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An Attempt of Estimation of Annual Fog Frequency over Gyeongsangbuk-do of Korea Using Weather Generator MM5

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Abstract

In this study an attempt has been made to predict the annual foggy days over Gyeongsangbuk-do of Korea, using the regional mesoscale model (MM5). The annual meteorological conditions are simulated, and the annual and seasonal foggy days are predicted from the simulated results based on the seasonal and spatial information of the observed meteorological characteristics for fog occurrence such as wind speed, relative humidity, and temperature. Most of observed inland fog over Gyeongsangbuk-do occurs in autumn under the meteorological conditions such as a calm, a high temperature range (above 10°C), and a high relative humidity (above 85%). The predicted results show the various foggy days, about 10~60 days, depending on the season and the site locations. The predicted annual foggy days at inland sites are about 30~60 days, but at coastal sites, about 10~20 days. Also, a higher frequency of fog occurrence at inland sites is shown in autumn (about 60% of the annual foggy days). Otherwise, a higher frequency of fog occurrence at coastal sites is shown in summer (about 60% of the annual foggy days), unlike the inland. These annual foggy days and their seasonal variations agree reasonably well with the observed values. It can be concluded that it is possible to predict the occurrence of annual or seasonal foggy days by MM5.

Keywords: Annual and seasonal foggy days, Meteorological characteristics, Numerical prediction, MM5

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1. Introduction

Of late, a lot of change has taken place in the atmosphere with the development of industries and growth of population. This change has affected human health as well as the economy of the country. Korean Peninsula experiences various weather phenomena. This is because of the complex terrain and the sea around the country. One of the most important phenomena which affect the country is fog. Many fields of activities are affected by fog, in particular the aviation and the road transport.1,2) The socioeconomic impact and significance of fog have been documented by many authors.3-5) The aircraft operations and marine activities at the airports and harbors are often slowed or delayed due to fog thereby causing a significant financial loss.6)

Many studies have been devoted to the estimation and prediction of fog. Roach (1976)7), Gerber (1981)8), and Leipper (1994)9) have conducted statistical analysis and field investigations of fog and meteorological conditions. They have shown that fog occurs when the lower part of the atmosphere becomes saturated under specific meteorological conditions (e.g., radiation fog; clear skies, weak wind, large amount of moisture in the lower layers and stability of the atmosphere). Roach et al. (1976)10), Brown and Roach (1976)11), and Koziara et al. (1983)12) have shown that the physical processes involved in the formation of a fog layer include thermal cooling, turbulent transport, and deposition of water on the soil. A number of numerical models have been developed for the prediction of fog.1,5,13,14) However, it is difficult to determine the exact causes of a particular type of fog and this makes forecasting of fog more difficult. Not only does the formation of fog depend on the meteorological condition but also geographical and physical condition of the regions.15-17) Some other meteorological phenomena also show similar characteristics as those of fog. As an example high relative humidity and calm winds are also associated with light rain or formation of frost. It is, therefore, necessary to find out some practical method of prediction of occurrence of fog considering meteorological conditions over the region.

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In this study, an attempt has been made to predict annual fog occurrence using mesoscale meteorological model. The brief descriptions of data and experimental design used in this study are given in Section 2. In Section 3, the actual meteorological conditions are investigated for foggy days over Gyeongsangbuk-do, Korea with the observed data and then annual meteorological simulation experiment is performed. A numerical method based on atmospheric phenomena has been developed for the prediction of annual fog occurrence. The results and conclusion have been presented in the Section 4.

2. Methodology

Model simulation is performed with a three-dimensional meteorological model, MM5 (Pennsylvania State University/National Center for Atmospheric Research mesoscale model, fifth generation).[18-22] The multiple nesting (two-way interacting nested grid system) by dynamic downscaling[23] is used for a regional meteorological simulation. MM5 with 27 km horizontal resolution and 18 layers of sigma-coordinate in vertical is nested. Fig. 1 shows in MM5 nesting domains (a) East Asia (125 grid × 10^5 grid, grid distance = 27 km), (b) South Korea (82 grid × 82 grid, grid distance = 9 km), and Gyeongsangbuk-do (64 grid × 64 grid, grid distance = 3 km). The points in Fig. 1(c) represent the monitoring stations of regional meteorological conditions. In addition, Gyeongsangbuk-do domain is equally divided into 9 sectors (S1~S9 in Fig. 1(c)) for studying fog occurrence as a regional meteorological phenomenon. Also, the simulation is carried out for a period of one year to discuss the annual fog occurrence in the region, of interest.

Based on NetCDF global data (Network Common Data Form, NCEP/NCAR reanalysis pressure level data from NOAA/CDC)[24] from 1990 to 1999, the annual meteorological characteristics of the simulation region are investigated and used for MM5 initial boundary conditions. Also, the annual and seasonal mean values of the observed fog and meteorological conditions from 1990 to

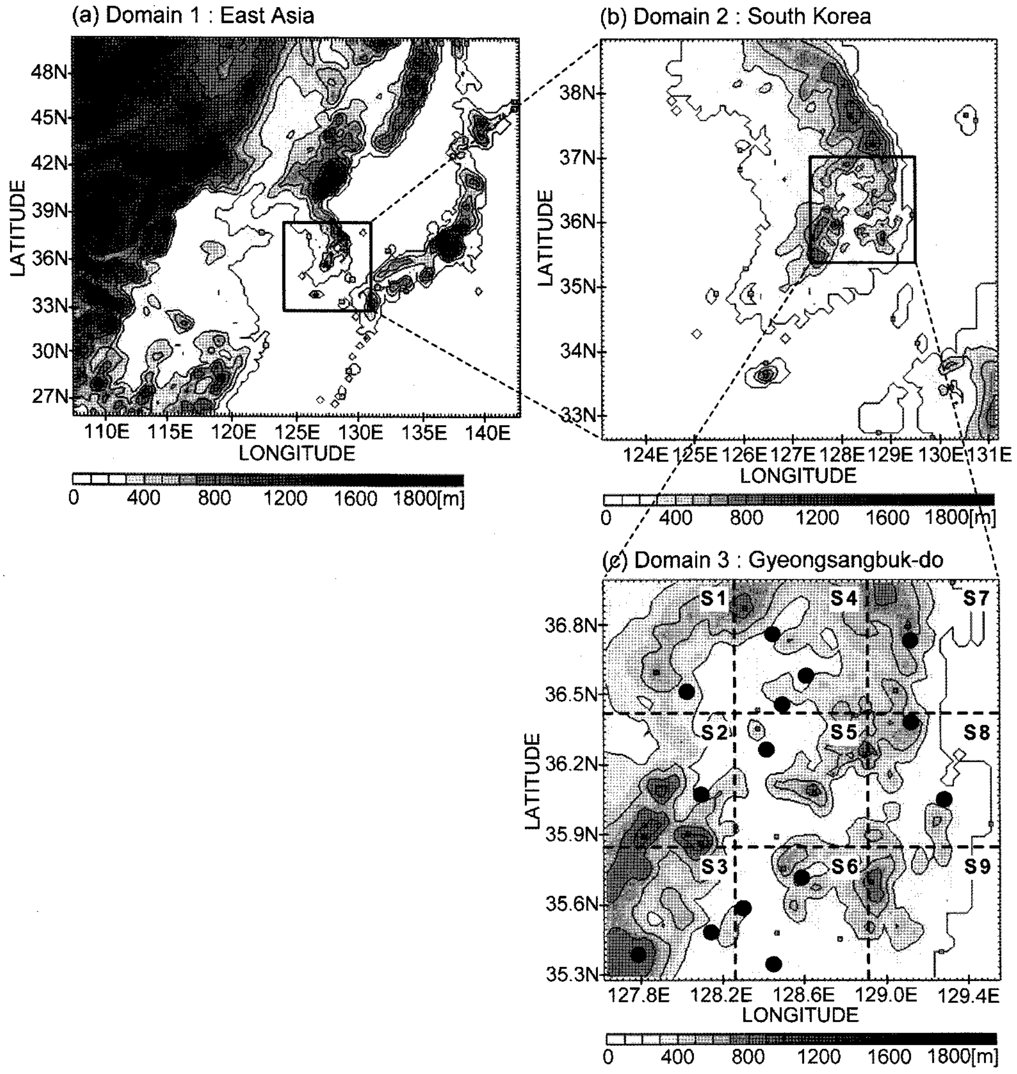

Fig. 1. Site locations and simulation areas. (a), (b), and (c) represent the MM5 nesting domains of East Asia, South Korea, and Gyeongsangbuk-do, respectively. The points in (c) Domain 3 are meteorological monitoring stations. S1~S9 represent 9 divided sectors. The shading indicates the height [m] of topography.

1999 at the monitoring stations in Fig. 1(c) (supported by Korea Meteorological Administration, KMA) are used to investigate characteristics of foggy days over Gyeongsangbuk-do, and to predict annual and seasonal fog occurrence from the simulation results.

3. Results and Discussion

3.1. Analysis of Observed Data

The observed annual foggy days and seasonal frequency were investigated at 9 sectors Fig. 1(c), and the results are shown in Table 1. The spatial mean observed values for each sector are calculated with the values of the involved monitoring stations. The annual fog occurrence was more then 30 days for S1~S6 where as for S7 and S8 it was 13.7 and 8 days, respectively. There is no regional monitoring station at S9. These results showed that the fog at inland (S1~S6) occurred more frequently than at the coastal areas (S7 and S8).[25] Also, Table 1 shows the percentage of occurrence of seasonal fog is more than 40% in autumn at S1-S6, but 80.1% and 68.0% in summer at S7 and S8 respectively. The radiation fog at inland stations (S1~S6) occurs frequently in the later part of summer and autumn over the Korean peninsula. This is due to higher radiation cooling and presence of large amount of moisture after the rainy season.[9,10] A lot of research has been done to study the fog over coastal region and sea fog in summer by Byers (1959)[26], Seung et al. (1990)[27], Croft et al. (1997)[5], Cho et al. (2000)[25], and Lewis et al. (2004)[28]. According to their researches, the occurrence of the summer coastal fog at S7 and S8 may be attributed to the following: The first is the steam fog caused by the advection of the northeast cold air current on the Korea East Sea due to the extension of Okhotsk High. The second is the advection fog caused by cooling and saturation of warm air-mass on cold sea surface. And the last is the frontal fog caused by the supply of enough water vapor due to the movement of low-pressure system and the advection of cold air behind a cold front.

The meteorological factors (such as wind speed, relative humidity, temperature, dew point temperature etc.) for the occurrence of fog were investigated, and the results are shown in Table 2. For the first factor (Wind Speed), the most of fog at S1~S6 occurs under the calm condition (< 1.0 m/s), and it suggests that the higher frequency of the radiation fog occurrence may be due to stable atmospheric condition.[7,10,29] The coastal fogs at S7 and S8 occur for 1.0~3.5 m/s wind speed, and it can be affected by the advection fog and water vapor from the Korea East Sea.[9,30] For the second factor, the fog occurrence is largely influenced by relative humidity above 85% as a whole. Especially, the coastal fog occurs for a higher relative humidity (> 90%) than over inland.[25,26,28,31] For the third factor (Temperature), a drop in the range of daily temperature from the maximum temperature of the day before foggy day (T_H) to the minimum temperature at foggy day (T_L) exerts a significant influence on fog occurrence. T_H-T_L presents 10°C~15°C at all sectors. Also, the difference between dry bulb temperature (T) and dew point temperature on foggy days (T_d), T- T_d, is below 2°C at all sectors, and it shows that the probability of occurrence of fog is very high when the dry bulb temperature is close to dew point temperature.[25]

3.2. Prediction of Annual Fog Occurrence

The annual meteorological characteristics over Gyeongsangbuk-do of Korea were predicted by MM5 model. Based on the meteorological characteristics for fog occurrence (Table 2), the occurrence of seasonal and annual fog was investigated with the simulation results. Fig. 2 shows the spatial distribution of predicted seasonal foggy days. During the autumn season (Fig. 2(c)), the foggy days are around 12, and more than in other seasons. Especially, the foggy days at inland area (left side and middle of the simulation area) are about 20~30 days, and more than at coastal area (right side of the simulation area). During the spring and winter seasons (Fig. 2(a, d)), the foggy days at inland are also more than those at coastal area, but the foggy days are relatively less (below 10 days) than other seasons. However, during the summer season (Fig. 2(b)), the frequency of occurrence of fog over the coastal areas is either higher or equal than that over the inland. The predicted annual foggy days were shown in Fig. 3. As a whole, the annual foggy days over the inland areas (about 30~60 days) are more than that over the coastal areas (about 10~20 days). These seasonal and annual trends of the predicted results over Gyeongsangbuk-do of Korea agree reasonably well with the observed values shown in Table 1.

The predicted values are compared with observations taken

Table 1. Observed annual and seasonal fog occurrences over Gyeongsangbuk-do

Sectors	Frequency of seasonal fog occurrence [%]				Annual foggy days
	Spring	Summer	Autumn	Winter	
S1	16.6	32.4	40.2	10.8	34.4
S2	12.3	27.7	52.4	7.6	32.8
S3	17.3	25.9	49.0	7.8	48.0
S4	16.6	34.0	40.7	8.7	35.8
S5	14.8	25.8	49.9	9.5	39.9
S6	17.1	24.6	46.4	11.9	30.6
S7	16.1	80.1	2.4	1.4	13.7
S8	23.0	68.0	5.0	4.0	8.0
S9			No data		

Table 2. Meteorological factors for fog occurrences over Gyeongsangbuk-do

Meteorological characteristics	Sectors	Spring	Summer	Autumn	Winter	Annual mean values
Wind speed [m/s]	S1	0.56	0.45	0.59	0.70	0.58
	S2	0.53	0.44	0.42	0.43	0.46
	S3	0.41	0.42	0.32	0.28	0.36
	S4	0.61	0.48	0.53	0.75	0.59
	S5	0.40	0.60	0.40	0.50	0.48
	S6	0.80	1.18	0.79	0.71	0.87
	S7	3.36	2.19	1.15	1.00	1.93
	S8	1.35	1.11	3.44	0.75	1.66
	S9			No data		
Relative humidity [%]	S1	87.7	89.3	87.1	90.9	88.8
	S2	87.9	88.3	90.3	91.9	89.6
	S3	88.4	85.1	86.1	85.8	86.4
	S4	90.2	89.6	89.3	88.0	89.3
	S5	90.3	90.4	88.6	89.5	89.7
	S6	90.0	89.9	89.1	90.9	89.9
	S7	92.4	92.7	94.5	97.0	94.2
	S8	91.7	90.6	92.9	94.5	92.4
	S9			No data		
T_H-T_L [°C]	S1	13.1	11.8	15.0	12.7	13.2
	S2	13.4	12.9	15.2	11.4	13.2
	S3	12.2	15.5	13.7	12.1	13.4
	S4	12.8	11.2	14.1	11.0	12.3
	S5	13.4	10.7	14.4	13.3	13.0
	S6	13.1	11.8	15.5	13.7	13.6
	S7	15.3	13.2	14.8	15.2	14.6
	S8	15.3	14.2	11.3	13.5	13.6
	S9			No data		
T-T_d [°C]	S1	1.90	1.95	1.90	1.50	1.81
	S2	1.34	1.58	1.25	1.48	1.41
	S3	1.49	1.51	1.28	1.49	1.44
	S4	1.50	1.70	1.61	1.20	1.50
	S5	1.30	1.70	1.40	1.40	1.45
	S6	1.32	1.49	1.20	1.27	1.32
	S7	1.28	1.21	0.90	1.30	1.17
	S8	1.35	1.72	1.20	0.80	1.27
	S9			No data		

T : Dry bulb temperatures of fog occurrence
T_H : Maximum temperature of the day before foggy day
T_d : Dew point temperature of foggy day
T_L : Minimum temperature of foggy day

at the monitoring stations to verify the accuracy of the predicted results. Fig. 4 shows the comparison between the observed seasonal frequency of occurrence of fog with predicted ones at each sector (S1~S9). Also, the spatial mean values of observed and predicted annual foggy days for each sector are given in each panel of Fig. 4. Furthermore, the mean observed values are calculated with the values at involved monitoring stations in each sector. There is no regional monitoring station at S9. The annual foggy days are predicted about 30~40 days at inland stations (S1~S6), and 10~20 days at coastal areas (S7 and S8). Also, the inland fogs are predicted to be about 20% and 60% in summer and autumn, respectively. The lower frequency (about 10%) of fog occurrence at inland sites is shown in spring and winter. The predicted frequency of occurrence of coastal fogs is about 60% in summer. These predicted results for the annual foggy days and the seasonal variations at all sectors agree reasonably well with the observed ones as a whole. The correlation between predicted and observed data using information in Fig. 4 is 0.93 (shown in Fig. 5). However, the frequency of occurrence of fog in spring and summer is lower and higher in autumn and winter, compared to the observed ones. Therefore, the detailed investigation of the meteorological conditions for seasonal or monthly fog occurrence is necessary and will continue to improve the accuracy of the predicted results.

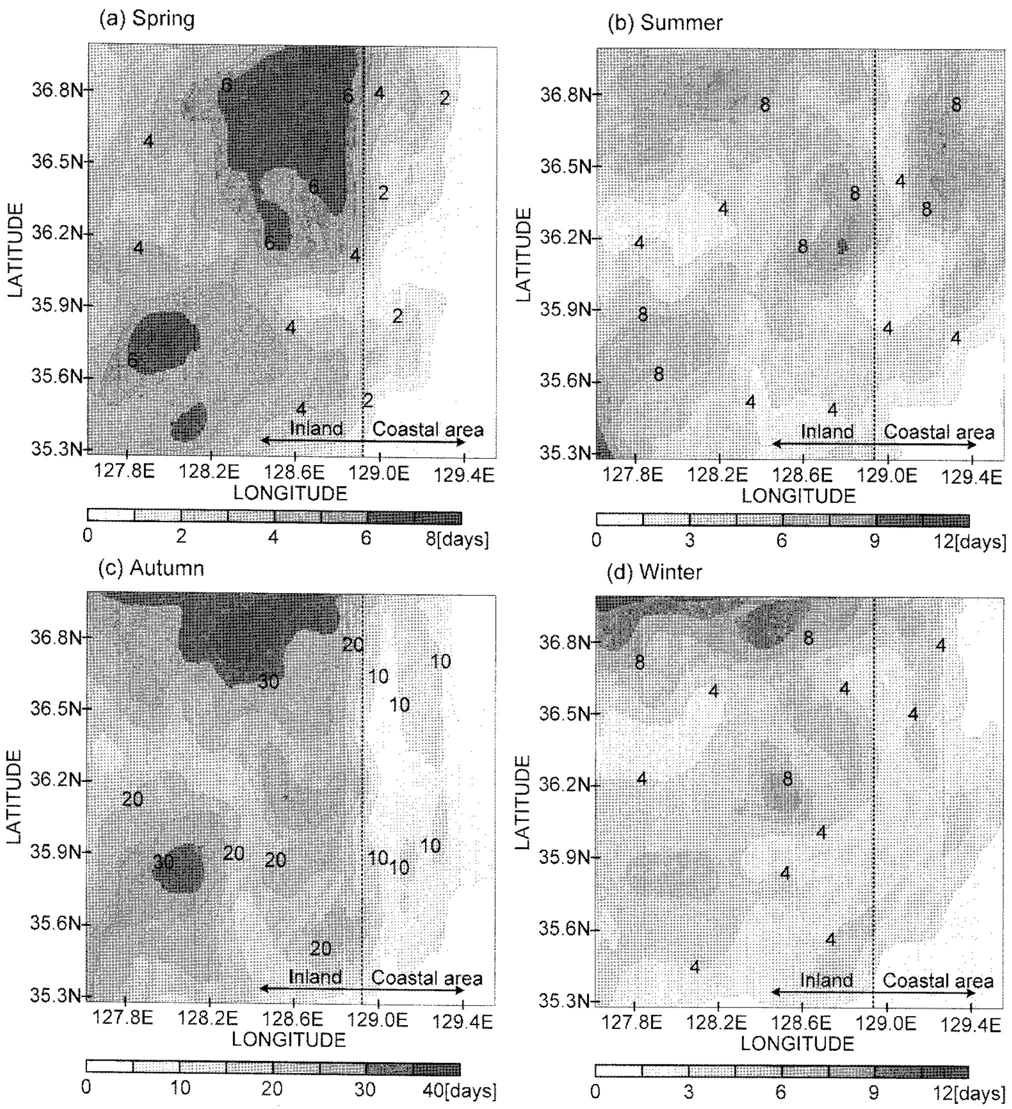

Fig. 2. Spatial distributions of the predicted foggy days during (a) Spring, (b) Summer, (c) Autumn, and (d) Winter over Gyeongsangbuk-do of Korea. The shading indicates the foggy days.

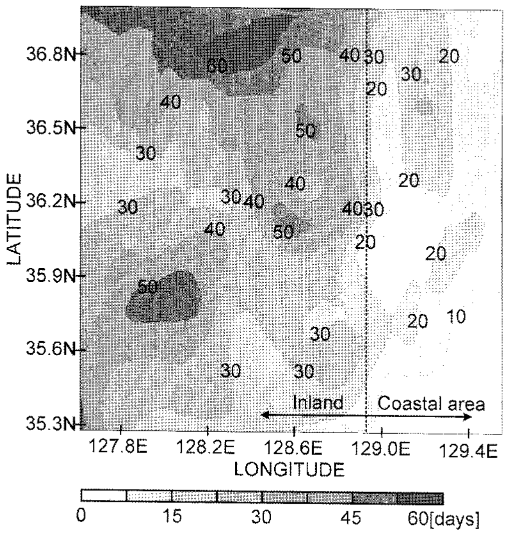

Fig. 3. Spatial distributions of the predicted annual foggy days over Gyeongsangbuk-do of Korea. The shading indicates the foggy days.

4. Summary and Conclusions

This paper suggests that it is possible to predict the annual occurrence of fog over Gyeongsangbuk-do of Korea, from a mesoscale meteorological simulation by MM5 model. Firstly, the observed foggy days and meteorological conditions favorable for occurrence were investigated. The higher frequency of fog occurrence at inland is shown in autumn (about 40~50% of the annual foggy days), under the meteorological conditions such as calm wind (below 1.0 m/s wind speed), a higher T_H-T_L (10~15°C), and sufficiently high relative humidity (above 85%). Most of the coastal fogs occur in summer, normally advection fog (60~80%), and it may be influenced by the sea breeze (1.0~3.5 m/s wind speed) and moisture from the east sea (above 90% relative humidity). Secondly, the annual meteorological simulation was performed, and the annual and seasonal fog occurrence was predicted with the results of the first step. The foggy days at inland areas were predicted about 30~60 days, and more than at coastal area (about 10~20 days). Higher frequency for

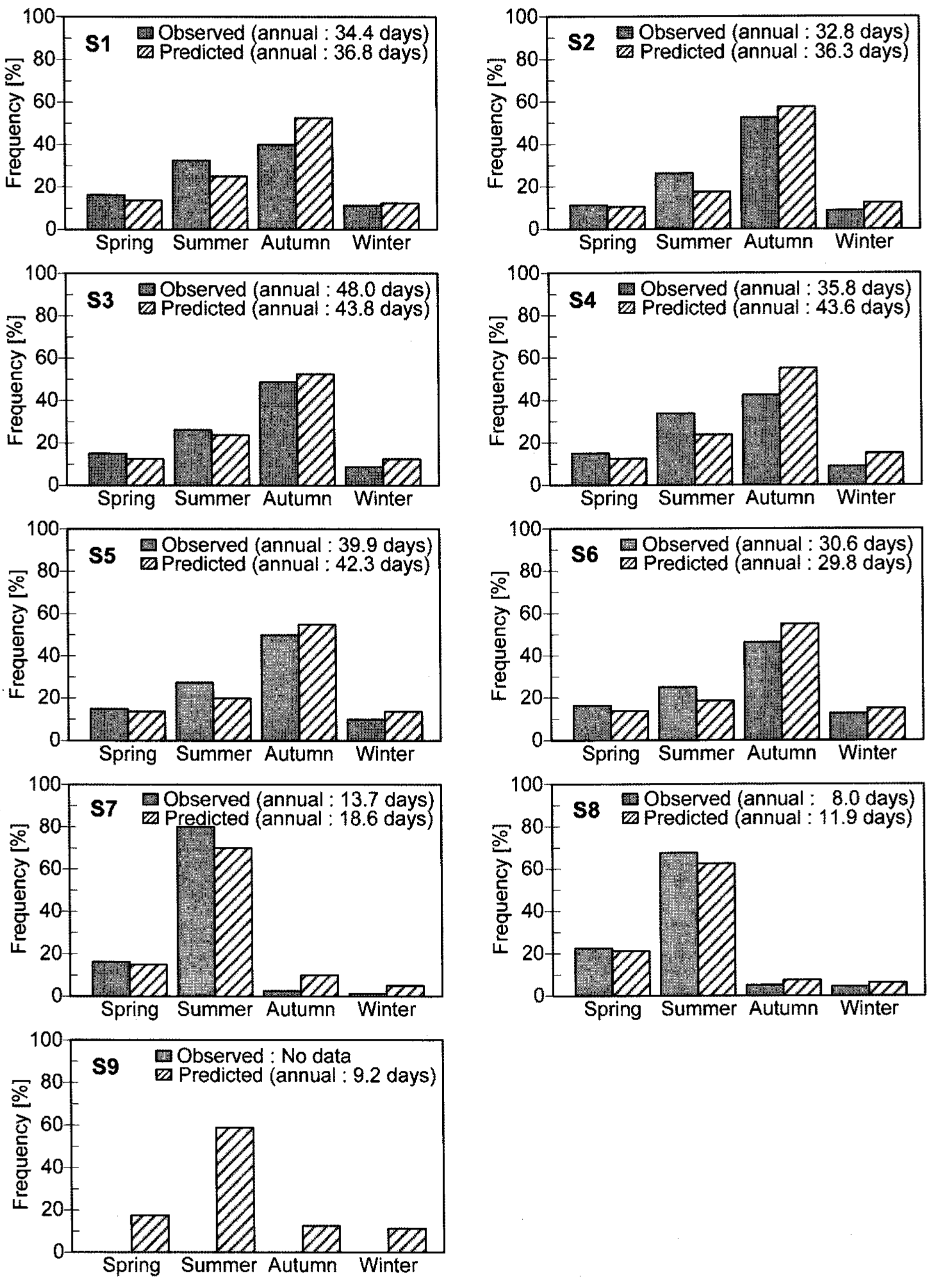

Fig. 4. Comparison of observed (■) seasonal frequency of occurrence of fog with predicted (▨) ones. S1~S9 represent the sectors shown in Fig. 1(c). The observed and predicted annual foggy days for each sector are also given in each panel.

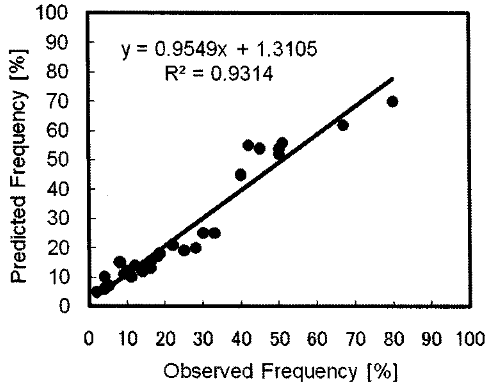

Fig. 5. Correlation between predicted and observed seasonal frequency of occurrence of fog using information in Fig. 4.

over the inland and coastal areas was predicted as 60% of the annual foggy days in autumn and summer, respectively. The number of annual foggy days and the seasonal variations of the predicted results over Gyeongsangbuk-do of Korea agree reasonably well with the observed values. Therefore, this is a simplified and practical method for prediction of the frequency of occurrence of the annual and seasonal fog.

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