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Possibility of Climate Change and Simulation of Soil Moisture Content on Mt. Hallasan National Park, Chejudo Island, Korea

Kim, Eun-Shik and Young-Sun Kim

Department of Forest Resources, Kookmin University, Seoul 136-702, Korea

ABSTRACT: Changing patterns and the possibility of climate change in the area of Chejudo island, the southernmost Island in Korea, were analyzed using daily temperature and precipitation data observed at the Cheju Regional Meteorological Office from May 1923 to December 1998. A hydrologic simulation model "BROOK" was used to simulate and analyze the dynamics of daily soil moisture content and soil moisture deficit by applying the daily weather data. During the period, significantly increasing pattern was observed in temperature data of both annual and monthly basis, while no significantly changing pattern was observed in precipitation data. During the last 76 years, mean annual temperature was observed to have risen about 1.4℃, which may show the possibility of the initiation of climate change on the island whose validity should be tested in future studies after long-term studies on temperature. Based on the simulation, due to increased temperature, significant increase was predicted in evapotranspiration, while no significant decrease was detected in simulated soil moisture content during the period. Changing pattern of annual soil moisture content was markedly different from those of precipitation. In some dominant trees, negative effects of the drought of the late season for the previous year were shown to be statistically significant to radial growth of the tree for the current year. As annual variation of radial growth of trees is mainly affected by the soil moisture content, the information on the dynamics of soil moisture deficit possibly provides us with useful information for the interpretation of tree growth decline on the mountain.

Key words: Climate change, Decline of Korean fir, Drought, Mt. Hallasan, Simulation, Soil moisture content, Temperature increase,

INTRODUCTION

Climate is generally defined as "the composite or generally prevailing weather conditions of a region, as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds (Random House, Inc. 1987)," or "the average weather over the course of the year, where weather is defined as the result of the combined action of various meteorological factors at a given moment (Walter 1979)."

The mostly prevailing weather conditions of a region, that affect the living patterns of people as well as the existence of biota, are temperature and hydrature (the state of hydration) throughout the year. While temperature is easily measured throughout the year, it is not easy to measure hydrature in the soil throughout the year.

Although all of the weather patterns are originally affected by the solar radiation, temperature and soil moisture conditions are the factors that affect the growth of trees and herbaceous plants locally, regionally and globally (Kimmins 1987, Kim 1988). Differently from the general conception, precipitation, however, is only an indirect indicator of soil moisture content which is affected by such combined factors as the storage, interception, evaporation, transpiration, surface run-off, streamflow, and deep seepage of moisture in a forest. Therefore, continuous monitoring or the simulation of soil moisture content is the main prerequisite to understand the dynamics of soil moisture contents as well as successful evaluation of the effects of weather or climate to tree growth in a forest.

Federer and Lash (1978) and Federer (1992a) made a hydrologic model (BROOK) that simulates daily soil moisture content and "evapotranspiration" (a collective term of evaporation added to transpiration) as well as streamflow at a northern hardwood forests (Hubbard Brook Experimental Forest) in U.S.A., which is one of the US LTER sites where intensive and extensive studies on ecosystem functioning have been carried out (Likens *et al.* 1977, Bormann and Likens 1979). As the hydrologic simulation model was well validated not only at the forest but also at the other forests of the world (Federer 1992b), the author thought it useful to infer the dynamics of daily soil moisture content by applying daily weather data collected from 1923 to 1998, at the Cheju Regional Meteorological Office in Cheju City, Chejudo Island, Korea. In simulating daily soil moisture content, daily data of temperature and precipitation were used, which made it possible to simultaneously analyze the possibility of climate change on annual as well as monthly basis in the forests on Mt. Hallasan National Park, where growth decline of Korean fir (*Abies koreana* Wilson) has been speculated from the last 40 years due to unknown causes (Kim 1994a).

The main objectives of this paper are to analyze changing patterns of daily precipitation and temperature in Cheju area, to find the possibility of changing signals of climate, to simulate and analyze the dynamics of daily evapotranspiration, soil moisture content, and soil moisture deficit, and to extend the interpretation of the information on the factors to the growth of Korean fir trees in the forests on Mt. Hallasan National Park, Chejudo Island, Korea.

MATERIALS AND METHODS

Fig. 1 shows the area of Chejudo Island, the southernmost Island in Korea, and the location of the study site.

Daily soil moisture contents, streamflow, and evapotranspiration in the forest were simulated by applying the hydrologic model BROOK with daily input of mean temperature and precipitation data. Instead of explanation of the specifics of the mechanisms of the model BROOK, the flow chart for the revised model, BROOK90, is outlined in Fig. 2 (Federer 1992a).

As long-term daily temperature and precipitation data for the simulation of soil moisture content on the mountain were not available, climatic data collected at the Cheju Regional Meteorological Office in Cheju City, from May 1923 up to present on daily basis, which is the nearest weather station from the site on the mountain, were used for the simulation. In order to adjust the temperature difference between the Meteorological Office and the site on the mountain, daily temperature was adjusted using the equation,

$Y_i = 1.0694 X_i - 10.9167$ ($r^2 = 0.886$ and $p < 0.0001$),
where X_i and Y_i represent the temperature on the Meteorological Office and estimated temperature at the site on the mountain, respectively.

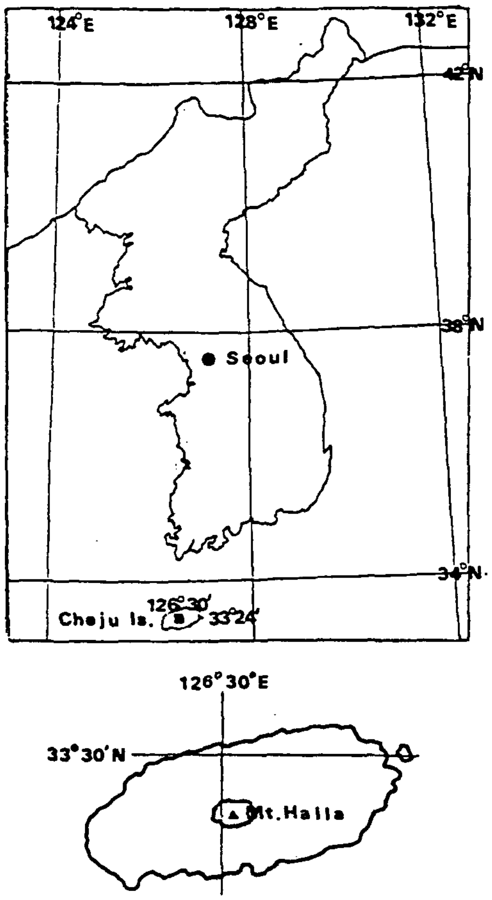

Fig. 1. Map showing the study site.

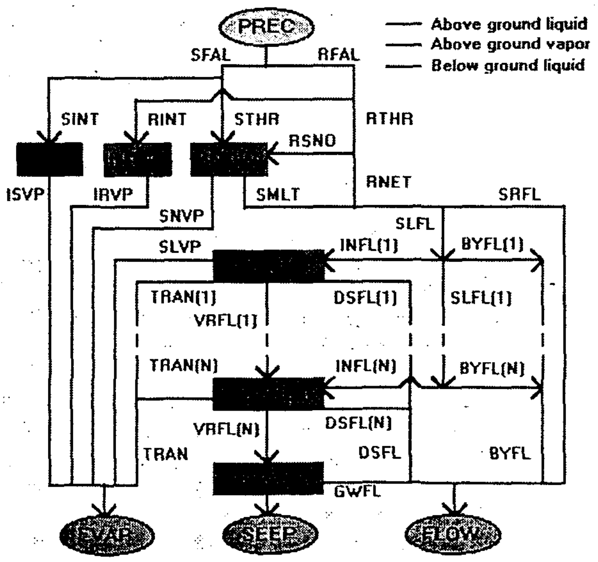

Fig. 2. Flowchart for the BROOK90 model. Dotted lines show possibility of multiple soil layers (Federer and Lash 1978, Federer 1992a).

Table 1. Information on the location of the Cheju Regional Meteorological Office in Chejudo (Korea Meteorological Service 1985)

Latitude	33° 30′ N
Longitude	126° 31′ E
Elevation of the station above MSL	22.0 m
Height of thermometer above the ground	1.5 m
Height of raingauge above the ground	0.2 m

The linear equation was statistically derived from the data sets observed at the two sites (Kim 1994). Information on the location of the weather station is summarized in Table 1.

The simulation of soil moisture content provides us with a unique potential to estimate soil moisture deficit in soil. Soil moisture deficit is defined as the deviation of current soil moisture content from saturated soil moisture content. In the BROOK model, Federer (1980) assumed the moisture content of field capacity and wilting point as 175.5 mm and 55 mm, respectively, in the soil with the depth of 600 mm. With this soil moisture content, water potentials at the field capacity and wilting point are −0.06 bar and −15 bar, respectively. Consequently, daily soil moisture deficit was calculated using the equation:

soil moisture deficit (mm)
= 175.5 - daily soil moisture content,
when soil moisture content went below 175.5 mm.

Federer (1980) put that soil moisture deficit greater than 60 mm might indicate the occurrence of agricultural drought at Hubbard Brook Experimental Forest in New Hampshire, U.S.A. Based on this information, the duration and the severity of soil moisture deficit (drought) were evaluated and the potential effects of the drought to the growth of the Korean fir trees were discussed.

Graphics and statistical results were presented to discuss the interrelationships among the factors. Climatic data have been processed by using the MS-FORTRAN compiler in an IBM-PC compatible personal computer and statistical analysis were carried out by the SAS (Statistical Analysis System) package.

RESULTS AND DISCUSSION

Changing patterns of temperature and the increase of temperature by year

As the site is located in cool temperate zone, seasonal temperature change is evident. Mean daily temperature was the highest in August 1 (18.05℃) and the lowest in February 2 (−6.47℃) (Fig. 3). Generally, variation in temperature in winter was higher than that in summer.

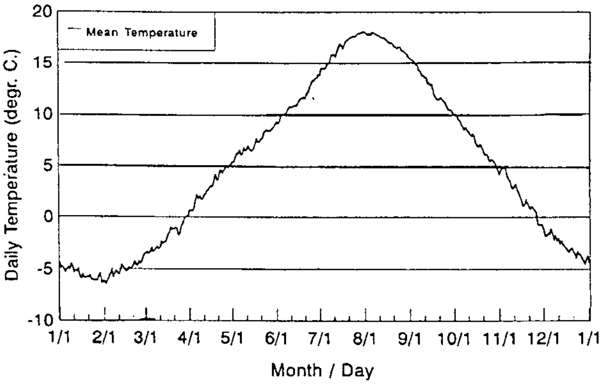

Fig. 3. Mean daily temperature change on Mt. Hallasan for the last 76 years.

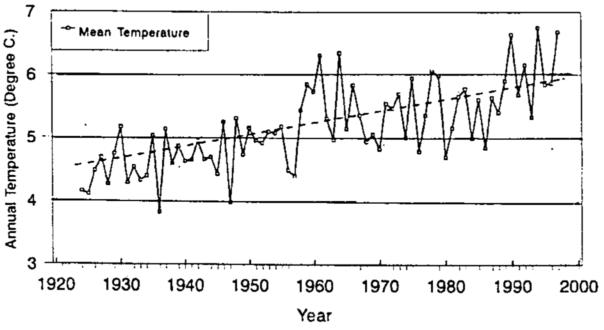

Fig. 4. Mean annual temperature change on Mt. Hallasan for the last 76 years.

When mean annual temperature was plotted against time (year), statistically significant increasing trend was observed (Fig. 4). During the past 76 years, mean annual temperature seems to have risen about 1.4℃, which may show the possibility of the initiation of climate change on the island whose validity should be tested in future studies after long-term studies on the temperature. Mean of the annual temperature for the last 76 years was 5.25℃, and it was the highest in 1941 (6.75℃) and the lowest in 1936 (3.83℃), which indicates that mean annual temperature is quite variable by year (Fig. 4).

When mean monthly temperature was regressed against time (year), statistically significant increasing trends were observed for all the month (Table 2).

Changing patterns of precipitation

As the precipitation shows monsoonal patterns, daily mean precipitation was the highest in June 25 (15.63 mm) and the lowest in December 10 (0.62 mm) (Fig. 5). In summer, variation in precipitation was higher than that in winter.

Table 2. Trend of temperature change from 1923 to 1998 on Mt. Hallasan by month

Month	Intercept (temperature in the 1920s)	Trend of Change (by year)	Significance Level	Significance
January	-6.78	+0.021	0.01	**
February	-6.62	+0.025	0.001	***
March	-3.61	+0.026	0.0001	****
April	+0.67	+0.035	0.0001	****
May	+5.09	+0.032	0.0001	****
June	+9.82	+0.022	0.0001	****
July	+15.41	+0.015	0.05	*
August	+16.07	+0.018	0.002	**
September	+11.31	+0.025	0.0001	****
October	+5.84	+0.028	0.0001	****
November	+1.18	+0.017	0.003	**
December	-3.50	+0.013	0.05	*

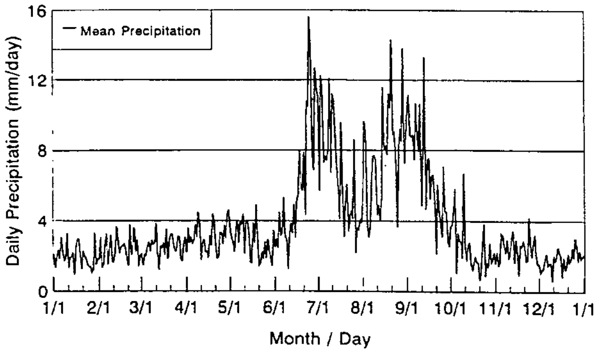

Fig. 5. Mean daily precipitation change on Mt. Hallasan for the last 76 years.

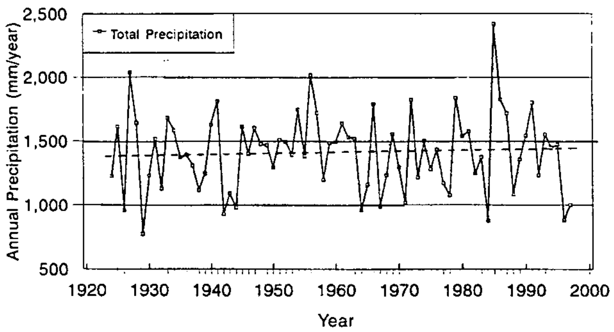

Fig. 6. Total annual precipitation change on Mt. Hallasan for the last 76 years.

When total annual precipitation was plotted against time (year), no statistically significant increasing trend was observed (Fig. 6). Mean of the total annual precipitation for the last 76 years was 1,413 mm, and it was the highest in 1985 (2,420 mm) and the lowest in 1929 (774.1 mm), which indicates that annual precipitation is very variable by year.

When total monthly precipitation was regressed against time (year), no statistically significant changing trends were observed for all the month except December (Table 3).

Simulated evapotranspiration

While precipitation is the major hydrologic input to the system, output comprises streamflow as well as evapotranspiration. Evapotranspiration is highly affected by the transpiration, which is then affected by temperature conditions. As temperature shows seasonal trends, so does the evapotranspiration. Daily evapotranspiration was the highest in July 16 (3.26 mm), and the lowest in

Table 3. Trend of total precipitation change from 1923 to 1998 on Mt. Hallasan by month

Month	Intercept (precipitation in the 1920s)	Trend of Change (by year)	Significance Level	Significance
January	50.3	-0.155	0.40	NS
February	85.7	-0.282	0.17	NS
March	49.3	+0.411	0.08	NS
April	70.8	+0.341	0.11	NS
May	83.2	+0.114	0.64	NS
June	150.2	+0.428	0.50	NS
July	214.7	-0.013	0.99	NS
August	199.2	+0.572	0.44	NS
September	289.7	-1.338	0.06	NS
October	75.2	+0.026	0.95	NS
November	68.3	+0.066	0.75	NS
December	78.1	-0.365	0.04	*

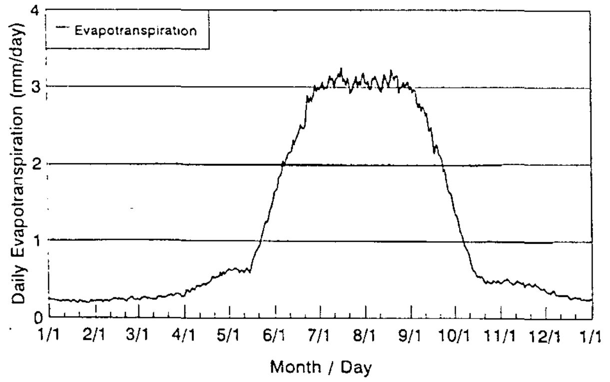

Fig. 7. Mean daily evapotranspiration change on Mt. Hallasan for the last 76 years

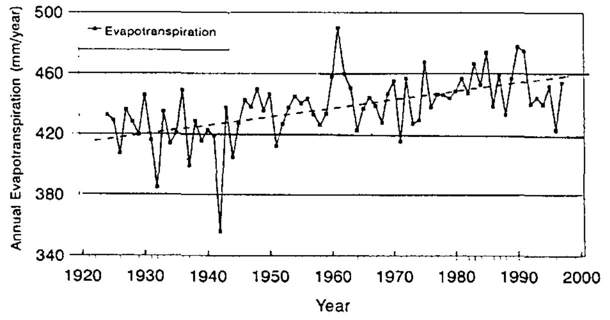

Fig. 8. Mean annual evapotranspiration on Mt. Hallasan for the last 76 years

January 27 (0.19 mm) (Fig. 7).

When simulated annual evapotranspiration was plotted against time (year), statistically significant increasing trend was observed (Fig. 8). Mean of the annual evapotranspiration for the last 76 years was 436.9 mm, and it was the highest in 1961 (490.0 mm) and the lowest in 1942 (356.0 mm), which indicates that annual evapotranspiration is quite variable by year.

When the simulated data are examined, active transpiration generally begins in mid-May and ends in early-October. It is important to note that the period between mid-May to early-October are to be considered as the growing period in the site, especially from June to September.

Simulated soil moisture content and soil moisture deficit

As soil moisture content is affected by the balance between the input of precipitation and the outputs of streamflow and evapotranspiration, soil moisture content showed very different patterns from those of precipitation, temperature, and evapotranspiration.

At the site, during the winter season, as the surface of the land is covered with snow, soil moisture content is not limited. Soil moisture content culminates in early-April during the season of snow melt. Since mid-May, when active transpiration begins, it rapidly declines until mid-June. It is interesting to note that soil moisture can limit early growth of trees during the earlier part of June at the site, which can be called as the "First Dry Season" of a year. Further analysis indicates that the variability of soil moisture contents in June was very high. Therefore, the limitation of soil moisture content due to low precipitation and high temperature in June will result in the low growth of trees in forests.

From mid-June, when monsoonal season initiates with heavy precipitation, soil moisture content increases again. During the summer season, soil moisture content shows similarly changing pattern as that of precipitation until early September. From late-July to mid-August, soil moisture is very low and limiting tree growth at the site. This period may be called as the "Second Dry Season" of a year, which is the driest period of the year. From mid-October, soil moisture increases due to low temperature and low evapotranspiration. Simulated mean daily soil moisture content was the highest in April 7 (176.7 mm) and the lowest in August 7 (138.8 mm) (Fig. 9).

Based on this general trend, when daily soil moisture content data of certain year were comparatively plotted with mean daily data, the figure shows good information to evaluate the soil moisture status of certain year, including the severity, longevity, variability, fluctuation, and the normality.

When simulated annual soil moisture content was plotted against time (year), no statistically significant decreasing trend was observed (Fig. 10). Mean of the annual soil moisture content for the last 76 years was 160.6mm. It was the lowest in 1997 (146.5 mm) and the highest in 1972 (169.0 mm), which indicates that mean annual soil moisture content is quite variable by year.

This indicates that the information on the dynamics of soil moisture content derived from the simulation provides us with useful information for better understanding of the dynamics of soil moisture content and annual variation of soil moisture deficit and drought in the forest.

As the pattern of soil moisture deficit is symmetric to that of soil moisture content at the level of field capacity and was explained before, the figure showing the general pattern of soil moisture deficit and its explanation will be omitted.

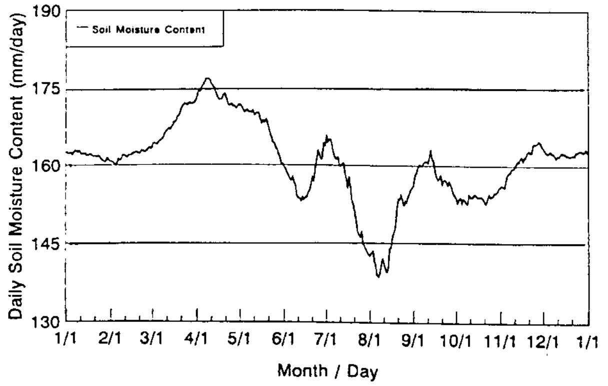

Fig. 9. Mean daily soil moisture content change on Mt. Hallasan for the last 76 years.

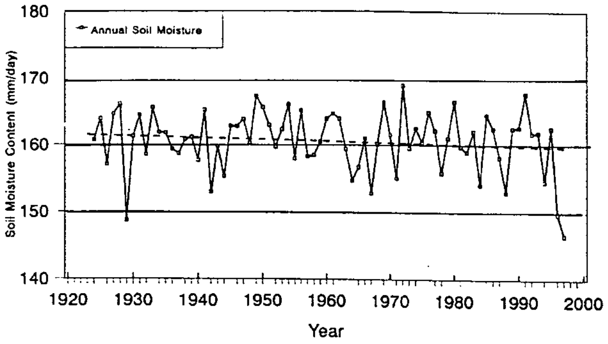

Fig. 10. Mean annual soil moisture content change on Mt. Hallasan for the last 76 years.

Soil moisture content and tree growth

Kim (1994b) reported that there was strong correlation between drought simulated by the BROOK model and tree growth for Japanese red pine (*Pinus densiflora* Sieb. et Zucc.) growing in central Seoul, Korea. He suggested that trees showed generally negative correlations to the length of drought of the current year and the previous year. In some dominant trees, negative effects of the drought of the late season for the previous year were shown to be statistically signifiant to radial growth of the tree for the current year.

Although it is premature to draw the same conclusion as him for the Korean fir trees growing on Mt. Hallasan National Park, some trees showed statistically significant negative correlation between the occurrence of drought and tree growth as was shown in Fig. 11 at the site.

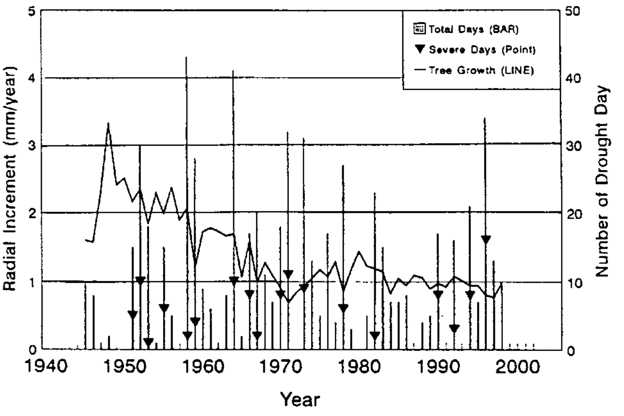

Fig. 11. Tree growth affected by drought during the growing season of the current year and the previous year for a dominant tree of Korean fir on the site

As annual variation of radial growth of trees is mainly affected by the soil moisture content, the information on the dynamics of soil moisture deficit provide us with the key information for the interpretation of tree growth decline on the mountain. Further studies should be carried out to elucidate the relationships between them and the potential complexity caused by the tree growth decline at the site.

CONCLUSIONS

It was very significant to find out that mean annual temperature was observed to have risen about 1.4℃ during the last 76 years, which may show the possibility of the initiation of climate change on the island, whose validity should be tested by future long-term studies on temperature. Simulation of a hydrologic model "BROOK" provide us with the useful information on the dynamics of daily soil moisture content, which are markedly different from those of precipitation. It provides us with further potential to interpret tree growth decline of Korean fir trees on Mt. Hallasan National Park, Chejudo Island, Korea.

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