Evaluating the Effect of Dryness on Wildfire in Tohoku Region Using Several Dryness Indices

Tohoku University	Graduate Student	○ Chenling Sun
Tohoku University	Member	Yoshiya Touge
Tohoku University	Member	So Kazama

1. INTRODUCTION

There is a significant link between dryness and wildfire because dryness on a time scale of climate and weather can significantly affect the moisture content of available fuel. Many dryness indices have been developed to effectively evaluate dryness and thus be used to assess wildfire risk. The Keetch/Byram dryness index (KBDI) is typical index for assessing dryness and widely used in wildfire monitoring that has been applied in a variety of areas, including the United States, south eastern Australia and Malaysia. Palmer (1965) developed the Palmer Dryness Severity Index (PDSI) using temperature data and physical water balance models that take into account precipitation, soil moisture, runoff, and potential evapotranspiration. Neither of KBDI and PDSI can consider the impact of snowmelt on dryness, so there is a limit to the evaluation effect of dryness in areas with long snowfalls. Taking into account the heavy snow in the Tohoku region of Japan, we also utilized soil moisture from land surface model for analysis. Effective humidity is widely used in fire warning in Japan, it is said that the number of wildfires will increase when this effective humidity is 60 to 50% or less.

The purpose of this study is to use KBDI, PDSI, soil moisture form SiBUC model, effective humidity to evaluate dryness in Tohoku of Japan, and compare the results with wildfire statistics, so as to evaluate the impact of dryness on wildfire in Tohoku region of Japan.

2. STUDY AREA

Study area of this study is Tohoku region of Japan. In Japan, Tohoku region is prone to wildfire. Kamaishi and Kurihara wildfires occurred successively on May 8, 2017. For Kamaishi wildfire, it was a big-scale fire and its burned area was 413ha, which was greater than the total of burned area for the whole of Japan in 2016.

3. METHODOLOGY

Daily precipitation data covering a period of 1995–2012 were obtained from the Asian Precipitation Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) of Water Resources project and were analyzed in this study. We also used wind speed, air temperature and radiation data obtained from dynamical regional downscaling of the JRA-55 reanalysis data set (DSJRA-55).

3.1 Keetch/Byram dryness index

KBDI is a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff and upper soil layers. This index requires only few meteorological data, maximum daily temperature, total daily precipitation and the mean annual precipitation. The KBDI is calculated from the following equation in metric system:

$$KBDI^t = KBDI^{t-1} + DF^t - RF^t \tag{1}$$

Where DF^t is dry factor in one day, DF^t is rainfall factor.

$$RF^t = \frac{(203-KBDI^{t-1})(0.968e^{(0.875\times T_m+1.552)}-8.3)\times 10^{-3}}{1+10.88e^{(-0.001736\times R_0)}} \tag{2}$$

RF^t is depended on daily precipitation. T_m represents daily maximum temperature, R_0 is the mean annual rainfall. When the daily precipitation is more than 5mm (0.2in), the daily precipitation will decrease KBDI. The value of KBDI ranges from 0 to 203mm, the larger the KBD value indicates the drier condition.

3.2 Palmer Dryness Severity Index

The calculation of PDSI requires precipitation and potential evapotranspiration, as well as the available water capacity (AWC) of the soil. Firstly, the difference between the actual precipitation (P) and climatically appropriate for existing conditions precipitation ($\hat{P}$) can be calculated based on the water balance. It is an indicator of water deficiency or surplus.

$$d = P - \hat{P} \tag{3}$$

The same water deficiency (d) value may reflect different humidity conditions given specific region and specific month. To correct for this aspect, the climatic characteristic K is used to weight the water deficiency.

Then, d and climatic characteristic K were used for climate correction to obtain water deficit index Z, which indicates the deviation of actual wetness/dryness conditions from the long term annual average water availability in a given region during a given month. Considering the influence of early water shortage on dryness conditions, the dryness duration and Z value of each dryness event were calculated to analyze the influence of early water shortage on dryness intensity (Equation 4). The PDSI is a standardized measure, ranging from about −10 (dry) to +10 (wet).

$$PDSI_i = 0.897PDSI_{i-1} + \frac{1}{3}Z_i \tag{4}$$

3.3 Land Surface Model

The Simple Biosphere including Urban Canopy (SiBUC) model was proposed by Tanaka. SiBUC is different from other land surface models in that it can represent not only the biosphere but also the city and water, so it has higher precision. There are three sub-models in SiBUC model: green area, urban area, water body. Generally, SiBUC has prognostic physical-state variables for each sub-model that are five surface temperatures, three deep layer temperatures, five interception water stores and three soil moisture stores.

3.4 Effective humidity

Effective humidity is the humidity that takes into account the history of humidity over the past few days. It indicates dryness of the wood and is related to fire. It can be calculated by the following equation:

$$H_e = (1-r)\,(H_0+rH_1+r^2H_2) \tag{5}$$

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Tohoku University, 6-6-06 Aramakiaza Aoba, Aoba, Sendai, Miyagi

The r is usually taken as 0.7 and H_0, H_1, H_2 is the average relative humidity in three days. The specific standard value varies depending on the region, but the effective humidity is about 60% (the minimum humidity varies greatly).

4. RESULTS AND DISCUSSION

4.1 Relationship of burned area (BA) to intervals of dry indices values

Not only did more than 100 hectares of wildfire occur in Tohoku between 1995 and 2012, but there were also many wildfires burning less than one hectare. In order to make better use of the dryness index to analyze the impact of dryness on wildfire, we divided the discussion into three categories according to the burned area: less than 1 hectare,1-10 hectare and more than 10 hectares. In this study, we selected the KBDI, PDSI value, soil moisture (SM) and effective humidity (EH) in the city where wildfire occurred to compared them with wildfire statistics (Fig 1, Fig 2, Fig 3, Fig 4). The frequency in these figures was defined by following equation:

$$\text{Frequency} = \frac{\text{Number of wildfire occurrence in the interval}}{\text{Number of wildfire occurrence}} \qquad (6)$$

The result showed that KBDI is not suitable for evaluation of dryness in Tohoku region. In contrast, as the PDSI, SM, EH decrease in value (dry condition), wildfire with large burned area is likely to occurred in Tohoku region.

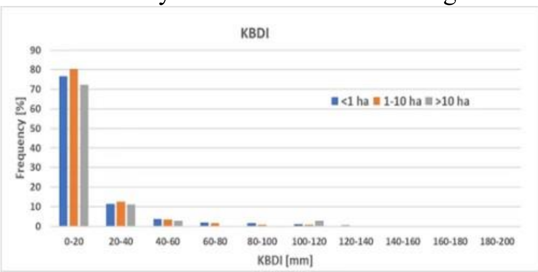

Fig 1. Frequency of BA values in 10 intervals of KBDI

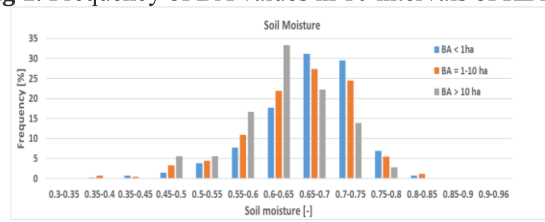

Fig 2. Frequency of BA values in 13 intervals of SM

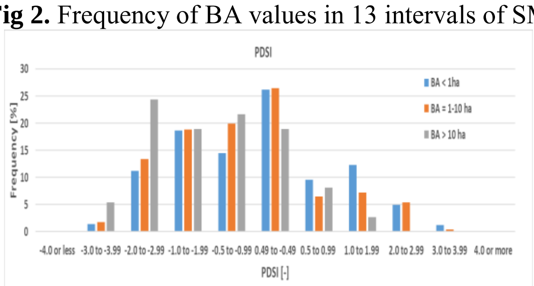

Fig 3. Frequency of BA values in 11 intervals of PDSI

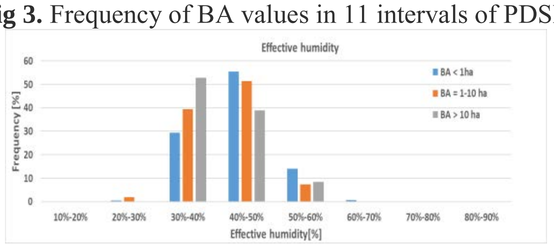

Fig4. Frequency of BA values in 8 intervals of EH

4.2 Correlations between these indices and the occurrence of wildfire/burned area

The first approach involves the use of an ordinary Pearson correlation to investigate the relationship between PDSI, monthly minimum soil moisture (SM), monthly minimum effective humidity (EH) and the number of fires/the burned area on a monthly time scale (Fig 5, Fig 6). The results for all prefectures are all statistically significant with extremely low p-values. A p-value of 0.05 is the standard used for statistical significance. The results showed that both SM and EH showed a strong negative correlation with wildfire in Tohoku region. As the SM, EH decrease in value, the possibility of more wildfires per month and more burned area per month also increases. Additionally, from these distribution map, it is obviously seen that PDSI displayed a weak correlation with MTNO and MTBA. This is probably caused by that snowfall, snow cover, and frozen ground are not considered in the PDSI.

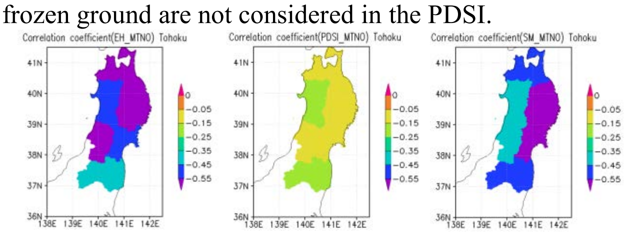

Fig 5. The correlation coefficient map of EH, PDSI, SM with MTNO

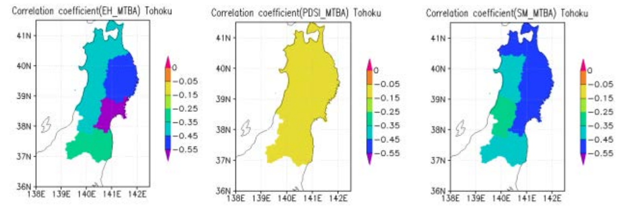

Fig 6. The correlation coefficient map of EH , PDSI, SM with MTBA

5. CONCLUSIONS

Most wildfire are concentrated in low value interval of KBDI (0-20) and the interval indicated that soil is moist. That indicated that KBDI is not suitable for evaluation of dryness in Tohoku region. On the other hand, as the SM, EH decrease in value, the possibility of more wildfires per month and more burned area per month also increases. But because of the limitation of PDSI that cannot consider snowfall, snow cover, and frozen ground, the result of PDSI shows weak correlation with MTBA and MTNO in Tohoku region.

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