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The influence of snow depth on the variation of vegetation activity and evapotranspiration

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Abstract The influence of snow conditions on the seasonal variation of vegetation and evapotranspiration were investigated in a low snow year (1998), a normal snow year (1999) and a heavy snow year (2000). First, a NDVI (Normalized Difference Vegetation Index), evapotranspiration and a snow cover map were composed with NOAA/AVHRR data. The Warm Index (WI) was compiled with meteorological data. Secondly, seasonal variation of NDVI and evapotranspiration were evaluated considering WI and the snow area map. Finally, the spatial distribution of vegetation growth ratio to temperature increase was calculated with the proposed new index. The results indicate that vegetation activity and evapotranspiration in the snowmelt season are related to the area of the remaining snow-covered area because snow cover restrains plants from vegetating. Next, the vegetation growth ratio to temperature increase is greater in the low elevation area, less in the middle elevation area and greater in the high elevation area. This shows the relationship between snow condition and vegetation types.

Key words NDVI; NOAA/AVHRR; snow condition; snow cover; Warm Index

INTRODUCTION

Most of Northern Japan is covered with snow during the winter, and the snow depth is over 5 m in some places. Snow has an important role in vegetation growth because snow protects vegetation from strong winds and cold and provides enough water for vegetation during the winter. Recently, precipitation and temperature have varied due to global warming effects. If global warming continues, snowfall will become rainfall, snow accumulation will decrease, and snowmelt rates will become faster. Vegetation activity has an influence on hydrological process and potential water resources such as evapotranspiration. Hence, The for water resources and hydrological processes, it is important to understand the relationships between snow condition, seasonal variation of vegetation activity, and evapotranspiration. In this paper, the influence of snow condition on the seasonal variation of vegetation activity and evapotranspiration was investigated in different years: a low snow year (1998), a normal snow year (1999) and a heavy snow year (2000).

STUDY AREA AND DATASETS

Study area

The Taki Dam basin on the Agano River, Japan, 1991.4 km^2, was selected as the study area (Fig. 1). It is located on the Oh Range, is famous as a heavy snow area in Japan, and is usually covered with snow until early summer. This basin consists of six dams, the Taki, Tadami, Tagokura, Ohtori, Okutadami, and Outsumata dams, from downstream to upstream. The elevation of the basin varies from about 300 m at the lowest point in the north to over 2300 m in the south, as shown in Fig. 2. This area is primarily covered by broad-leaved trees (about 89.1%) and also needle-leaved trees (9.5%) and other land use (1.4%).

Study period

The study period is three years from 1998 to 2000. In order to investigate the influence of snow condition, it was necessary to classify "heavy snow year", "normal snow year"

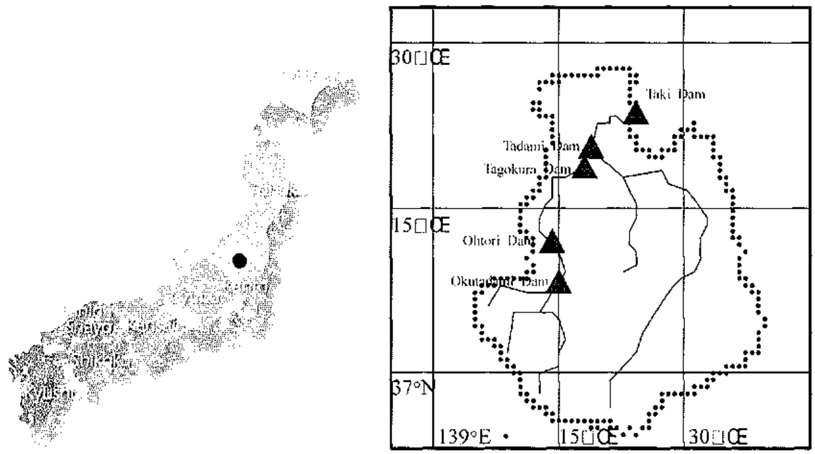

Fig. 1 Map of the Taki Dam basin.

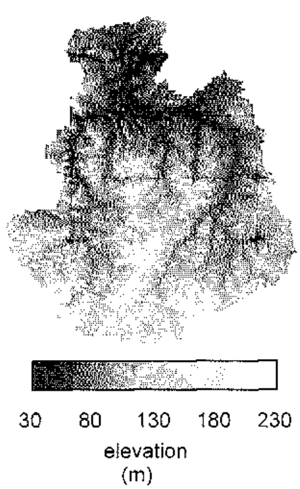

Fig. 2 Elevation in the Taki Dam basin.

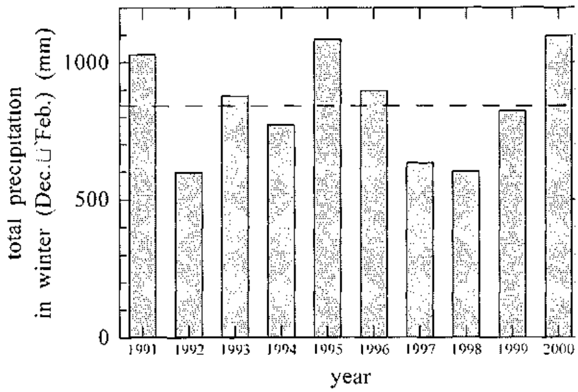

Fig. 3 Precipitation in winter (from December to February) during the past 10 years.

and "low snow year". We assumed that 1998, 1999 and 2000 represent low, normal, and heavy snow years, respectively. Figure 3 shows the total precipitation in winter (from December to February) from 1991 to 2000 at Tadami meteorological observation point (34°20.4'N, 139°19.0'E, elevation 377 m), which is near Taki Dam. Mean precipitation in winter over the 10 years was 841 mm and the ratio to average precipitation is 71.5% in 1998, 97% in 1999 and 130% in 2000, respectively.

Data set

NOAA/AVHRR data was used to monitor spatial vegetation activity. The ground resolution of a pixel is about 1.1 km^2 and the recurrent time is about half a day. CNEAS (Centre for Northeast Asian Studies), Tohoku University, Japan, receives AVHRR data from NOAA satellite every day. This data is pre-processed, e.g. geometric correction, and released on the internet (http://aiadb.cneas.tohoku.ac.jp/jaidas/) as the database JIDAS (JApan Image DAtabaSe). Meteorological data is obtained from J-Power Co. Ltd and AMeDAS (Automated Meteorological Data Acquisition System), which is conducted by the Japan Meteorological Agency. In order to interpolate observed data, the temperature lapse rate is 0.6°C/100 m. The DEM (Digital Elevation Model) is obtained from the Ministry of Land, Infrastructure and Transport.

SEASONAL VARIATION OF VEGETATION ACTIVITY AND EVAPOTRANSPIRATION

In order to investigate the influence of snow condition on the seasonal variation of vegetation activity and evapotranspiration, spatial and temporal vegetation activity were monitored first. Secondly, potential vegetation activity was evaluated with the climatic condition because the factor with the most impact on vegetation growth is climatic condition. Therefore, in this study, Normalized Differential Vegetation Index (*NVDI*) and Warm Index (*WI*) were utilized for the above analysis. In addition, evapotranspiration and snow covered area are estimated.

Normalized Difference Vegetation Index (*NDVI*)

NDVI indicates vegetation activity. It is derived from NOAA/AVHRR satellite data as:

$$NDVI = (channel2 - channel1)/(channel2 + channel1) \times 100 \quad (1)$$

where *channel*1 is radiance value of visible band (0.58–0.68 μm) and *channel*2 is radiance value of near-infrared band (0.75–1.10 μm). It is possible to obtain NOAA/AVHRR data every day. However, if the image includes cloud area, the *NDVI* value is underestimated on these pixels. Therefore it is necessary to make a cloud-free image from some images in a period. Monthly maximum images from April to October and yearly maximum images were composed.

Warm Index (*WI*)

There is a close relationship between the type of vegetation distribution and temperature distribution. Kira (1949) suggested that the temperature condition plants can live at is more than 5°C, and proposed the Warm Index as a cumulative temperature index:

$$WI = \sum^{n} (T_m - 5) \quad (2)$$

where T_m is mean monthly temperature and n is the month in which T_m is more than 5°C. Summer is the most vegetated season and vegetation growth depends on the conditions from the previous autumn. Therefore, equation (2) cumulates mean monthly temperature of more than 5°C from October in the previous year to September.

Evapotranspiration and snow covered area

Tada *et al.* (1994) proposed an estimation method for evapotranspiration using the relationship between *NDVI* and evapotranspiration. Kazama *et al.* (1992) also proposed an estimation method for snow area using multi-spectral analysis of NOAA/AVHRR data. Monthly evapotranspiration and snow covered area were estimated with these methods. Vegetation growth and its activity depend on climatic conditions such as cumulative temperature and precipitation from the previous autumn. In Japan, the most important factor for potential vegetation is only cumulative temperature because Japan has a humid climate and total precipitation is very high. To investigate the influence of temperature condition on basin vegetation, Fig. 4 shows the relationship between mean *WI* and mean maximum *NDVI* in the basin. There is a positive correlation and the correlation coefficient $R^2 = 0.85$. It is confirmed that plants vegetate under warm conditions more than under cold conditions and that the most important factor is climatic condition. Seasonal variation of mean *NDVI* in the basin is shown in Fig. 5. Seasonal variation of *NDVI* in a low snow year is higher than a heavy snow year because a low snow year is warm and a heavy snow year is cold. In Fig. 5,

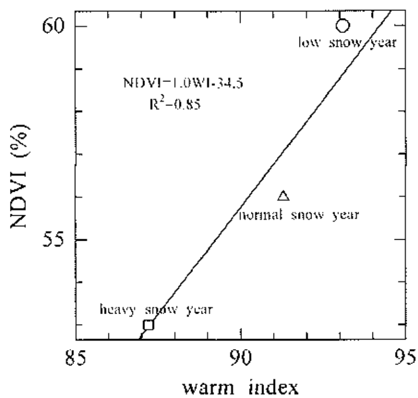

Fig. 4 The relationship between mean *WI* and maximum mean *NDVI* in the basin.

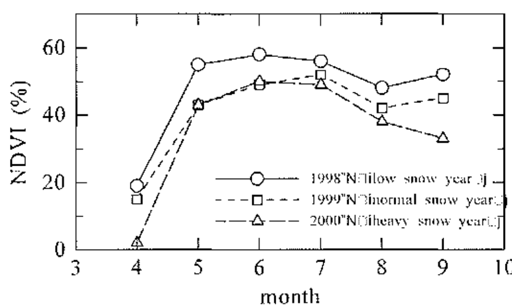

Fig. 5 Seasonal variation of *NDVI*.

mean *NDVI* increases steeply from April to August and decreases from September. It is possible that mean *NDVI* in April is related to remaining snow covered area in April. Figure 6 shows the snow covered area at the end of April and the *NDVI* distribution in April 2000. Table 1 shows the number of snow covered area pixels and no-snow covered area pixels. There is negative correlation between remaining snow covered area and basin *NDVI*. In Fig. 6, *NDVI* on the pixel of snow covered area is nearly equal to 0. On the other hand, *NDVI* on the pixel of no-snow covered area becomes high as it is far from the snow covered area. Figure 7 shows the histogram of *NDVI* in April 2000, which is divided into snow covered area and no-snow covered area. According to Fig. 7, it is confirmed that *NDVI* is higher in no-snow covered areas than in snow covered areas. This is because plants begin to grow after snow disappearance and snow cover restrains plants from growing. Mean evapotranspiration (mm month^{-1}) in April is 35 mm month^{-1} in 1998 (low snow year), 31 mm month^{-1} in 1999 (normal snow year) and 15 mm month^{-1} (heavy snow year). The difference in evapotranspiration between the low and heavy snow years is 21 mm month^{-1}. From the view point of water resources, a decrease of snow accumulation by a warming effect not only decreases storage by snow accumulation but also promotes vegetation activity and water resource losses as evapotranspiration. It is a serious problem for water resources planning.

Table 1 The number of snow covered area pixels and no-snow covered area pixels at the end of April.

Year	Snow (pixel)	Land (pixel)
1998	985	612
1999	1005	592
2000	1015	582

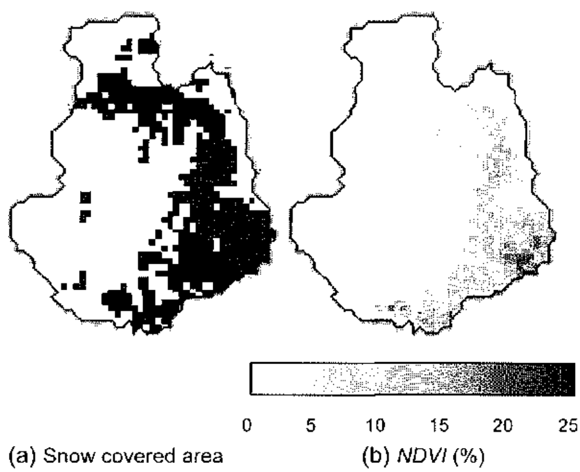

Fig. 6 (a) Snow covered area at the end of April; white pixel: snow covered area; black pixel: no snow covered area. (b) *NDVI* distribution in April, 2000.

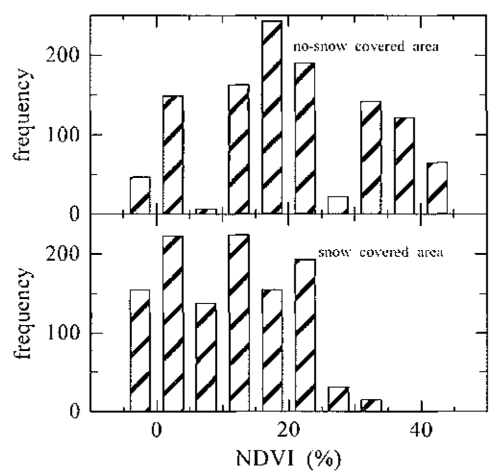

Fig. 7 The *NDVI* histogram in April 2000.

VEGETATION GROWTH AND SNOW CONDITION

In the previous section, the relationship between mean *NDVI* of the basin and mean *WI* of the basin was shown. However, there are many kinds of plants in the basin and vegetation growth and activity vary with climatic and geographic condition. In this chapter, the difference of regional vegetation growth (maximum yearly *NDVI*) between a heavy snow year (1998) and a low snow year (2000) were evaluated by *NDVI* and *WI*. We assumed that *NDVI* and *WI* can express actual and potential vegetation growth, respectively. It was considered that correlation difference between *NDVI* and *WI* is influenced by snow. A new index, *WGR* (warm growth ratio), indicates the relationship between the vegetation growth ratio and increasing temperature:

$$WGR = (myNDVI_l - myNDVI_l) \;/\; WI_l - NDVI_h) \times 100 \quad (3)$$

where subscript *h* and *l* mean a heavy snow year and a low snow year. *myNDVI* means maximum yearly *NDVI*. For example, if *WGR* in a pixel is positive, plants grow in the pixel as temperature increases. On the other hand, if *WGR* in a pixel is a negative value, plants do not grow as temperature increases.

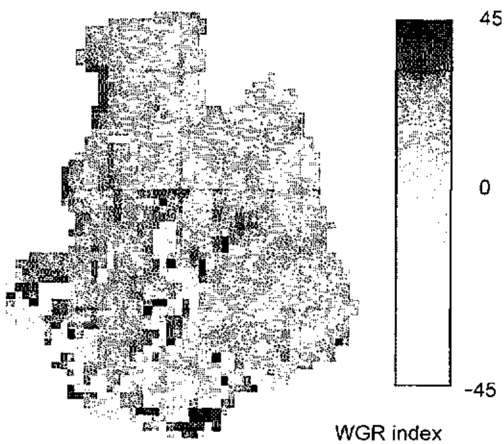

Fig. 8 Vegetation growth ratio to temperature.

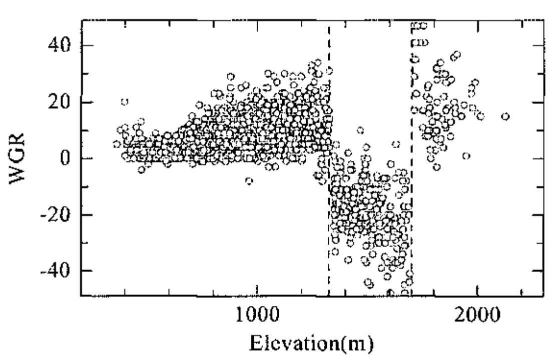

Fig. 9 The relationship between elevation and *WGR*.

WGR distribution in the Taki Dam Basin is shown in Fig. 8. There are two zones where *WGR* is positive and negative. Figure 9 shows the relationship between *WGR* and elevation. *WGR* is divided into three zones: (a) 300–1300 m; (b) 1300–1700 m; and (c) 1700 m, according to Fig. 9.

(a) 300–1300 m area. In this area, the *WGR* index ranges from 0 to 40 and this result indicates that plants have a tendency to vegetate as elevation becomes higher with increasing temperature. This area primarily consists of broad-leaved deciduous forest zone. It seems that vegetation growth in this forest zone is not so dependent on water supply from snow accumulation and snowmelt because there is a stable supply from underground water.

(b) 1300–1700 m area. In this area, the *WGR* index ranges from –40 to 0 and this result indicates that plants do not vegetate as elevation becomes higher with increasing temperature. This area is the southern part of the basin and hillside, and consists of deciduous forest. Generally speaking, plants will vegetate as temperature increases. However, in this area plants do not vegetate so much. This is very interesting. It seems that vegetation growth on the hillside is dependent on the snow condition. This is because snow condition restrains plants from vegetating. If snow accumulation decreases, the groundwater from snowmelt decreases and plants cannot vegetate.

(c) Over 1700 m area. In this area, the *WGR* index ranges from 0 to 40 and this result indicates that plants have a tendency to vegetate as elevation becomes higher with increasing temperature. This area consists of alpine plants. It seems that vegetation growth is not so dependent on snow condition and is only dependent on increasing temperature. This is because, even in the case of a low snow year, there is enough snow accumulation in high elevation area for alpine plants to vegetate.

SUMMARY

The influence of snow condition on vegetation activity was investigated. Remaining snow restrains the plants from vegetating. However, vegetation activity in a low snow year is more than in a heavy snow year.

The vegetation growth ratio is greater in the low elevation area, less in the middle elevation area, and greater in high elevation area, as temperature increases. This is related to snow condition and the type of vegetation.

Although this study was carried out by a simple analysis with *NDVI* and *WI*, the results are useful for water resources planning and ecology in a cold region.

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