Rainfall Intensity Estimation with Cloud Type using Satellite Data

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ABSTRACT : Rainfall estimation is important to weather forecast, flood control, hydrological plan. The empirical and statistical methods by measured data(surface rain gauge, rainfall radar, Satellite) is commonly used for rainfall estimation.

In this study, the rainfall intensity for East Asia region was estimated using the empirical relationship between SSM/I data of DMSP satellite and brightness temperature of GEOS-9(10.7 ㎛) with cloud types(ISCCP and MSG classification). And the empirical formula for rainfall estimation was produced by PMM (Probability Matching Method).

KEY WORDS: Rainfall intensity, Rainfall estimation, Cloud type, Satellite data, GOES-9, SSM/I, PMM

1. INTRODUCTION

Water is one of the most general materials in the world, and the most important in human life and activity. Unfortunately, its availability to man is restricted by factors of local supply, natural purity, and its unique ability to be present in gaseous, liquid, and solid forms within the common range of environmental conditions found at or near the surface of the earth. The source of all water in its most desirable state is precipitation. It is not surprising that so much time and effort has been and is being spent in the evaluation of rainfall through both time and space(Barrett and Martin,1981)

Infrared (IR) of geostationary satellite rainfall estimates have long since been available and suffered from the difficulty in associating cloud top features to precipitation at ground level(Levizzani, 1999). Physically-based passive Microwave(MW) methods were developed mainly using data from the Special Sensor Microwave/Imager(SSM/I) and are based on several different physical principles. Limitations of MW algorithms include the relatively large footprint and the low earth orbits not suitable for most of the operational strategies. Combined MW and IR algorithms using SSM/I radiometric data have normally been focused on monthly averages over wide areas, although their need for instantaneous estimations was recognized already some time ago. Recently blended MW and geostationary IR techniques have been proposed oriented towards rapid-update operational use over large areas and data assimilation into NWP models(Turk et al., 2003, Vincente et al., 1998).

In this paper, we estimated the rainfall intensity with cloud type classification using the brightness temperature data of geostationary orbit satellite and SSM/I rainfall data.

2. DATA AND ALGORITHM

GOES-9 satellite provides the kind of continuous data necessary for intensive data analysis. It circles the Earth in a geosynchronous orbit which means the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows it to hover continuously over one position on the surface. The geosynchronous plane is about 35,800 km above the equator, high enough to allow the satellites a full-disc view of the Earth. This satellite started operational observation from May 22. 2004, and its band specification is presented in Table 1.

Table 1. Band center and range of GOES-9 satellite.

Band	Center(μm)	Range (μm)
VIS	0.65	0.55-0.75
SWIR	3.9	3.8-4.0
WV	6.75	6.5-7.0
IR1	10.7	10.2-11.2
IR2	12.0	11.5-12.5

SSM/I is a microwave radiometer system flown on the DMSP satellites. The SSM/I orbit is near-circular, sun-synchronous, and near-polar with an altitude of 850 km and inclination of 98.8°. The orbital period is 102 minutes. This orbit provides complete coverage of the Earth, except for two small circular sectors 2.4° centered on the North and South poles (Wentz, 1988). SSM/I rainfall intensities provide 0~25 mm/hr with 12.5 km spacing. Table 2 show information about the SSM/I sensor of the DMSP which is currently used.

Table 2. Observational information of SSM/I instruments in the DMSP series satellites.

	Launching date	Perigee(Apogee)	Inclination	Period
F13	1995-05-25	849(837) Km	98.8°	102 min
F14	1997-04-04	847(836) Km	98.6°	102 min
F15	1999-12-12	846(831) Km	98.6°	102 min

RDPS(Regional Data Assimilation and Prediction System) data of KMA(Korea Meteorological Agency) was used as the atmospheric temperature values for cloud type classification. They are forecasted with every 3 hour interval, and spaced out 30X30 km and 23 pressure levels.

The cloud types are classified with a cloud altitude and cloud optical thickness from GOES-9 satellite data. The cloud types are classified 3, 10 and 9 categories due to development stage, altitude, transparency, and optical depth of cloud. 3 category is classified according to IR1 and IR2 brightness temperature of the split window channel(Inoue; 1989). 10 category is used in MSG (Meteosat Second Generation; Meteo-France, 2005) of Europe and is due to the cloud altitude, optical thickness, and transparency. 9 category is due to the cloud altitude(i.e. cloud top pressure) and optical thickness calculated by radiation model(Nakajima and King, 1991), and this classification is generally used other climate study(ISCCP method; Rossow and Schiffer, 1999). The following Figure 1 is the schematic diagrams for the classification of cloud types used in this study.

(a) 3 category (a) MSG (b) ISCCP

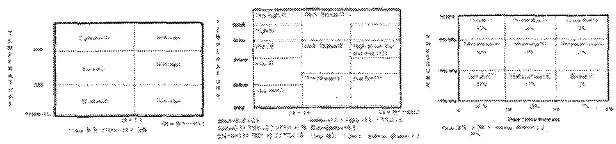


Figure 1. Schematic diagrams for cloud type using 3 category(a), MSG(b) and ISCCP(c) method.

The cloud albedo varies with the cloud optical thickness, vertical temperature, cloud altitude, cloud droplet size, and cloud compositions (i.e. water or ice). The cloud albedo change calculated by radiative transfer model is presented in Figure 2, and standard mid-latitude summer profile data was used for this calculation.

(a) Water (b) Ice

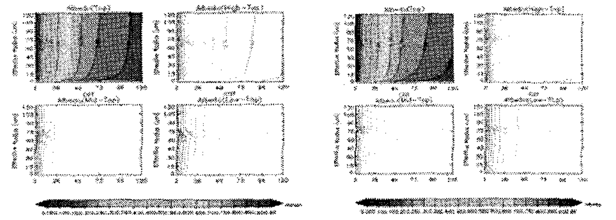


Figure 2. Albedo and its differences calculated for cloud altitude with cloud optical thickness and effective size using by SBDART(Ricchiazzi et al., 1998).

Figure 2 shows that the cloud albedo can be varied about 5% with the cloud altitude, effective radius, cloud droplet size, and cloud compositions.

In order to solve the inconsistency problem of the time and space between geostationary and orbital satellite data is not coincided, we applied following PMM(Probability Matching Method; Calheiros and Zawadzki, 1987).

$$\int_{R_t}^{R_i} P(R)dR = \int_{TB_t}^{TB_i} P(TB)dTB \quad (1)$$

Where, R is the SSM/I rainfall, TB is IR1 brightness temperature of cloud and P() is probability function. Then coefficient a and b are calculated in following empirical equation with IR1 brightness temperature of cloud and SSM/I rainfall.

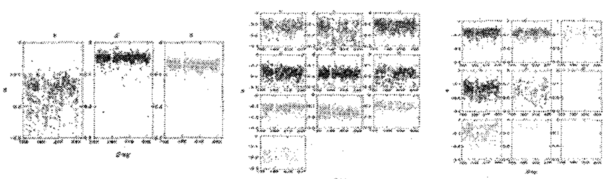
$$RI = \exp[a \times (TB - b)] \quad (2)$$

Where, RI is rainfall intensity by SSM/I. So, rainfall intensity produced by coefficient a and b in equation (2) with GOES-9 IR1 brightness temperature of cloud.

3. RESULTS

The coefficient a and b in equation (2) are calculated with cloud type during Jun. ~ Aug. 2004, and the results are presented in Figure 3 and Table 3.

(a) a(3 category) (b) a(MSG) (c) a(ISCCP)



(d) b(3 category) (e) b(MSG) (f) b(ISCCP)

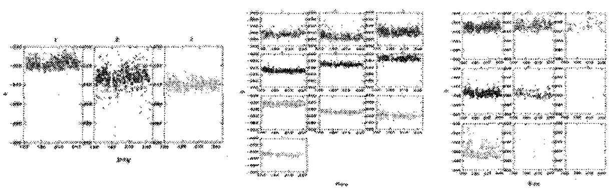


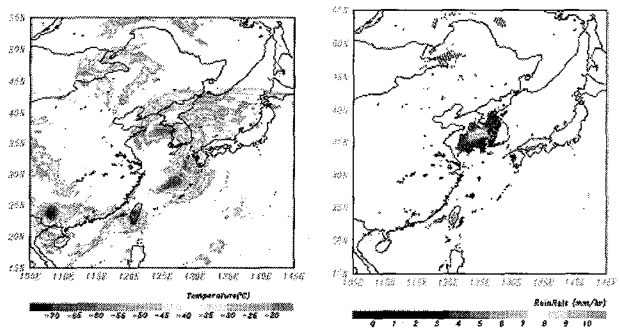
Table 3. Statistics of coefficients with cloud types(CT) for 3 category, MSG and ISCCP method during Jun.~Aug. 2004.

CT	3 category				MSG				ISCCP			
	Mean		Standard Deviation		Mean		Standard Deviation		Mean		Standard Deviation	
	a	b	a	b	a	b	a	b	a	b	a	b
1	-0.162	-217.3	0.046	4.57	-0.122	-262.8	0.047	7.83	-0.086	-230.3	0.026	5.94
2	-0.050	-232.5	0.018	9.73	-0.155	-270.3	0.068	9.31	-0.089	-226.6	0.029	7.76
3	-0.071	-239.7	0.015	6.46	-0.112	-257.2	0.039	7.91	-0.095	-225.1	0.039	9.55
4					-0.164	-248.2	0.040	3.32	-0.137	-253.9	0.038	5.36
5					-0.172	-230.3	0.031	2.89	-0.161	-256.9	0.060	6.45
6					-0.179	-213.0	0.045	4.45	-0.219	-261.8	0.074	3.16
7					-0.123	-223.5	0.038	5.47	-0.101	-257.6	0.057	15.32
8					-0.156	-247.9	0.040	4.03	-0.083	-253.1	0.059	20.18
9					-0.104	-257.5	0.041	9.51	-0.083	-266.5	0.020	9.87
10					-0.175	-247.8	0.047	3.84				

Figure 3. Coefficient a and b with 3 category (a,d), MSG(b,e) and ISCCP(c,f) method during Jun.~Aug. 2004.

In Figure 3, we see that the daily variation of coefficient a and b by ISCCP method is relatively little than MSG method. However, ISCCP method cannot estimate them at nighttime pixels

(a) GOES-9 CTT (b) SSM/I RI



(c) 3 category (d) MSG (e) ISCCP

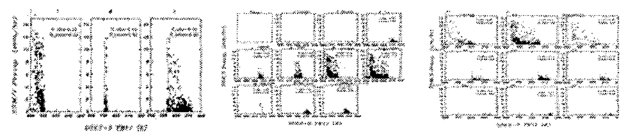


Figure 4. (a)GOES-9 Cloud Top Temperature(CTT), (b)SSM/I RI, (c)~(e) relationship between GOES-9 CTT and SSM/I RI by 3 category, MSG and ISCCP method at Jul. 4. 2004 00UTC.

In the case at July 4 2004 00UTC, Rainfall intensity is estimate and the results are presented in Figure 4. GOES-9 CTT and SSM/I rainfall are coincided well in intensely precipitation region of west Korea and Taiwan. The correlation coefficients between collocated GOES-9 CTT and SSM/I rainfall values with cloud types are less than 0.3, 0.4 and 0.5 about 3 category, MSG and ISCCP method, respectively. But these correlation coefficients are more than 0.8 for all methods in the case of applying PMM.

(a) 3 category (b) MSG (c) ISCCP

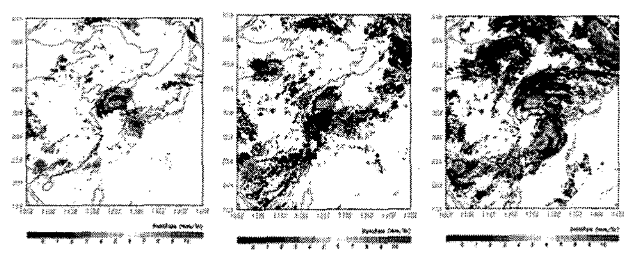


Figure 5. Estimated RI by (a)3 category, (b)MSG and (c)ISCCP at Jul. 4. 2004 00UTC.

Figure 5 presents the rainfalls estimated by 3 category, MSG and ISCCP method. And all methods are similar to SSM/I rainfall intensity of Figure 4(b), but the precipitation regions in Figure 5 are more extensive than SSM/I rainfall.

The statistical analysis between SSM/I Rainfall and estimated rainfalls is presented Table 4.

Table 4. Statistics between SSM/I and estimated RI by 3 category, MSG and ISCCP at Jul. 4. 2004 00UTC.

	RC	STD	RMSE	TS	POD	FAR
3 category	0.40	14.04	13.78	0.78	0.89	0.13
MSG	0.48	6.26	5.75	0.76	0.91	0.18
ISCCP	0.55	4.00	3.69	0.72	0.83	0.16

The statistic values between the rainfall estimated by ISCCP method and SSM/I rainfall are better in correlation coefficient, standard deviation and RMSE(root mean square error) than value by MSG method. But the ISCCP method about the category validation values of POD and TS for rainfall region detection(over 5 mm/hr) are worse than MSG method.

4. SUMMARY

The precipitation region estimated by ISCC and MSG method was more extensive than SSM/I rainfall region, but the rainfall intensities estimated by all methods (3 category, MSG and ISCCP method) are similar to SSM/I rainfall intensity. Particularly, ISCCP method is better in daytime than MSG method.

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