considered to be good after discrimination were used for the analysis.

AVAILABLE HYDROLOGICAL DATA ON THE GROUND

Inflow and outflow data are only available for the biggest five dams (six after Aug. 1989). There is no record at any small intake dams except that of Inagawa Power Station. By calculating the water balance of each dam, the total daily runoff of snowmelt from the basin into the five dam lakes is estimated as follows;

[Runoff from the basin of the Taki dam]
= Σ[Inflow into all five(six after Aug.1989) dam lakes]
-Σ[Outflow from upper four(five after Aug.1989) dams]
+ [Intake flow by Inagawa Power Station]

There are four meteorological stations in the basin, Hinoemata, Taki Dam, Tagokura Dam and Okutadami Dam. The data of daily precipitation and temperature are available. The precipitation at each station is assumed to represent the precipitation of the catchment of each dam. Because the set of records shows the temperature decreases with elevation(Fig.12), the temperature distribution in the basin is assumed to be linearly varied in the calculation of snowmelt intensity.

RESULTS AND CONSIDERATIONS

Snowmelt Runoff

Two examples of runoff from the basin are shown in Fig.4. We can easily understand the snowmelt runoff is prominent in spring. Figure 5 shows a cumulative relationship between precipitation and runoff. The abscissa represents a total precipitation volume in the basin where the precipitation in each catchment of dam is assumed to be equal to that at the dam site and the ordinate represents the cumulative runoff volume. The tangent of the curve corresponds to a runoff ratio of the basin.

Those figures show the runoff in snowmelt season is quite different from that in other seasons. Though half or 0.6 of the precipitation is lost in summer and autumn, we expect more than 1.2 times runoff of the precipitation in spring. Therefore, we conveniently define new parameters "a" and "b" shown in the figure. The former is a measure relating to the cumulative snowmelt runoff volume and the latter relating to equivalent water volume of the remaining snow in the basin.

The value of parameter "b" is not a precise equivalent water volume of the remaining snow because the mechanism of loss in snow and snowmelt seasons is different from the other seasons. An example is shown as follows. Distribution of snow depth is measured every early spring by the Electric Power Development

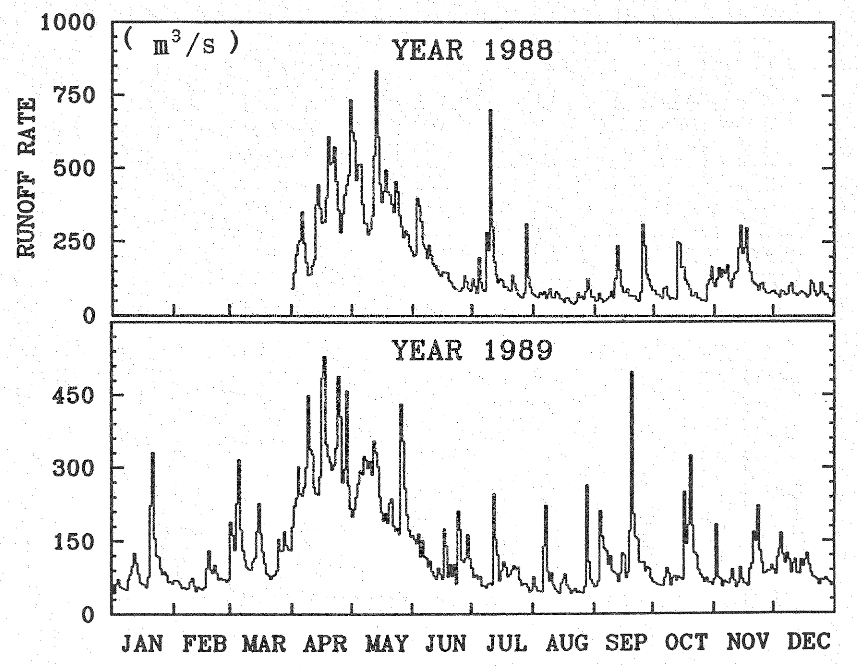

Fig.4 Runoff from the Taki Dam catchment, 1988 and 1989

Company in this basin. Figure 6 shows an example of the relation between snow depth and elevation. Using the relation in Fig.6 and the hypsometric curve of the basin(Fig.7), we can evaluate total snow volume in the basin. Comparison of the results with the value of "b" mentioned above before snowmelt starts is shown in Table 1. The ratio of those value means a specific gravity of snow, values of which are 0.26, 0.24 and 0.28, respectively. Though actual values were not reported, those values seems rather small just before snowmelt season. In other words, "b" is a parameter showing a relation between the precipitation observed at the dams and snowmelt runoff from the basin and its value is smaller than the actual water equivalent volume of the remaining snow. The further detailed consideration is given in Kazama, Sawamoto and Jirayoot(2). However, the parameter "b" is still a useful measure for estimation of the runoff expected in snowmelt season.

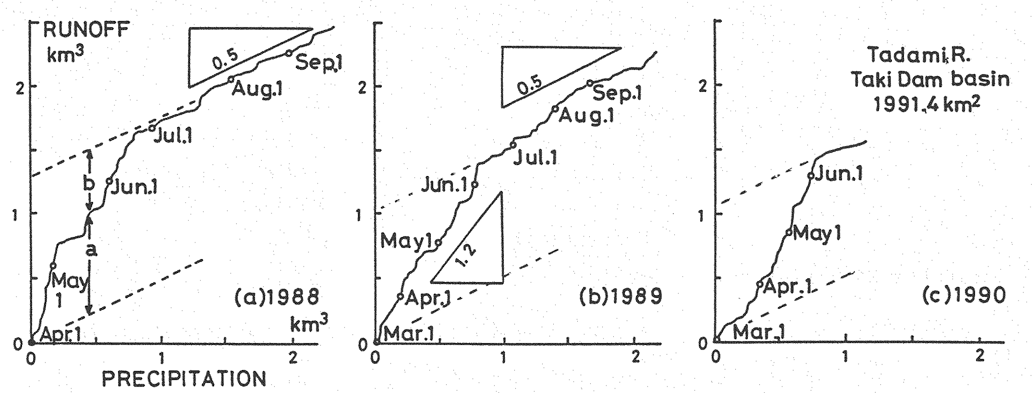

Fig.5 Relationship between Precipitation and Runoff
(a) 1988, (b) 1989 and (C) 1990

Table 1 Comparison of Snow Volume and "b"(km^3)

Snow Volume Vs (Snow Survey)	"b" in Fig.5	b/Vs
5.07(1988.3.17)	1.32(1988.4.1)	0.26
4.53(1989.3. 9)	1.10(1989.3.1)	0.24
3.67(1990.3. 7)	1.05(1990.3.1)	0.28

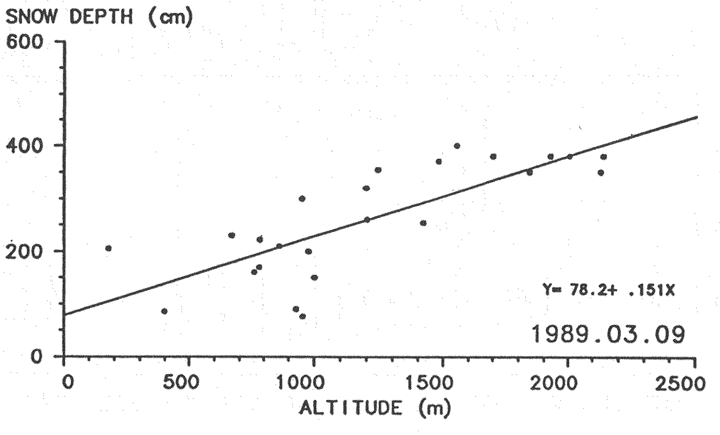

Fig.6 An Example of Snow Depth Distribution in the Basin

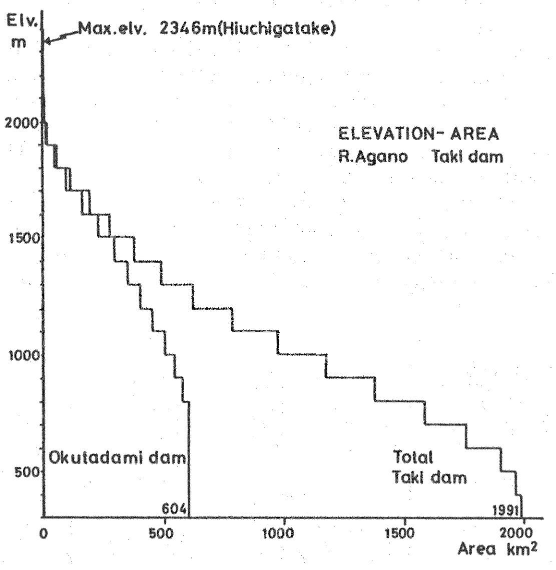

Fig.7 Hypsometric Curve of the Basin

Remaining Snow Area and Snowmelt Volume

Figures 8(a) to (h) show the discriminated snow covered region in the basin. By counting the number of mesh in the figures, we can obtain the decrease of snow area as a set of time series data.

Figures 9(a) to (c) show changes of snow area obtained from NOAA data in the basin from 1988 to 1990. Because snow usually falls until mid-April in this basin, snow area does not always decrease monotonously. From these figures we also understand that there was less snowfall in 1989 and 1990 than in 1988.

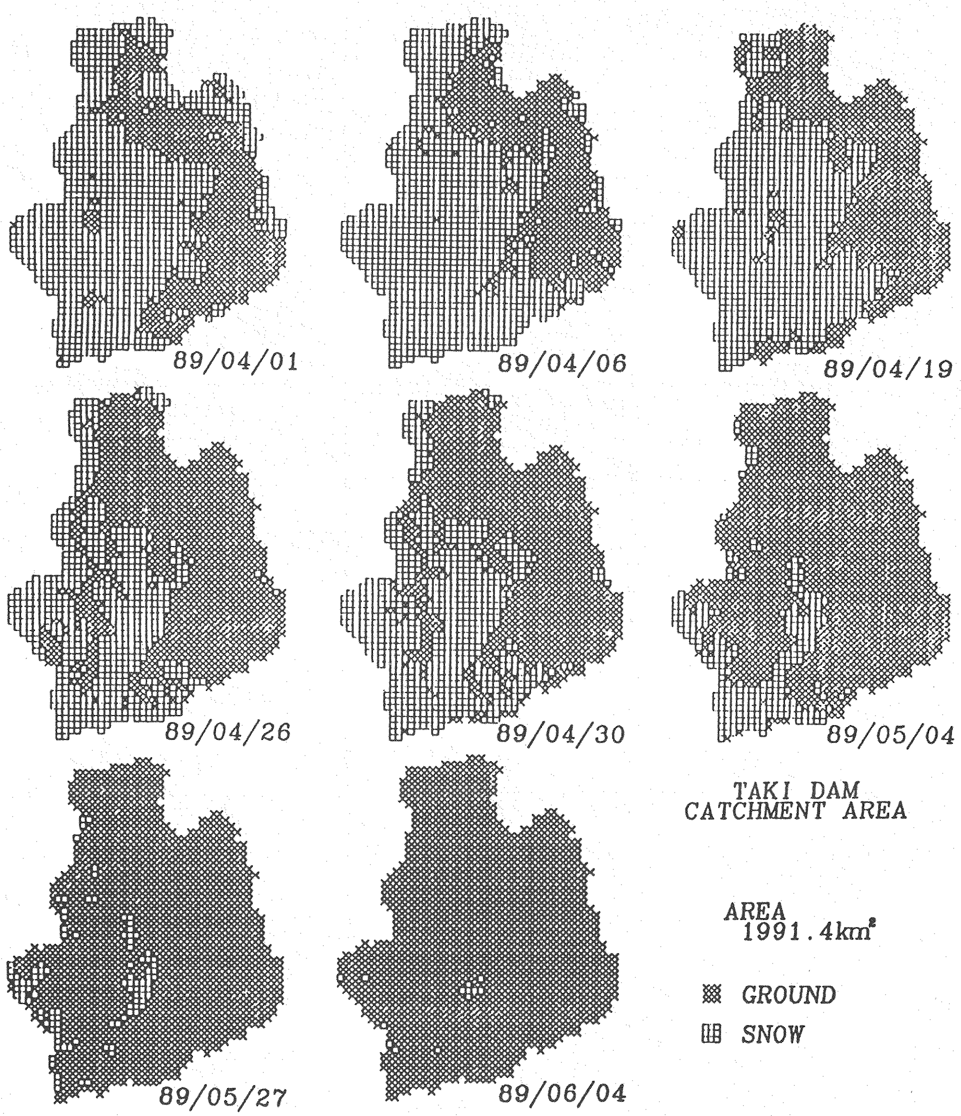

Fig.8 An example of variation of snow area(1989)

Relationship between Water Equivalent Volume and Area of Remaining Snow

The relationship between the parameter "b" in Fig.5 and area of remaining snow is shown in log-log scale in Fig.10. Koike(3) reported that if the distribution of area is uniform with regard to the elevation in the basin, water equivalent volume of snow is proportional to the square of the snow area. Although the hypsometric curve is somewhat different from Koike's case, the parameter "b", which relates to the water equivalent volume of snow, seems to be proportional to the square of snow area in the early stage of snowmelt. In the last stage, however, the parameter "b" shows different tendency. For example, the curve shows clearly steeper inclination in 1989. In other words, the average water equivalent depth of snow increases as snow area decreases. This will be resonable because the snow in the Ina River basin, whose mean elevation is relatively low, melts in earlier stage than the snow in the Okutadami catchment and only heavy snow remains in the Tadami River basin.

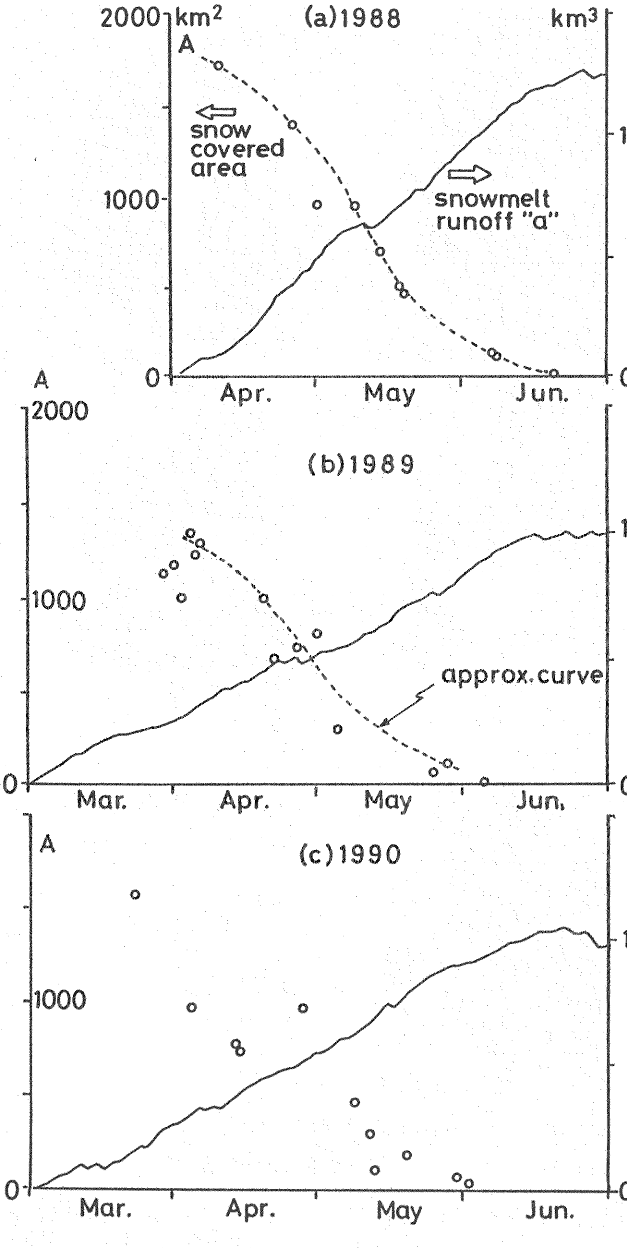

Fig.9 Variation of snow area and snowmelt runoff "a"

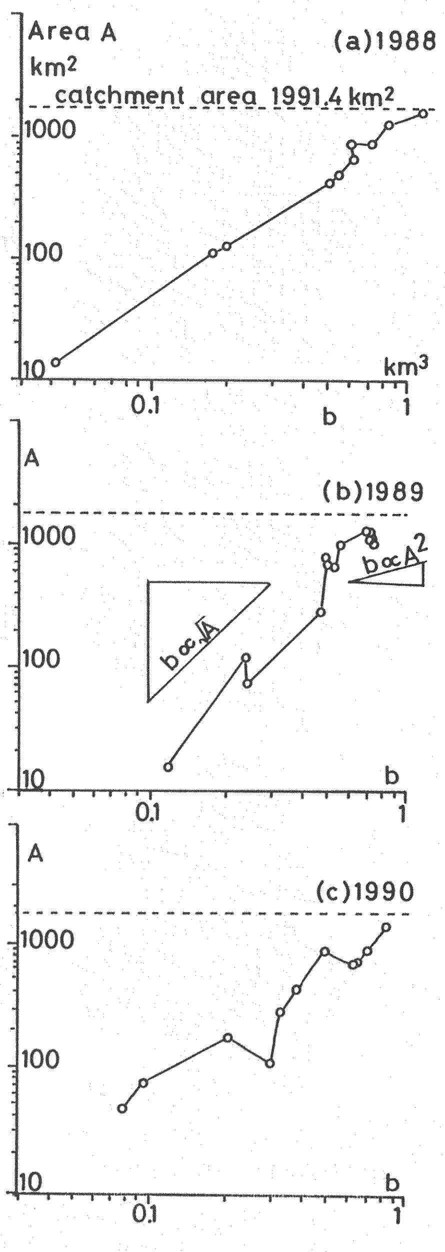

Fig.10 Relation between the parameter "b" and snow area, A

Calculation of Daily Snowmelt Runoff

Although we had a relationship between the snow covered area and the parameter "b" relating to the water equivalent volume of the remaining snow as mentioned above, it is not recommended to evaluate a daily variation of snowmelt runoff directly from a decrease of snow covered area observed by the satellite because of following reasons. Firstly, the estimation of precise daily decrease of snow covered area is difficult because the satellite image can not be obtained every day. Secondly, the direct estimation from decrease of the snow covered area will not be applicable to a prediction of snowmelt runoff because it is obtained after the snowmelt. Thirdly, physical process based on meteorological information such as air temperature should be also taken into account.

Here we attempt an alternative method to evaluate a daily snowmelt runoff. For precise modelling, we need the data of solar radiation, albedo of snow surface, wind speed, air temperature, structure of snow layer and so on. However, we adopt the simple degree·day method as shown below, because only air temperarture, rainfall and the snowcovered area mentioned above are available in the basin. Sugawara's tank model with snow component(Fig.11,Sugawara et al.(4)) is used to analyze the daily snowmelt runoff. The top tank represents a snowmelt model where the snowmelt intensity is evaluated as

$$QSM = SCR \cdot T_{he} \cdot (CSM + (1/80) \cdot P) \quad \text{when } T_{he} \geqq 0$$

$$= 0 \quad \text{when } T_{he} < 0$$

where QSM : daily snowmelt intensity (mm/day),
T_{he} : mean temperature over the snow covered area (degree in centigrade),
SCR : snow covered ratio obtained from NOAA data,
CSM : snowmelt factor (mm/degree/day),
P : rainfall which is assumed uniform in the basin (mm/day).

The last term in the right-hand side represents a latent heat flux due to rain where the unit of constant 80 is in degree. Evaporation is assumed 2mm/day for simplicity in the model.

The variation of the snow covered area is approximated by smoothed curve as shown in Fig.9, because the number of NOAA images is limited.

The procedure is as follows:

1) to estimate a mean elevation of snow line by Fig.7 and the value of snow area obtained from NOAA data,
2) to calculate a mean elevation of the snow area,
3) to evaluate air temperature T_{he} at the elevation calculated above by using temperature lapse rate obtained from Fig.12,

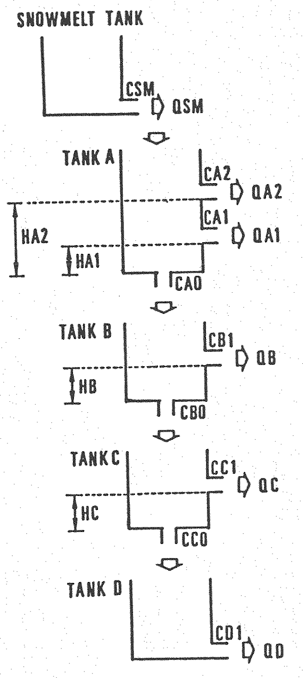

TABLE OF OPTIMIZED TANK MODEL PARAMETERS

TANK NAME	PARAMETER NAME & VALUE					INITIAL DEPTH
SNOWMELT TANK	CSM	-	-	-	-	-
	5.227					
TANK A	CA0	CA1	CA2	HA1	HA2	0.0
	0.574	0.036	0.242	0.00	14.182	
TANK B	CB0	CB1	HB	-	-	47.34
	0.226	0.071	13.80			
TANK C	CC0	CC1	HC	-	-	101.77
	0.0348	0.0343	80.141			
TANK D	CD1	-	-	-	-	277.26
	0.0023					

UNIT

SNOWMELT FACTER, CSM = mm / d/ °C

SIDE-OUTLET HEIGHT = mm

INITIAL DEPTH = mm

Fig.11 Tank Model with snow component(Sugawara et al.(4))

4) to evaluate a snowmelt intensity by the equation above,
5) to input the snowmelt intensity and the rainfall into the tank model in Fig.11.

A set of parameters in the model was evaluated by the optimizing method (Powell(5), Zangwall(6), and Kobayashi and Maruyama(7)) and shown in Fig.11, together. The result of optimization is shown in Fig.13 for the data of April to September of the year 1988. Although agreements are good both for whole period hydrograph and for monthly discharge, we notice that the model tends to give more smooth variation than the observation in snowmelt season. This implies that the process of snowmelt and runoff is more complicated than the model.

Other sets of parameters were estimated from only the data in summer season or only the data in snowmelt season. The results were not very different from those mentioned above.

Figure 14 shows the result of runoff estimation in 1989 in which the parameters of the model obtained above were used. The model can calculate at some degree of accuracy.

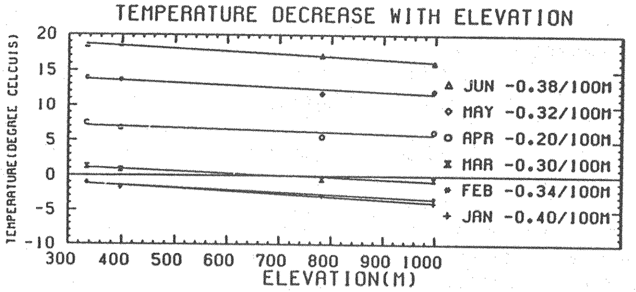

Fig.12 Temperature Lapse Curve in the Basin

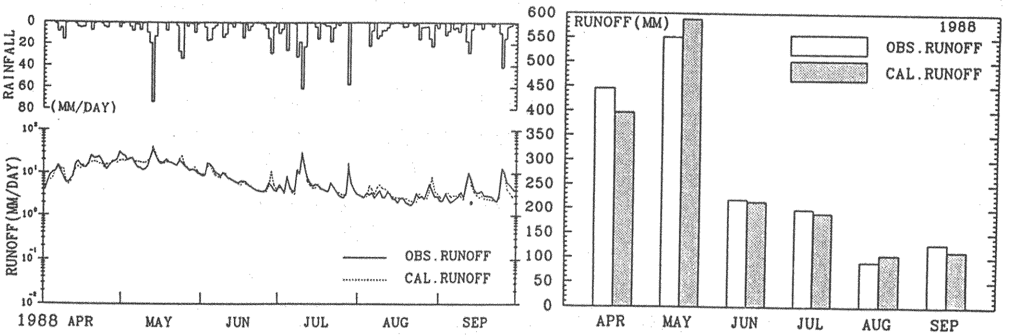

Fig.13 Model Calibration : 1988 (a) Hydrograph, (b) Monthly Discharge

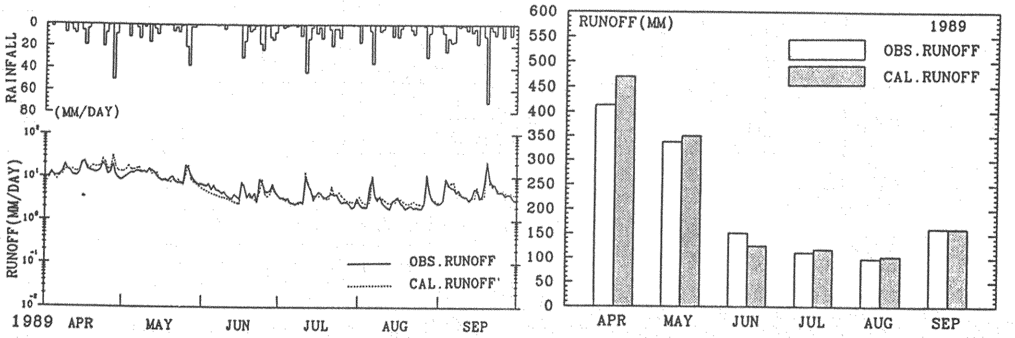

Fig. 14 Model Calculation : 1989 (a) Hydrograph, (b) Monthly Discharge

CONCLUSIONS

The use of the satellite data is attempted for the snowmelt runoff analysis and the followings are concluded.

1) The data of NOAA-AVHRR can be used as a time series data of snow covered area.
2) The combination of some channels of NOAA-AVHRR makes possible to detect the snow covered area.
3) A relationship between the snow covered area and the water equivalent volume of the remaining snow in the basin of Okutadami is derived.
4) The obtained snow area data from the NOAA data can be used for the daily snowmelt runoff analysis.

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