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Predicting the Potential Impact of Climate Change on People–Caused Forest Fire Occurrence in South Korea

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We investigated the potential impact of climate change on people–caused forest fire occurrence in South Korea. Logistic regression analysis methods were used to develop daily fire occurrence prediction models for each of nine study areas. These models were then coupled with climate scenario data produced by two General Circulation Models (CCCma and CCSR/NIES) to predict future people–caused fire occurrence in those nine areas. Our results suggest the number of fire days will increase by roughly 7 to 58% depending upon the district. However, as the prediction of fire occurrence was varied by the land use, the vegetation, human activity, forest management policy and etc., more factors related this part should be need to research more with this study.

Key words: forest fire, forest management, General Circulation Models

INTRODUCTION

The forested area of Korea amounted to 6.4 million ha and covered about 64% of total land area in 2003 (Korea Forest Service 2004). The total growing stock in that year was estimated to be 468 million m^3 and almost 76% of all trees are less than 30 years of age. The forests were classified as Conifer (42%), Hardwood (26%), and Mixed forests (30%) (Korea Forest Service, 2004).

The spring and fall sub–seasons are relatively dry and the summer is hot and humid. The winter is dry and very cold due to Siberian air masses that sweep down from the north. The annual average temperatures are ranged from 10 to 16°C. Annual rainfall ranges from 1,000 mm to 1,800 mm and its seasonal distribution is irregular. The rainy season usually begins in late June and lasts approximately 30 days and two or three typhoons often strike between June and October of each year. As a result, 50–60% of the annual mean rainfall occurs during the summer from June to August (Korea Meteorological Administration, 2004).

Most forest fires in South Korea occur during the dry and windy spring and fall sub–seasons and more than 60 percent of the fires occur during March through May (Table 1 and Fig. 1). During this period, the air is relatively dry and many people use forested areas for recreational purposes. Most of forest fire occurred in South Korea were originated from a variety of human activities including camping, recreation and railway transportation. The major causes of people–caused fires in South Korea are accidental fires in mountainous areas (42%) and those that result from agricultural burning (18%). A total of 5,070 fires were reported during 1994–2003. There were 729 fires in 2000 and 786 fires in 2001, two particularly bad years (Korea Forest Service, 2004) (Table 1 and Fig. 1).

National Forest Fire Danger Rating Index (NFDRI) of South Korea was developed for daily fire danger forecasting and forest fire prevention of South Korea. Lee *et al.* (1997) used wooden stick (fuel moisture stick) by the moisture contents for developing forest fire danger rate in the 12 area of South Korea during fire seasons(March to May and Mid–November to mid–December). They were developed forest fire danger rate equations by regression analysis using weather conditions (effective humidity, precipitation, maximum temperate and radiation) and wooden sticks. They were classified to 5 flammability degree in accordance with moisture contents of fuel moisture stick that extreme (moisture contents (%) of fuel moisture stick; 12–10%), High (14–12%), Medium (16–14%), Low (20–16%), Nil (over 21%). Currently, Daily Fire Danger Rating of South Korea is posted on the web site (http://www.foa.go.kr) of Korea Forest Service during forest fire seasons (Spring (February 1 to May 15) and Fall (November 1 to December 15) in every year. The National Forest Fire Danger Rating Index (NFFDRI) of South Korea has three components, the Daily Weather Index (DWI), the Fuel Model Index (FMI) and the Topography Model Index (TMI). DWI was developed using maximum temperature, effective humidity and average wind speed by the logistic model. FMI and TMI were developed using forest type (Conifer, Hardwood and Mixed forest), aspect and location of ignition in area of the burned forest fire at past. NFDRS is classified as 10 degree index (1 to 10) by the sum of the three compo-

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Table 1. Number of forest fires in South Korea by cause and month during the years 1994 through 2003

Month	Number of fire	Visiting Mountain	Farmer	Refuse	Smoking	Tomb visits	Children	Other
Jan	226	121	15	7	6	16	14	47
Feb	723	278	141	47	50	42	40	125
Mar	1,314	449	329	123	107	59	57	190
Apr	1,781	763	307	99	144	210	49	209
May	310	178	30	7	42	6	2	45
Jun	110	50	24	4	4	6	0	22
Jul	13	7	3	0	0	0	0	3
Aug	5	3	0	0	0	0	0	2
Sep	75	33	10	1	4	21	0	6
Oct	112	66	14	4	7	3	0	18
Nov	166	99	9	7	12	5	3	31
Dec	244	147	13	10	23	1	4	46
Total	5,079	2,194	895	309	399	369	169	744

- The data used to produce this table was downloaded from Korea Forest Service (http://www.foa.go.Kr, cited October 2004). Tomb visit fires result when many Koreans visit their ancestor's grave site in mountain areas and some use fire to cook or for weed control at their ancestor's grave site

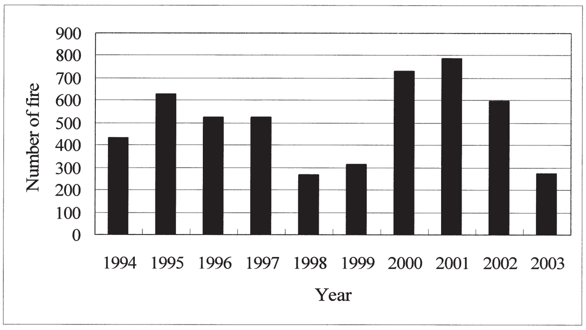


Fig. 1. Number of forest fires in South Korea from 1994 through 2003.

nents that components have a different weighted value (0.6 in the DWI , 0.2 in the FMI and TMI). NFDRS for daily fire danger rate forecasting is divided as three degrees that is danger (over 81 Index– if the national fire danger index(NFDRI) is 8, daily fire danger rating index for forecasting would be 80), caution (61–80 Index), and low danger (below 61 Index) (Lee and Won, 2004).

Choi and Han (1996) developed a forest fire occurrence model that relates daily fire occurrence to weather data (relative humidity, temperature, wind speed, duration of sunshine, rainfall and duration of rainfall) in the Taegue, Andong and Pohang area of South Korea. The used both logistic and probability models and found that fire occurrence was significantly effected by relative humidity, duration of sunshine, duration of rainfall. Lee *et al.* (2004) developed a forest fire occurrence probability model by logistic analysis using meteorological characteristics (maximum temperature, effective humidity) for eight provinces (Chungcheongbuk–Do, Chungcheongnam–Do, Gangwon–Do, Gyeonggi–Do, JeollaBuk–Do, JeollaNam–Do, Kungsanbuk–Do, and Kungsannam–Do) area in Korea. The maximum temperature was significant in Gangwon–Do, Gyeonggi–Do, and JeollaBuk–Do. The effective humidity was significant in the Chungcheongbuk–Do, Chungcheongnam–Do, Gangwon–Do, Gyeonggi–Do, JeollaNam–Do, Kungsanbuk–Do, and Kungsannam–Do. Lee *et al.* (2004) and An *et al.* (2004) used GIS and Mapping to show forest fire risk by the logistic regression analysis for classification of forest fire risk area. They reported that probability of forest fire occurrence in forest fire occurrence risk area was significant to various environmental factors (forest type, aspect, forest age, and etc). They classified fire danger indexes as 1 to 20 range (index 1 is high probability of fire occurrence) according to probability of forest fire occurrence. These fire danger indexes were classified for forest fire occurrence risk map as five group that were Extreme (Fire danger index 1–4), High (5–8), Moderate (9–12), Low (13–16), Very Low (17–20).

Weather and climate have significant impacts on forest fire processes in many forested and climatic warming from increased atmospheric concentrations of CO_2 and other greenhouse gases could have significantly ecological and economic impacts on agriculture and forests (Graham *et al.* 1990). Jun *et al.* (2001) investigated climate change in Korea change using 5 GCM models (CCSR/NIES, CCCma, CSIRO MK2, HAD CM2, ECHAM4). They found that temperature is expected to increase 2.3–4.1°C and precipitation change is expected is range from –1.6 – +14.3%. General Circulation Models (GCM) predict an increase in global temperature of about 1.5–5.0°C under a doubling of atmospheric CO_2 ($2 \times CO_2$) (Schlesinger and Mitchell, 1987).

Flannigan and Van Wagner (1990) investigated the impact of greenhouse warming on the severity of the forest fire season in Canada using three GCM'S, the Geophysical Fluid Dynamics Laboratory Model (GFDL), the Goddard Institute for Space Studies Model (GISS), and the Oregon State University Model (OSU). They found that the seasonal severity rating of wildfire in Canada increased 46% with a 2 × CO_2 GCM models.

Wotton *et al*. (2003) used two GCM models (CCCma and HadCM3 GCM) in Ontario and found that temperature will increase and precipitation will either unchanged and slightly increased or decreased. Others studies of the impact of climate change on forest fire occurrence processes using GCM models include Price and Rind (1994), Goldammer and Price (1998), Stocks *et al*. (1998), Flannigan *et al*. (2000), Whitlock *et al*. (2003), Wotton *et al*. (2003) and Fried *et al*. (2004). All those studies predicted that climate change will increase the frequency of weather conditions associated with forest fire occurrence and subsequent increase in fire ignitions.

The objective of this study was to assess the potential impact of climate change on people–caused forest fire occurrence in South Korea. Therefore, we used the Canadian Forest Fire Danger Rating System (CFFDRS) to represent current and future fire danger in South Korea. The Fine Fuel Moisture Code (FFMC) that is one of the components of the Canadian Forest Danger Rating System (CFFDRS) (Stocks *et al*. 1987) is a good indicator of people–caused fires occurrence potential (Van Wagner 1970). And Cunningham and Martell (1973) demonstrated that it is reasonable to assume the probability distribution of number of people–caused fires that occur the Sioux Lookout area of Northwestern Ontario each day is Poisson with the expected number of fires day dependent upon FFMC.

MATERIALS ANA METHODS

We used the provincial boundaries of South Korea to produce eight districts (Chungcheongbuk–Do, Chungcheongnam–Do, Gangwon–Do, Gyeonggi–Do, JeollaBuk–Do, JeollaNam–Do, Kungsanbuk–Do, and Kungsannam–Do) (Table 2). We partitioned Gangwon–Do province into two areas (Chuncheon and Gangneung) due to differences in weather that result from the mountain ridge that bisects Gangwon–Do from north to south.

We used 10 years (1994–2003) daily fire occurrence data that had been compiled by the Korea Forest Services (2004). Weather information (temperature, relatively humidity, precipitation and wind speed) for this period was obtained from the Korea Meteorological Administration (2004). The daily weather data for this study was downloaded from the Korea Meteorological Administration web site (http://www.Kma.go.kr). We used weather data observed at following weather stations located in the nine study areas: Chungju weather station (latitude (N) : 36˚38', longitude (E) ; 127˚27') in Chungcheongbuk–Do, Daejeon (36˚22', 127˚22') in Chungcheongnam–Do, Chuncheon (37˚54', 127˚44') and, Gangneung (37˚45', 128˚54') in Gangwon–Do, Seoul (37˚34', 126˚58') in Gyeonggi–Do, Jeonju (35˚49', 127˚09') in JeollaBuk–Do, Kwangju (35˚10', 126˚54') in JeollaNam–Do, Daegue (35˚53', 128˚37') in Kungsangbuk–Do, and Busan (35˚06', 129˚02') in Kyungsangnam–Do.

Weather data streams representative of projected climate change were generated by using two GCM model projections. For the CCCma model we used the 16 grid cell locations (longitude; 123˚5700', 127˚5000', 131˚2500', 135˚000', and latitude 42˚6776', 38˚9666', 35˚2556', 31˚5445') shown in Figure 2. For the CCSR/NIES we used the 9 grid cell locations (longitude 123˚7500', 129˚3750', 135˚000' and latitude 41˚5325', 35˚9951', 30˚4576') also shown in Fig. 2.

Forest fire occurrence exhibits seasonal variation and South Korea has two activity forest fire sub–seasons, the Spring and Fall sub–seasons. We divided each year into three sub–seasons for this study; Spring (February 1 to May 15), Summer (May 16 to October 31) and Fall fire (November 1 to December 15) to relate daily fire occurrence in the 1994–2003. We did not use fire occurrence data for the period from December 16 to January 31 because South Korea's official fire season starts on February 1 and ends on December 15.

Cunningham and Martell (1973), Martell *et al*. (1987, 1989), Todd and Kourtz (1992), Vega Garica (1995), Pew and Larsen (2001) and Wotton *et al*. (2003) developed people–caused fire occurrence prediction

Table 2. People–caused fire occurrence during the 1994 to 2003 study period by study area

Province	Size (km^2)	Number of days	Number of fires	Number of fire days
Chungcheongbuk–Do	7,431	3,080	348	225
Chungcheongnam–Do	12,585	3,080	519	283
Gangwon–Do (Chuncheon)	12.584	3,080	408	273
Gangwon–Do (Gangneung)	4,028	3,080	242	186
Gyeonggi–Do	11,723	3,080	904	442
JeollaBuk–Do	8,050	3,080	368	227
JeollaNam–Do	12,547	3,080	492	286
Kungsanbuk–Do	20,967	3,080	802	421
Kungsannam–Do	11.281	3,080	578	358

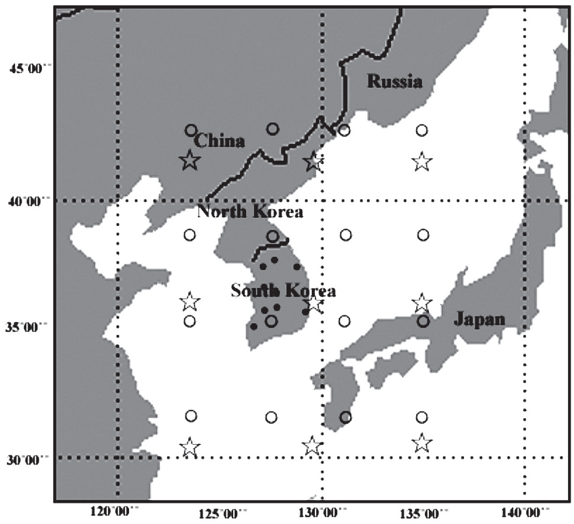


Fig. 2. The locations of the grid point of the CCCMa and CCSR. NIES GCM models and observed weather stations in South Korea (○: CCCma grid point, ☆: CCSR/NIES grid point ●: observed weather stations) (IPCC Data Center, 2004 and Korea Meteorological Administration, 2004).

models for areas in Canada. We used the logistic regression analysis methods that Martell *et al*. (1987) used for the province of Ontario, to develop fire occurrence models for each of the nine study areas in South Korea. The form of the logistic model we used is

$$P = \exp(\beta_0 + \beta_1 FFMC)/1+\exp(\beta_0 + \beta_1 FFMC) \quad (1)$$

Where P is the probability of a fire day and β_0 and β_1 are model parameters. We used SPSS Program (SPSS 12.0 for Windows) to estimate our model parameters.

Table 3 shows the results of our logistic regression analysis of the relationship between people–caused fire occurrence and the FFMC on each of nine study areas of South Korea. The FFMC was statistically significant in most areas and during the exception of Fall season in the Chungcheongnam–Do area and JeollaNam–Do area. P values were significant ($P<0.05$) on sub–season in nine study areas. Chi–square statistic for sub–season of the nine study areas was significant (<0.05). Although chi–square statistics in all sub–season of nine study areas were significant for the probability model of forest fire occurrence in South Korea, Spring fire sub–season of

Table 3. Logistic regression models for the probability of a fire day for each study area and sub–season

Sub–season	Location	FFMC	Constant	R Square	Chi–square	P
Spring	Chungcheongbuk–Do	0.325	–29.441	0.346	249.99	<.001
	Chungcheongnam–Do	0.226	–20.33	0.346	272.812	<.001
	Chuncheon	0.252	–22.587	0.335	253.849	<.001
	Gangneung	0.277	–26.185	0.311	190.044	<.001
	Gyeonggi–Do	0.242	–21.157	0.39	345.755	<.001
	JeollaBuk–Do	0.182	–16.607	0.298	212.198	<.001
	JeollaNam–Do	0.171	–15.428	0.326	255.816	<.001
	Kungsanbuk–Do	0.361	–32.481	0.421	365.374	<.001
	Kungsannam–Do	0.304	–27.412	0.365	286.715	<.001
Summer	Chungcheongbuk–Do	0.667	–63.249	0.201	41.447	<.001
	Chungcheongnam–Do	0.708	–66.616	0.234	55.704	<.001
	Chuncheon	0.182	–19.366	0.118	31.988	<.001
	Gangneung	0.335	–33.551	0.185	42.524	<.001
	Gyeonggi–Do	0.451	–43.103	0.203	76.31	<.001
	JeollaBuk–Do	0.874	–81.537	0.264	52.565	<.001
	JeollaNam–Do	0.404	–39.302	0.156	41.461	<.001
	Kungsanbuk–Do	0.533	–50.497	0.248	124.277	<.001
	Kungsannam–Do	0.637	–59.108	0.255	117.72	<.001
Fall	Chungcheongbuk–Do	0.595	–54.328	0.233	22.085	<.001
	Chungcheongnam–Do	0.330*	–31.57	0.154	12.495	<.001
	Chuncheon	0.351	–32.114	0.25	35.727	<.001
	Gangneung	0.288	–27.959	0.182	31.644	<.001
	Gyeonggi–Do	0.355	–32.601	0.253	48.146	<.001
	JeollaBuk–Do	0.233	–22.848	0.154	15.411	<.001
	JeollaNam–Do	0.198*	–20.812*	0.114	6.815	0.009
	Kungsanbuk–Do	0.339	–31.625	0.182	41.016	<.001
	Kungsannam–Do	0.45	–41.608	0.226	58.187	<.001

* : variable statistically not significant (P > 0.05)
R square : Nagelkerke R square, Chi–square : Hosmer–Lemeshow goodness–of–fit statistic, P : probability value.

nine study areas was more higher than them of other seasons. It might indicate that Spring fire sub–season models by the logistic regression analysis of nine study area is better fitting model than other forest fire sub–seasons models.

We used climate change projection data from two GCM's; the CCCma (Canadian Center for Climate Modeling and Analysis) and CCSR/NIES (Tokyo University National Institute for Environmental studies, Japan) and the data for this study was from the IPCC Data Distribution Center (IPCC Data Center, 2004). The Canadian Global Coupled Model is a spectral model with triangular truncation at wave number 32 (yielding a surface grid resolution of roughly 3.7° × 3.7°) and 10 vertical levels. This simulation predicts an effective greenhouse gas forcing change that corresponds to an increase of

Table 4. The current and projected weather in South Korea obtained by interpolating CCCma and CCSR/NIES model projections

	Current		CCCma projective						CCSR/NIES projective					
	1994–2003		2010–2039		2040–2069		2070–2099		2010–2039		2040–2069		2070–2099	
	Temp	Rain	Temp	Rain	Temp	Rain	Temp	Rain	Temp	Rain	Temp	Rain	Temp	Rain
Spring	13.8	2.2	15.2	2.3	16.0	2.0	17.5	2.4	15.4	2.4	16.0	2.3	17.0	2.2
Summer	24.8	6.5	25.9	6.7	26.5	7.0	27.6	8.1	25.9	7.2	26.5	7.7	27.3	8.0
Fall	8.5	1.2	9.5	1.1	10.3	0.9	11.6	0.8	9.9	1.2	10.5	1.3	12.0	1.4

Temp. : Average temperature (˚C) during each sub–season, Rain : Average rainfall per a day (mm/day) during each sub–season.

Table 5. The average FFMC based on observed weather and average FFMC obtained using projected CCCma and CCSR/NIES models for each sub–season in the nine study area of South Korea

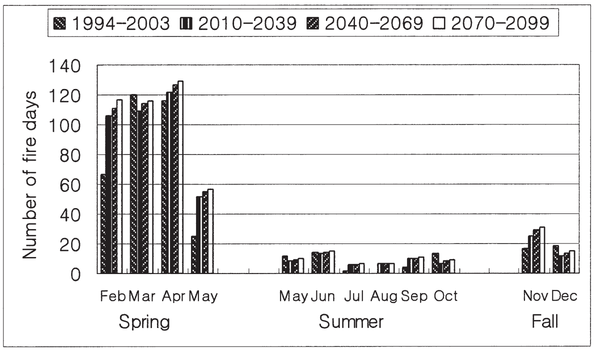
Locations	Subseasons	Current	CCCma			CCSR/NIES		
		1994–2003	2010–2039	2040–2069	2070–2099	2010–2039	2040–2069	2070–2099
		FFMC	FFMC	FFMC	FFMC	FFMC	FFMC	FFMC
Chungcheongbuk–Do	Spring	78.7	79.6	80.5	80.6	79.3	79.8	80.4
	Summer	77	77.6	78.1	78.5	77.4	77.6	78
	Fall	75.9	77	78.4	79.2	76.6	76.8	77.2
Chungcheongnam–Do	Spring	77.4	78.4	79.3	79.4	78	78.6	79.2
	Summer	75.3	76	76.5	76.9	75.7	75.9	76.4
	Fall	75.8	76.9	78.2	79.1	76.5	76.7	77
Chuncheon	Spring	76.9	77.8	79	79.1	77.4	78	78.6
	Summer	73	73.4	74	74.2	73.4	73.6	74
	Fall	72.8	74.2	76.1	76.7	73.6	73.8	74.3
Gangneung	Spring	76.8	77.9	78.7	78.9	77.4	78	78.6
	Summer	73.9	74.5	74.9	75	74.2	74.5	74.8
	Fall	78.1	79	80.1	80.7	78.7	79	79.5
Gyeonggi–Do	Spring	79.1	80.1	80.9	81.1	79.7	80.2	80.7
	Summer	75.3	76	76.4	76.7	75.8	76	76.4
	Fall	77	78.2	79.9	80.5	77.7	78	78.4
JeollaBuk–Do	Spring	75.8	76.9	77.9	78	76.5	77.1	77.7
	Summer	74.7	75.5	76.1	76.6	75.2	75.4	75.8
	Fall	74.3	75.5	76.7	77.8	75	75.2	75.6
JeollaNam–Do	Spring	76.5	77.4	78.4	78.7	77.2	77.8	78.4
	Summer	76.2	76.9	77.4	78	76.7	76.9	77.3
	Fall	75	76.2	77.4	78.4	75.6	76	76.3
Kungsanbuk–Do	Spring	80.4	81.2	81.9	82.1	81	81.5	82
	Summer	78.4	79	79.5	79.9	78.7	79	79.3
	Fall	82	82.6	83.4	84	82.5	82.6	83
Kungsannam–Do	Spring	77.3	78.1	78.8	79.2	78	78.6	79.1
	Summer	76.3	76.8	77.3	77.8	76.7	77	77.3
	Fall	83	83.5	84.2	84.8	83.5	83.7	84.1

Table 6. Predicted number of fire days for each sub–season in the nine study areas based on CCCma model and CCSR/NIES model fire weather projection. Observed number of fire days in each location was collected from Forest Service of Korea during 1994–2003

Location	Season	observed	Predictions based on CCCma model			Predictions based on CCSR/NIES model		
		1994–2003	2010–2039	2040–2069	2070–2099	2010–2039	2040–2069	2070–2099
Chungcheongbuk–Do	Spring	194	214	226	238	214	223	235
	Summer	20	23	27	30	23	26	28
	Fall	11	12	15	17	12	13	15
	Total	225	249	268	285	249	262	278
Chungcheongnam–Do	Spring	250	264	277	287	264	272	283
	Summer	24	26	30	34	26	29	33
	Fall	9	9	12	12	9	10	11
	Total	283	299	319	333	299	311	327
Chuncheon	Spring	224	242	256	266	236	244	255
	Summer	29	30	30	31	30	30	31
	Fall	20	21	25	27	22	23	25
	Total	273	293	311	324	288	297	311
Gangneung	Spring	135	143	151	158	142	145	152
	Summer	23	25	25	28	25	25	28
	Fall	28	29	31	34	29	30	32
	Total	186	197	207	220	196	200	212
Gyeonggi–Do	Spring	362	389	407	419	382	392	407
	Summer	45	51	54	59	50	55	58
	Fall	35	37	42	46	37	38	42
	Total	442	477	503	524	469	485	507
JeollaBuk–Do	Spring	196	212	223	228	211	218	227
	Summer	19	22	25	30	22	24	29
	Fall	12	13	15	17	13	13	15
	Total	227	247	263	275	246	255	271
JeollaNam–Do	Spring	252	257	270	277	257	265	274
	Summer	28	28	33	35	29	33	33
	Fall	6	7	7	8	7	7	7
	Total	286	292	310	320	293	305	314
Kungsanbuk–Do	Spring	308	321	337	351	326	337	351
	Summer	68	74	80	89	74	78	85
	Fall	45	48	51	55	48	50	54
	Total	421	443	468	495	448	465	490
Kungsannam–Do	Spring	240	252	264	277	253	265	276
	Summer	60	68	72	83	66	71	79
	Fall	58	62	65	71	62	64	70
	Total	358	382	401	431	381	400	425

CO_2 at a rate of 1% per year (compounded) until year 2100 (IPCC Data Center 2004). The CCSR/NIES model is a coupled ocean–atmosphere model that consist of the CCSR/NIES atmospheric GCM and a thermodynamic sea–ice model. The spatial resolution is T21 spectral truncation (roughly 5.6° latitude/longitude) and 20 vertical levels for the atmospheric part, and roughly 2.8° horizontal grid and 17 vertical levels for the oceanic part. The increase in greenhouse gases is based on the historical data recorded from 1890 to 1990 and is increased by 1%/yr (compounded) after 1990 (IPCC Data Center, 2004).

Future daily weather scenarios were created by applying temperature and precipitation anomalies from the GCM scenarios based on the 1994 to 2003 observed daily weather following the methods of Stocks *et al.* (1998). A monthly temperature average was created using GCM for each time slice (2010–2039 and 2070–2099). To create a temperature anomaly for each month, the monthly average temperatures for what we defined as the current time slice (1994–2003) were subtracted



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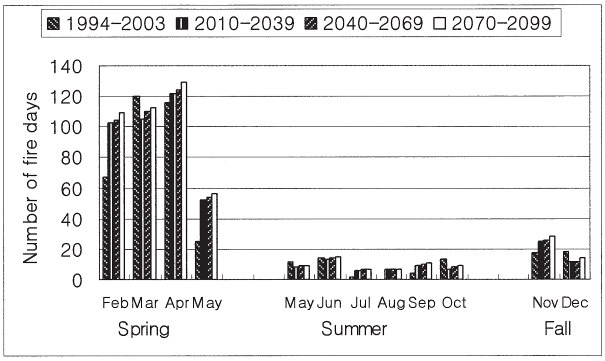


B

Fig. 3. The average predicted number of fire days by logistic regression model of the simulated weather data from CCCma GCM (A) and CCSR/NIES GCM (B) according to fire sub–seasons (each month) in Gyeonggi–DO. The month of May appears in two sub–seasons because end of day of the Spring sub–season is May 15 and the first day of Summer sub–seasons is May 16.

from the average temperature for the same month in each future time slice. In a similar manner a monthly precipitation anomaly was created by dividing the monthly precipitation average for the future time slice by the average precipitation from the current time slice.

Monthly anomalies were created for each of the grid points for each GCM and for each time slice. These monthly anomalies were then used along with inverse distance weighting interpolation to estimate an anomaly value at each of the locations of the original weather stations used in the fire occurrence analysis (the 1994 to 2003 daily weather dataset). Future fire weather scenarios were created by adding ($T_{future} = T_{OBS} + \Delta T_{GCM\ (month)}$) the monthly temperature anomaly from each GCM time slice to each observed daily temperature (1994–2003) and multiplying ($P_{future} = P_{OBS} \times \Delta P_{GCM\ (month)}$) the observed daily precipitation by the monthly precipitation anomaly. The relative humidity and wind speed were left unchanged. Each new future fire weather scenario was then used with the FWI System (Van Wagner 1987) to calculate a set of daily FFMC values. We calculated the FFMC from current weather conditions for daily forest fire occurrence probability analysis and simulated new weather conditions in of the each nine study areas and this new FFMC values are considered to be representative for the each nine districts (Table 5).

RESULT AND DISCUSSION

Average temperature and precipitation during the three sub–seasons that Spring, Summer and Fall seasons in nine study areas shows from two GCM models (Table 4). Using the CCCma GCM, the average temperature increase is projected to be 1.2°C for 2010–2039, 1.9°C for 2040–2069 and 3.2°C for 2070–2099. The average precipitation increase is projected to be 0.04 mm per a day for 2010–2039, 0.0 mm for 2040–2069 and 0.5 mm for 2070–2099. In the case of the CCSR/NIES GCM, the average temperature increase is projected to be 1.4°C for 2010–2039, 2.0°C for 2040–2069 and 3.9°C for 2070–2099. The average precipitation increase is projected to be 0.3 mm for 2010–2039, 0.4 mm for 2040–2069 and 0.6mm for 2070–2099.

With the CCCma and CCSR/NIES GCM models, the average temperature increase is projected to be 20–24% in Spring sub–season, 12–16% in the Summer sub–season and 34–37% in the Fall sub–season and the average precipitation increase is projected to be 0.5–13% in the Spring sub–season, 22–23% in the Summer sub–season and 20%–14% in the Fall sub–season in 2070–2099 (Table 4).

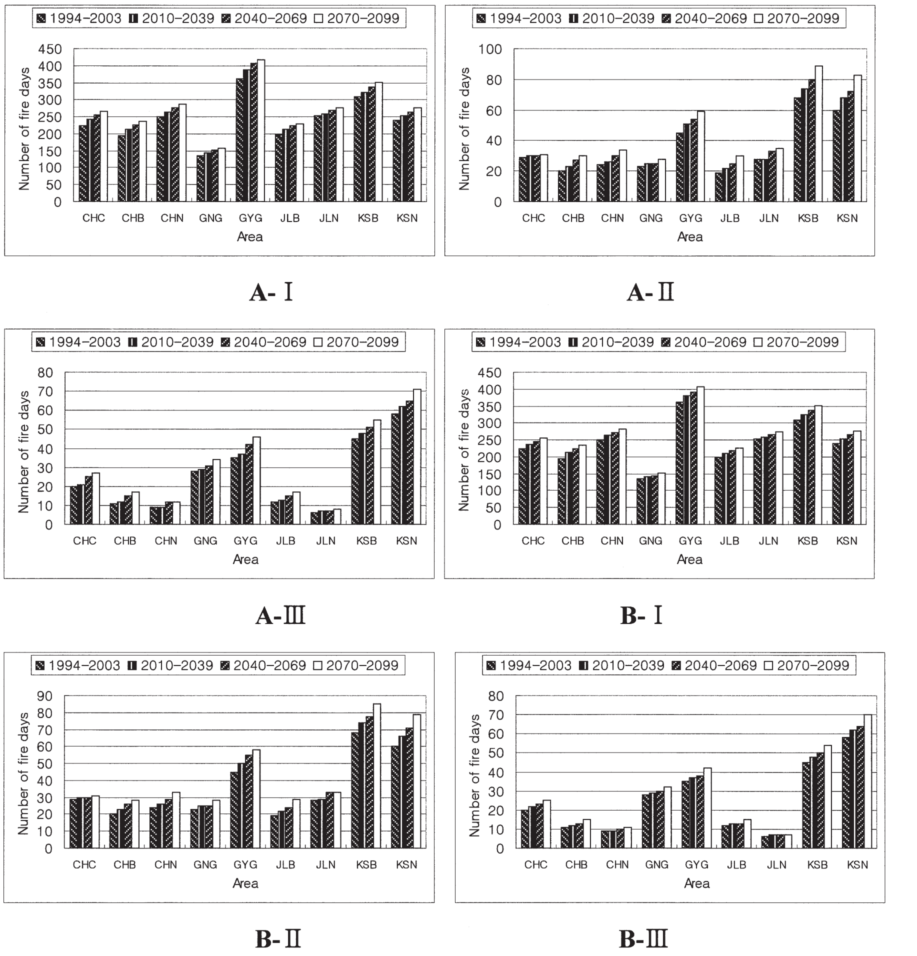
Table 5 shows the projected FFMC values for each of the nine study areas using the current weather (1994–2003). With both GCM models, the FFMC is projected to increase in the future.

Table 6 shows the predicted number of fire days in the future climate obtained by applying the logistic model to the future climate projections. Using the CCCma GCM model, the number of fire days in 2070–2099 increases about 10–23% in the Spring compared with current period (1994–2003), 7–58% in the Summer and 21–55% in the Fall fire sub–seasons.

Using CCSR/NIES GCM, the number of fire days in 2070–2099 increases about 9–21% in the Spring sub–season, 7–53% in the Summer sub–season and 14–36% in the Fall fire sub–season.

The Gyeonggi–Do study area is the most heavily populated of the study areas as it contains about 1/4 of Korea population and has more fires than the other study areas of South Korea. Figure 3 shows the predicted number of people–caused fire days during each sub–season in the Gyeonggi–Do study area. Using the CCCma GCM model, the number of fire days increases 16% in the Spring, 31% in the Summer and 31% in the Fall sub–season. Using the CCSR/NIES GCM model, the number of fire days increases 12% in the Spring, 29% in the Summer and 20% in the Fall sub–season. The observed number fire days and predicted number of fire days from CCCma GCM model and CCSR/NIES GCM model indicate most fire in the spring seasons.

Figure 4 shows the predicted average number of people–caused fire days obtained by using the logistic regression models. With the both two models, the predicted number of fire days were much more occurrence in Gyeonggi–Do area than other area in the spring sea-



CHC-Chuncheon, CHB- Chungcheongbuk-Do, CHN- Chungcheongnam-Do, GNG-Gangneung, GYG-Gyeonggi-Do, JLB-JeollaBuk-Do, JLN-JeollaNam-Do, KSB-Kyungsanbuk-Do, KSN-Kyungsannam-Do

Fig. 4. The average predicted number of fire days and number of fires of people–caused fire from regression model by simulated weather data on the each study locations from the CCCma models (A) and the CCSR/NIES models (B) (I: Spring sub–season, Ⅱ: Summer sub–season, Ⅲ: Fall sub–season).

son, but in the case of summer season and fall season, predicted number of fire days were much occurrence of fire in the Kyungsanbuk–Do and Kyungsannam–Do than other study area.

The result of this study was similar as the previous research – Martel *et al.* (2003) predicted that the people caused fire occurrence in Ontario, Canada, would increase across the province of around 50% or more by the end of the 21st century. Because the prediction of fire occurrence was effected by the variation of the land use, the vegetation, human activity, forest management policy and etc., more factors related this part should be studied further.

CONCLUSION

Climate change is expected to lead to an increase in temperature and decreases or slight increases in precipitation in South Korea. Daily fire occurrence prediction models were developed for each of nine study areas in South Korea. In the both the CCCma and CCSR/NIES GCM models, average temperature is increase 20–24% in Spring sub–season, 12–16% in the Summer sub–season and 34–37% in Fall sub–season for 2070–2099 and average precipitation per a day increase 0.5–13% at Spring sub–season, 22–23% in the Summer sub–season and Fall sub–season was range from –20% – + 14% for 2070–2099 compared with current period (1994–2003).

In the case of CCCma GCM models, number of fire days in 2070–2099 compared to current period increase about 10–23% in the Spring sub–season, 7–58% in the Summer sub–season, 21–55 in the Fall sub–season. In the case of CCSR/NIES GCM models, number of fire days in 2070–2099 compared to current period increase about 9–21% in the Spring sub–season, 7–53% in the Summer sub–season, and 14–36% in the Fall sub–season.

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