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Fog Sensing over the Korean Peninsula Derived from Satellite Observation of MODIS and GOES-9

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Abstract : Seasonal threshold values for fog detection over the ten airport areas in the Korean Peninsula have been derived, using the satellite-observed data of polar-orbit (Aqua/Terra MODIS) and geostationary (GOES-9) during two years. The values are obtained from reflectance at 0.65μm ($R_{0.65}$) and the difference in brightness temperature between 3.7μm and 11μm ($T_{3.7-11}$). In order to examine the discrepancy between the threshold values of two kinds of satellites, the following parameters have been analyzed under the condition of daytime/nighttime and fog/clear-sky, utilizing their simultaneous observations over the Seoul Metropolitan Area. The parameters are the brightness temperature at 3.7μm ($T_{3.7}$), the temperature at 11μm (T_{11}), and $T_{3.7-11}$ for day and night. The $R_{0.65}$ data are additionally included in the daytime. The GOES-9 thresholds over the seven airport areas except the Cheongju airport have revealed the accuracy of 50% in the daytime and 70% in the nighttime, based on statistical verification for the independent samples as follows; FAR, POD and CSI. However, the accuracy decreases in the foggy cases with twilight, precipitation, short persistence, or the higher cloud above fog.

Key Words : Fog detection, MODIS, GOES-9, infrared threshold, reflectance.

1. Introduction

Fog detection has been a considerable concern in the fields of ground-based meteorological measurements, remote sensing, and numerical modeling. It is because fog plays an important role in economic and ecological problems, particularly in terms of traffic safety due to the reduction of visibility, the exchange of water and pollutants, and hydrological cycle in agriculture (e.g., Underwood *et al.*, 2004; Cermak and Bendix, 2005). The fog detection by the help of satellite-observed data has been tried in many studies (e.g., Underwood *et al.*, 2004; Cermak and Bendix, 2005) using 0.65μm, 3.7 μm and 11μm channels of the AVHRR onboard the polar-orbit NOAA, and the geostationary GOES-series and GMS (e.g., Bendix, 2002). Polar-orbiting and geostationary satellites provide us with almost

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real-time fog observation over the wide areas. In particular, since a Korean geostationary multipurpose satellite of Communication, Oceanography and Meteorological Satellite (COMS) is supposed to be launched in 2008, the fog detection from the COMS data is an important issue in the Korean Meteorological Agency (KMA) weather forecast. The purpose of this study is to derive and verify the threshold values for fog detection over the Korean Peninsula, based on satellite observations of polar-orbit (MODIS) and geostationary (GOES-9) during two years.

2. Data and Method

We have used the MODIS data of visible (0.62-0.67μm; 0.65μm), near-infrared (3.66-3.84μm; 3.7μm), and infrared (10.78-11.28μm; 11μm) channels over the Seoul Metropolitan Area (SMA; 125.7-127.2 E, 37.2-37.7 N) during the period from January 2003 to December 2004, and the GOES-9 data in the three corresponding channels at ten airports in the Korean Peninsula during the period from June 2003 to May 2005. The data have been utilized to derive the threshold values for fog detection from two types of satellite observations and to verify their results with ground observations.

3. Results

1) Threshold values for fog detection

Table 1 shows seasonal threshold values for fog detection, which have been derived from satellite observations of GOES-9 and MODIS, and from ground observations of fog and clear-sky (or cloud amount) at the Incheon and Kimpo airports over the SMA during two years. Here the threshold values of

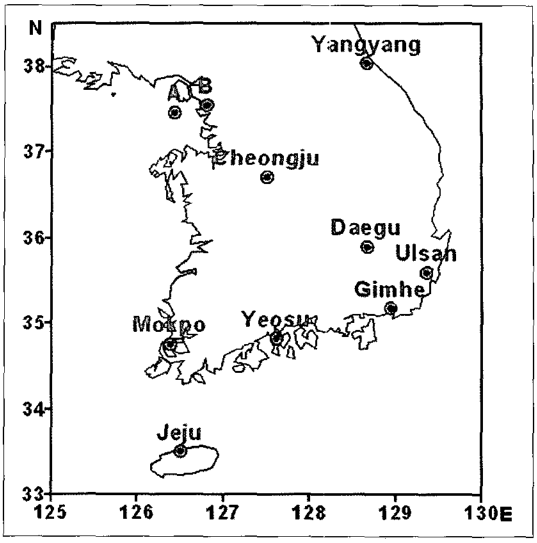

Fig 1. Location of meteorological stations at ten airports in the Korean Peninsula.

visible ($Th_{0.65}$) and infrared ($Th_{3.7-11}$) for fog detections have been calculated from the data of reflectance ($R_{0.65}$) and the difference in brightness temperature between 3.7μm and 11μm ($T_{3.7-11}$). The synoptic situation that cloud amount at the airport is less than 0.1 has been classified into the clear-sky, in contrast with fog case. In Table 1, the values in parentheses were presented for the MODIS thresholds, compared with the GOES-9 thresholds. The values at the two airports are applied to the fog detection at other eight airports (Yangyang, Cheongju, Daegu, Ulsan, Gimhae, Mokpo, Yeosu, and Jeju) in order to examine their validation over other independent areas (Fig 1). Seasonal infrared threshold values (i.e., $Th_{3.7-11}$) of GOES-9 (MODIS) are 7.25~9.70K (21~23.5K) during daylight, and -0.91~-0.40K (2.6~3.6K) during night (Table 1). The $T_{3.7-11}$ and $R_{0.65}$ values during daytime fog were higher than those during daytime clear-sky, while the $T_{3.7-11}$ during nighttime fog was lower than that during nighttime clear-sky. The fog particles during nighttime fog tend to lower $T_{3.7-11}$ values, compared to atmospheric gases during clear-sky. It was because

Table 1. Seasonal average values of the GOES-9 brightness temperature difference ($T_{3.7-11}$) between 3.75 μm and 11 μm, and the $T_{3.7-11}$ threshold ($Th_{3.7-11}$) values for fog detection during daytime fog (DF), daytime clear (DC), nighttime clear (NC), and nighttime fog (NF) over two 20 km×20 km areas of the Incheon (126.43 E, 37.47 N) and Kimpo (126.48 E, 37.33 N) airports for the period from June 2003 to May 2005. The values of GOES-9 reflectance at 0.65 μm ($R_{0.65}$) and the $R_{0.65}$ threshold ($Th_{0.65}$) are additionally used for daytime fog detection. The number (N) of observations and their standard deviations (σ) are also given. The values in parentheses stand for the MODIS thresholds. The units of $R_{0.65}$ and $T_{3.7-11}$ are % and K, respectively.

	DF	$Th_{0.65}$	DC	DF		$Th_{3.7-11}$	DC		NC		$Th_{3.7-11}$	NF	
	$R_{0.65}\pm\sigma$		$R_{0.65}\pm\sigma$	$T_{3.7-11}\pm\sigma$	N		$T_{3.7-11}\pm\sigma$	N	$T_{3.7-11}\pm\sigma$	N		$T_{3.7-11}\pm\sigma$	N
Spring	33.72 ±13.90	10.0 (15.0)	4.31 ±1.69	22.73 ±4.67	4	7.25 (23.5)	2.63 ±2.64	16	0.03 ±0.33	18	-0.40 (3.4)	-2.25 ±2.42	11
Summer	33.36 ±11.85	10.70 (18.0)	6.30 ±1.47	14.06 ±2.80	3	8.15 (21.0)	4.18 ±1.53	10	1.02 ±0.81	18	-0.65 (3.6)	-1.61 ±0.36	6
Fall	9.50 ±0.00	9.40 (15.5)	8.03 ±2.76	11.65 ±0	1	9.70 (22.0)	4.70 ±2.54	7	-0.35 ±0.76	18	-0.91 (2.6)	-1.83 ±2.07	20
Winter	14.81 ±4.19	8.90 (11.0)	4.57 ±1.21	16.15 ±3.41	4	7.00 (21.5)	3.31 ±1.53	9	0.26 ±2.81	10	-0.72 (2.8)	-2.55 ±1.87	12
Annual	25.31 ±14.24	9.98 (14.9)	5.46 ±2.26	17.45 ±5.35	12	8.0 (22.0)	3.60 ±1.90	42	0.24 ±1.08	64	-0.67 (3.1)	-2.07 ±2.02	49

the emissivity of opaque water like fog particles was 1.0 at 11μm and 0.8~0.9 at 3.7μm (Anthis and Cracknell, 1999; Eyre *et al.*, 1984). The visible threshold values, only available for daylight are 8.9~10.7% in GOES-9 (11~18% in MODIS), and higher than the reflectance (3~10%) of sea surface (Moran and Morgan, 1994). The threshold values of visible and infrared vary with the factors of day/night, seasons and spatial resolution of satellite. However, the seasonal threshold values suffer from the lack of observations in spite of the two year data. The fog observations from ground and satellites are less during daylight than during night and particularly during daylight in fall.

2) Verification for fog detection

We perform statistical verification for the seasonal threshold values which have been derived from satellite observations of GOES-9 at Incheon and Kimpo airports by applying to the fog detection over the extensive area of eight airports. For the verification, the statistical method in Bendix *et al.* (2004, 2005) has been used in this study (Table A1). In the method,

Table A1. Contingency table for verification of fog detection.

		SYNOP	
		Fog	No Fog
GOES ($R_{0.65}$)	Fog	YY	YN
	No Fog	NY	NN

False Alarm Ratio: $FAR = \frac{YN}{YY+YN}$

Probability Of Detection: $POD = \frac{YY}{YY+NY}$

Critical Success Index: $CIS = \frac{YY}{YY+YN+NY}$

three indices indicating accuracy of fog detection are as follows; False Alarm Ratio (FAR), Probability Of Detection (POD), and Critical Success Index (CSI). The visible ($R_{0.65}$) and infrared ($T_{3.7-11}$) threshold values for daylight are FAR (~10%), POD and CSI (~30%) in Table 2. In other words, the accuracy of threshold values was more than 30% for fog detection. The accuracy in the Cheongju airport has been the lowest among eight airports for the independent samples. In this study, the data at the Incheon International and Kimpo airports were used for the dependent samples to derive threshold values for fog

Table 2. Contingency tables of three kind of GOES-9 data (Daylight $R_{0.65}$, Daylight $T_{3.7-11}$, Nighttime $T_{3.7-11}$), and verification scores for fog detection over the eight airport areas (20 km × 20 km) of the Korean Peninsula during the period from June 2003 to May 2005 for the independent samples. Here the 'SYNOP' in table means the observation at ground stations. The scores for cases of twilight fog are given in parentheses.

			SYNOP		Verification Scores
Day	GOES ($R_{0.65}$)		Fog	No Fog	FAR: 0.13(0.00)
		Fog	21(1)	3(0)	POD: 0.31(0.02)
		No Fog	46(47)	102(29)	CSI: 0.30(0.02)
			SYNOP		Verification Scores
Day	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.15(0.00)
		Fog	23(10)	4(0)	POD: 0.34(0.21)
		No Fog	44(38)	101(29)	CSI: 0.32(0.21)
			SYNOP		Verification Scores
Night	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.21(0.41)
		Fog	22(10)	6(7)	POD: 0.76(0.43)
		No Fog	7(13)	34(8)	CSI: 0.63(0.33)

Table 3. Same as in Table 2 except for seven airports, excluding the Cheongju airport.

			SYNOP		Verification Scores
Day	GOES ($R_{0.65}$)		Fog	No Fog	FAR: 0.09(0)
		Fog	21(1)	2(0)	POD: 0.51(0.04)
		No Fog	20(27)	77(17)	CSI: 0.49(0.04)
			SYNOP		Verification Scores
Day	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.14(0.00)
		Fog	19(9)	3(0)	POD: 0.46(0.32)
		No Fog	22(19)	76(17)	CSI: 0.43(0.32)
			SYNOP		Verification Scores
Night	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.25(0.5)
		Fog	18(6)	6(6)	POD: 0.78(0.35)
		No Fog	5(11)	28(5)	CSI: 0.62(0.26)

detection. Three kinds of probability indices for the airport are with respect to visible and infrared thresholds during day/night as follows; $R_{0.65}$ (FAR = 1, POD = 0, CSI =0), daylight $T_{3.7-11}$ (FAR = 0, POD = 0.13, CSI =0.13), and night $T_{3.7-11}$ (FAR = 0, POD = 0.67, CSI =0.67). Therefore, the threshold values ($R_{0.65}$ and $T_{3.7-11}$) during daylight are less accurate than those during night particularly in the Cheongju airport. In addition, when we have investigated the verification at seven airports except for the Cheongju airport, the accuracy for fog detection is ~50% during daylight and ~70% during night (Table 3).

4. Conclusion

We have derived the seasonal visible and infrared threshold values for fog detection using satellite data of polar-orbit (MODIS) and geostationary (GOES-9) during two years, and performed verification with respect to their values at ten airports in the Korean Peninsula. Also, unlike MODIS, the seasonal visible and infrared thresholds of GOES-9 are small during both daytime and nighttime because of its low spatial resolution. The discrepancy between their thresholds is probably due to different wavelength of channels, smoothing effect by different spatial resolution, and calibration errors. The threshold values which have been obtained from GOES-9 show the statistical verifications (FAR, POD, CSI) ~50% accuracy during daylight and ~70% during night at seven airports in Korean Peninsula except for the Cheongju airport. But the accuracy for fog detection is reduced under the condition of twilight(Tables 2-3), precipitation, short persistence, or the higher cloud above fog. Based on the purpose of COMS meteorological data processing system, we need to improve the thresholds using long-term and extensive area data to reliably apply them over the Korean Peninsula. In addition, the seasonal visible and infrared threshold values which have been deduced from satellite observations of MODIS and GOES-9 are inappropriate particularly for twilight, so that we need to develop a new fog algorithm for twilight.

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