FOG DETECTION OVER THE KOREAN PENINSULA DERIVED FROM SATELLITE OBSERVATIONS OF POLAR-ORBIT (MODIS) AND GEOSTATIONARY (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 0.65 ㎛ ($R_{0.65}$) and the difference in brightness temperature between 3.7 ㎛ and 11 ㎛ ($T_{3.7-11}$). 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 3.7 ㎛ ($T_{3.7}$), the temperature at 11 ㎛ (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 nine airport areas except the Cheongju airport have revealed the accuracy of 60% in the daytime and 70% in the nighttime, based on statistical verification 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 WORD: 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 0.65 ㎛, 3.7 ㎛ and 11 ㎛ 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 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 (0.62-0.67 ㎛; 0.65 ㎛), near-infrared (3.66-3.84 ㎛; 3.7 ㎛), and infrared (10.78-11.28 ㎛; 11 ㎛) 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

3.1 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 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 3.7 ㎛ and 11 ㎛ ($T_{3.7-11}$). 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, 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 7.25~9.70 K (21~23.5 K) during daylight, and –0.91~-0.40 K (2.6~3.6 K) 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 the emissivity of opaque water like fog particles was 1.0 at 11 μm and 0.8~0.9 at 3.7 μm (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.

3.2 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 ten airports. For the verification, the statistical method in Bendix et al. (2004) has been used in this study (Table A1). In the method, 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 (~40 %) in Table 2. In other words, the accuracy of threshold values was more than 40 % for fog detection.

The accuracy in the Cheongju airport has been the lowest among ten airports. 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 nine airports except for the Cheongju airport, the accuracy for fog detection is ~60 % 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) ~60 % accuracy during daylight and ~70 % during night at nine airports in Korean Peninsula except for the Cheongju airport. But the accuracy for fog detection is reduced under the condition of twilight, 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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REFERENCES

Anthis, A. I., and Cracknell, A. P., 1999. Use of satellite images for fog detection (AVHRR) and forecast of fog dissipation (METEOSAT) over lowland Thessalia, Hellas. International Journal of Remote Sensing, 20(6), pp. 1107-1124.

Bendix, J., 2002. A satellite-based climatology of fog and low-level stratus in Germany and adjacent areas. Atmospheric Research, 64, pp. 3-18.

Bendix, J., Cermak, J., and Thies, B., 2004. New perspectives in remote sensing of fog and low stratus-TERRA/AQUA-MODIS and MSG. Proceedings, The third international conference on fog. Fog Collection and Dew, Cape Town, South Africa, University of Pretoria, G2.1-G2.4.

Bendix, J., Thies, B., Cermak, J., Nauss, T., 2005. Ground fog detection from space based on MODIS daytime data - a feasibility study. Weather and Forecasting 20(6), pp. 989-1005.

Cermak, J., Bendix, J., 2005. A microphysics-based approach to fog/low stratus detection and discrimination using satellite data. COST 722 Midterm Workshop, Langen, Germany.

Eyre, J. R., Brownscombe, J. L., and Allam, R. J., 1984. Detection of fog at night using Advanced Very High Resolution Radiometer (AVHRR) imagery. Meteorological Magazine, 113, pp. 266-271.

Moran, J.M., and Morgan, M.D., 1994. Meteorology (4th ed.). Macmillan College Publishing Company, New York, USA, pp. 49-50.

Underwood, S. J., Ellrod, G. P., and Kuhnert, A. L., 2004. A multiple-case analysis of nocturnal radiation-fog development in the central valley of California utilizing the GOES nighttime fog product. Journal of Applied Meteorology, 43, pp. 297-310.

Table 1. Seasonal average values of the GOES-9 brightness temperature difference ($T_{3.7-11}$) between 3.75 ㎛ and 11 ㎛, 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 ㎞ × 20 ㎞ 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 ㎛ ($R_{0.65}$) 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	
	$R_{0.65}$±σ		$R_{0.65}$±σ	$T_{3.7-11}$±σ	N		$T_{3.7-11}$±σ	N	$T_{3.7-11}$±σ	N		$T_{3.7-11}$±σ	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

Table 2. Contingency tables of three kind of GOES-9 data (Day time $R_{0.65}$, Day time $T_{3.7-11}$, Night time $T_{3.7-11}$), and verification scores for fog detection over the ten airport areas (20 ㎞ × 20 ㎞) of the Korean Peninsula during the period from June 2003 to May 2005. Here the 'SYNOP' in table means the observation at ground stations and in this study is considered as a ground truth.

			SYNOP		Verification Scores
Day	GOES ($R_{0.65}$)		Fog	No Fog	FAR: 0.11
		Fog	33	4	POD: 0.42
		No Fog	46	142	CSI: 0.40
			SYNOP		Verification Scores
Day	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.10
		Fog	35	4	POD: 0.44
		No Fog	44	142	CSI: 0.42
			SYNOP		Verification Scores
Night	GOES ($T_{3.7-11}$)		Fog	No Fog	FAR: 0.09
		Fog	58	6	POD: 0.74
		No Fog	20	97	CSI: 0.69

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

			SYNOP		Verification Scores
			Fog	No Fog	FAR: 0.08
Day	GOES ($R_{0.65}$)	Fog	33	3	POD: 0.62
		No Fog	20	117	CSI: 0.59

			SYNOP		Verification Scores
			Fog	No Fog	FAR: 0.09
Day	GOES ($T_{3.7-11}$)	Fog	31	3	POD: 0.58
		No Fog	22	117	CSI: 0.55

			SYNOP		Verification Scores
			Fog	No Fog	FAR: 0.10
Night	GOES ($T_{3.7-11}$)	Fog	54	6	POD: 0.75
		No Fog	18	92	CSI: 0.69

Table A1. Contingency table for verification of fog detection.

		SYNOP	
		FOG	No Fog
GOES-9	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: $CSI = \frac{YY}{YY + YN + NY}$

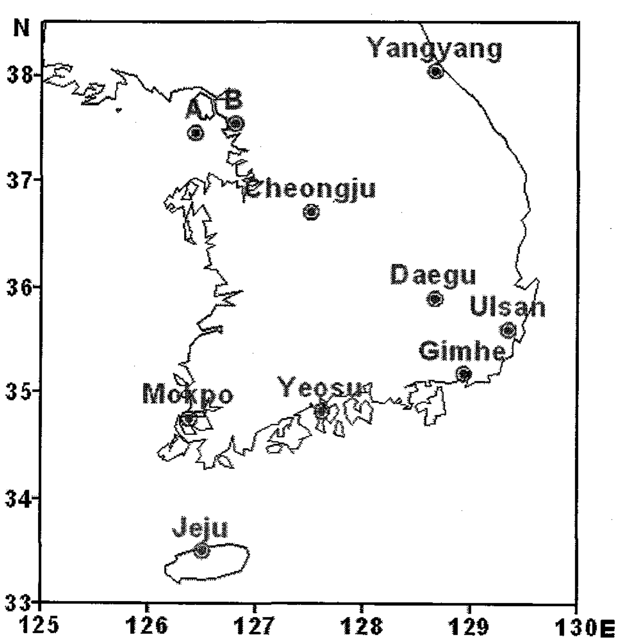

Fig 1. Location of meteorological stations at ten airports in the Korean Peninsula.