

# A Preliminary Study of Applying SSM/I Data in Rainfall Estimation around Taiwan Area

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## 1. INTRODUCTION

Rainfall is an important factor for weather and climate, especially in TAIWAN and other tropical areas. Microwave remote sensing has many benefits, which can penetrate cloud to detect rainfall. Estimating rainfall by empirical regression is rapid and easy, but it is always different from case to case. The physical basis of a technique as transformed by measurement imperfections of real instruments determines the ultimate performance capability of any microwave rain estimator (Jameson, 1991). Passive microwave techniques for sensing precipitation have been in experimental use for over a decade (e.g. Petty & Katsaros, 1990, 1992, Alishouse etc., 1990, Alliss, 1988, Weng, 1994). The principle of microwave is that the microwave brightness temperature of rain cloud changes in direct response to the vertical integrated liquid water content of the cloud.

Using microwave sensor to estimate global rainfall for a long period (eg. month) over ocean have a better retrieval result for the uniform of data. It is found that an overall difference over the global is small with less than 5% (Weng etc. 1994). It was found that the best fit to the data is obtained with a nonlinear global algorithm, while linear segmented and linear global algorithm give rms. differences (Alihouse. etc. 1990)

The residual error between observed and calculated brightness temperatures is found to be an important quantity in assessing the uniqueness of the solution (Kummerow, 1994). The minimization of rainfall estimation error over wide range of rainfall rate requires the simultaneous application of more than one microwave rainfall measurement technique (Jameson, 1991).

The objective of this article is to evaluate the result of using SSM/I rainfall rate regression algorithms in TAIWAN area. Comparison was made among precipitation from SSM/I and radar over ocean and rain gauge dataes over land. Analysis results of those algorithms and the best choice to improve this algorithm, which can be used for AMSU data next year will also be discussed.

## 2. DATA CHARACTERISTICS

SSM/I (Special Sensor Microwave/Image) datas include 7 microwave channels with different polarization. The 19.35GHz radiance is dominated by emission due to the rain below the freezing level (Spencer, 1988), The brightness temperature measured at 37GHz shows relatively strong emission from rain and only marginal effects caused by scattering ice above the rain cloud. At

frequencies below 37GHz, the observations made by these radiometers do not yield appreciable additional information about rain (Prabhakara.etc. 1992). An empirical method was used to estimate Nimbus-7 SMMR precipitation observations against surface radar near TAIWAN was done by Petty (1992), and relationships between the corrected pixel-averaged radar rainfall limit and the SMMR 37GHz observed microwave polarization are the most useful. The high sensitive of the SSM/I 85.5GHz channels to volume scattering by precipitation, especially ice above the freezing level, is the basis for this identification. At 85GHz, the volume extinction coefficient is considerably large, direct information about rain below the cloud is generally masked (Prabhakara.etc.1992). So 85.0 GHz reflect scattering above freezing level.

According to FASCOD3P simulation we found that low frequency brightness temperature is warming as rain rate on the increase until about 20mm/hr rainfall rate for saturated and is decreasing as rain rate increase continually for volume scattering. But the brightness temperature of high frequency (e.g. 85GHz) is decreasing as rain rate increase for volume scattering. Fig. 1 show the relationship between rain rate and SSM/I brightness temperature. When there is raining, surface emissivity does not affect the brightness temperature of 85GHz, but for lower frequency the surface emissivity will affect upward radiance except heavy rainfall. If rain rate is over 75mm/hr, the brightness temperature of 19.2GHz will not be affected by surface emissivity. In other words, surface warming effect is masked by rainfall. Fig 2 show the relationship between surface emissivity and brightness temperature when there is raining. The scattering diagram distribution, a good correlation among SSM/I 7 channels is as follows, 37GHz\_V Vs 19.2GHz\_V, 22GHz\_V vs. 19GHz\_V, 19GHz(V-H) vs. 19GHz\_V, 22GHz\_V vs. 19GHz\_V, 37GHz\_V vs. 19GHz\_V, 37GHz(V-H) vs. 37GHz\_V.

SSM/I datas were brought from Remote Sensing Systems Co.. These datas were processed after calibration and navigation correction. The resolution of 85GHz is 12.5Km and other low frequency is 25Km. The typhoon DOUG at 7-AUG-1994 went through TAIWAN and the mesoscale system during MIEYU season at day 8-JUN-1993 were selected to be our study target. In order to distinguish the effect of surface emissivity, we choose surface radar located at Kaoshun (south TAIWAN) and Hualien (east TAIWAN) as ground true over ocean, and over 250 remote raingage stations in west part of TAIWAN as ground true over land. All of these datas were collocated within 0.05degree(latitude/longitude) grid. The relationship between SSM/I data and ground true is estimated by PDF (Probability Distribution Function). The relation between Radar reflectivity Z and rainfall rate R is  $Z = 230R^{1.4}$  (petty,1992)

### 3. RAINFALL ESTIMATE ALGORITHM

#### 3.1 multichannel method

J.Hollinger(1989) suggested the algorithm as follow,

IF  $T_{85V} - T_{85H} < -2K$  or

$$T_{B37V} - T_{B37H} < -2K \quad \text{or}$$

$$T_{B19V} - T_{B19H} < -2K \quad ,\text{then flag as indeterminate}$$

ELSE IF SSM/I measurement is over land then

$$\text{IF } T_{B22V} - T_{B19V} < 4K \quad \text{and}$$

$$(T_{B19V} + T_{B37V})/2 - (T_{B19H} + T_{B37H})/2 \leq 4K \quad \text{and}$$

$$T_{B85V} - T_{B37V} < 0K \quad \text{and}$$

$$T_{B19V} > 262K$$

or

$$T_{B22V} - T_{B19V} \leq 4K \quad \text{and}$$

$$(T_{B19V} + T_{37V})/2 - (T_{B19H} + T_{B37H})/2 > 4K \quad \text{and}$$

$$T_{B37V} - T_{B19V} < -3K \quad \text{and}$$

$$T_{B85V} - T_{B37V} < -5K \quad \text{and}$$

$$T_{B85H} - T_{B37H} < -4K \quad \text{and}$$

$$T_{B19V} \geq 257K \quad ,\text{then compute rain rate over land}$$

ELSE rain rate = 0 mm/hr

ELSE if SSM/I measurement is over ocean then

$$\text{IF } -11.7939 - 0.02727T_{B37V} + 0.0992T_{B37H} > 0K \quad ,\text{then}$$

compute rain rate over ocean

ELSE rain rate = 0 mm/hr

ELSE SSM/I measurement is coastal, flag as indeterminate

Algorithms:

if a rainfall rate over land is to be computed, then use

$$R = \exp(1.32526 - 0.0815T_{B37V} + 0.01638T_{B37H} + 0.03561T_{B22V} + 0.05079T_{B19V} - 0.01875T_{B19H}) - 8.0\text{mm/hr} \quad (1)$$

if a rainfall rate over ocean is to be computed, then use

$$R = \exp(-0.36025 - 0.0091856T_{B85V} - 0.00555T_{B22V} + 0.02696T_{B19V}) - 4.0\text{mm/hr} \quad (2)$$

Alternatively, if the 85.5GHz vertical channel is unusable, then over ocean apply

$$R = \exp(-0.42383 - 0.0082985T_{B85H} + 0.01496T_{B19V} + 0.00583T_{B19H}) - 4.0\text{mm/hr} \quad (3)$$

If any of these formulae yield a rainfall less than zero, then set the rain equal to 0 mm/hr.

### 3.2 polarization corrected temperature(PCT)

Roy.W.Spenser(1989) suggested a PCT of 85GHz is formulated to isolate the precipitation effect. A PCT threshold of 255K is suggested for the delineation of precipitation. This threshold is shown to be lower than what would generally be expected from nonprecipitation cloud water alone. The PCT is defined as

$$PCT = 1.818T_{BV} - 0.818T_{BH} \quad (4)$$

### 3.3 $T^*$ method

C.Prabhkara(1992) developed an empirical method to estimate the rain rate in which it is assumed that over an oceanic area the statistics of the observed  $T_B$ 's at 37GHz in a rain storm are related to the rain rate statistics in that storm. The method is as follow

$$T_{37\min} = 126 + 6.8w \quad (5)$$

$w$ : water vapor content( $gcm^{-2}$ )

$$T^* = T_{37\min} + 15 \quad (6)$$

$$R = \{ \exp[\beta(T_{B37} - T^*)]^\chi - 1 \} r(w) \quad (7)$$

$$\chi = 1.7, \quad \beta(w) = 0.012 + 0.003w \quad (8)$$

$$r(w) = 1.5 - 0.1w \quad (9)$$

### 3.4 scattering index method

Fuzhong Weng.etc.(1994) suggested a procedure by using a scattering index to identify the scattering signal at 85.0GHz from precipitation over land and ocean. The scattering index is defined as

$$SI = F - T_{B85V} \quad (10)$$

$$F = 256.2 - 0.375 \times T_{B19V} - (0.2 - 0.00237 \times T_{B22V}) \times T_{B22V} \quad (11)$$

$$R(mm/hr) = -1.70 + 0.29 \times SI \quad (12)$$

### 3.5 multichannel algorithm

The following algorithms, developed by Olson, Fontaine, Smith and Ahtor(1990), were used to estimate rain rates from the measured  $T_B$ 's:

When data includes the 85 GHz

$$rainrate = (\exp(3.06231 - 0.0056036 \times 85TBV + 0.0029478 \times 85TBH - 0.0018119 \times 37TB - 0.0075 \times 22TBV + 0.009755 \times 19TBV) - 8.0$$

when data does not include the 85GHz

$$\text{rainrate} = (\exp(5.10196 - 0.05378 \times 37TBV + 0.02766 \times 37TBV + 0.01373 \times 19TBV) - 2).$$

#### 4. RESULT

At 07-AUG-1994 2204Z, typhoon DOUG was near northeast of TAIWAN. When heavy rainfall was observed near mountain, maximum rainfall rate over land is 64.5mm/hr as shown on Fig. 3. The infrared image of GMS4 is shown on Img.1. From radar echo we can found maximum rainfall to be 48.7mm/hr as shown on Img.2. The rain rate estimated by J.Hollinger is shown on Img.3. Maximum precipitation over ocean is 50mm/hr. The precipitation pattern is similar to 85GHz as shown on Img.4. Over land, the rain rate is underestimated, near coast area, the surface type cannot be classified nor rain rate can be estimated.

The rain rate by  $T^*$  method is shown on Img.5.  $T^*$  method is based on 37GHz emission theory so the rain rate pattern is very similar to 37GHz on Img.6. Over land area, rain rate is close to most middle raining area. Heavy rain rate area is underestimated very much. Over ocean area, the raining pattern is similar to radar.

Rain rate estimated by scattering method is shown on Img.7. Rain rate pattern is similar to 37GHz (Img.6). Over land area, rain rate is underestimated, but the pattern is similar. Over ocean, rain pattern is unmatched with radar echo pattern. The other two rain rates were estimated but were unmatched much more as shown on Tab. 1. So we can find that rain rate estimated by algorithm of Hollinger and scattering method has closely pattern as ground true. The relationship between ground true and SSM/I rain rate is shown on Fig.4. Within different algorithms, the one developed by J. Hollinger is more linear. For SSM/I, larger footprint than raining cloud and raining rate is not unique within a footprint, so all the algorithms may underestimate rain rate.

Surface microwave is polarized emission to SSM/I radiometer. When rain rate is increasing the polarized emission effect from surface will reduce. So using PCT could identify raining area as shown on Img. 8. Over land raining area is the area, located under PCT less than 255K, over ocean PCT threshold has to evaluate adjustment. The relationship between PCT value and surface rainfall observed is shown on Fig.5. PCT85 is a good index to identify raining area.

#### 5 CONCLUSION

In this case study, we could conclude that the algorithm of Hollinger is better than others over ocean, but over land scattering method is even better. Multichannel is necessary for rainfall retrieval algorithm. Radar and surface rain gauge data have different characteristics comparing with satellite data, so this comparison is very difficulty to do. Ground true should be a function of time and space, then more reasonable correlation could be estimated. PCT is a good index to classify raining area, then using other algorithm to estimate rainfall rate could reduce errors in dazzle. Since microwave

sensor can estimate rainfall rate very well, we need to do more case studies and find out different raining types. Over land, the algorithm of Hollinger should adjust the surface classify method or threshold to improve the rainfall estimate precision.

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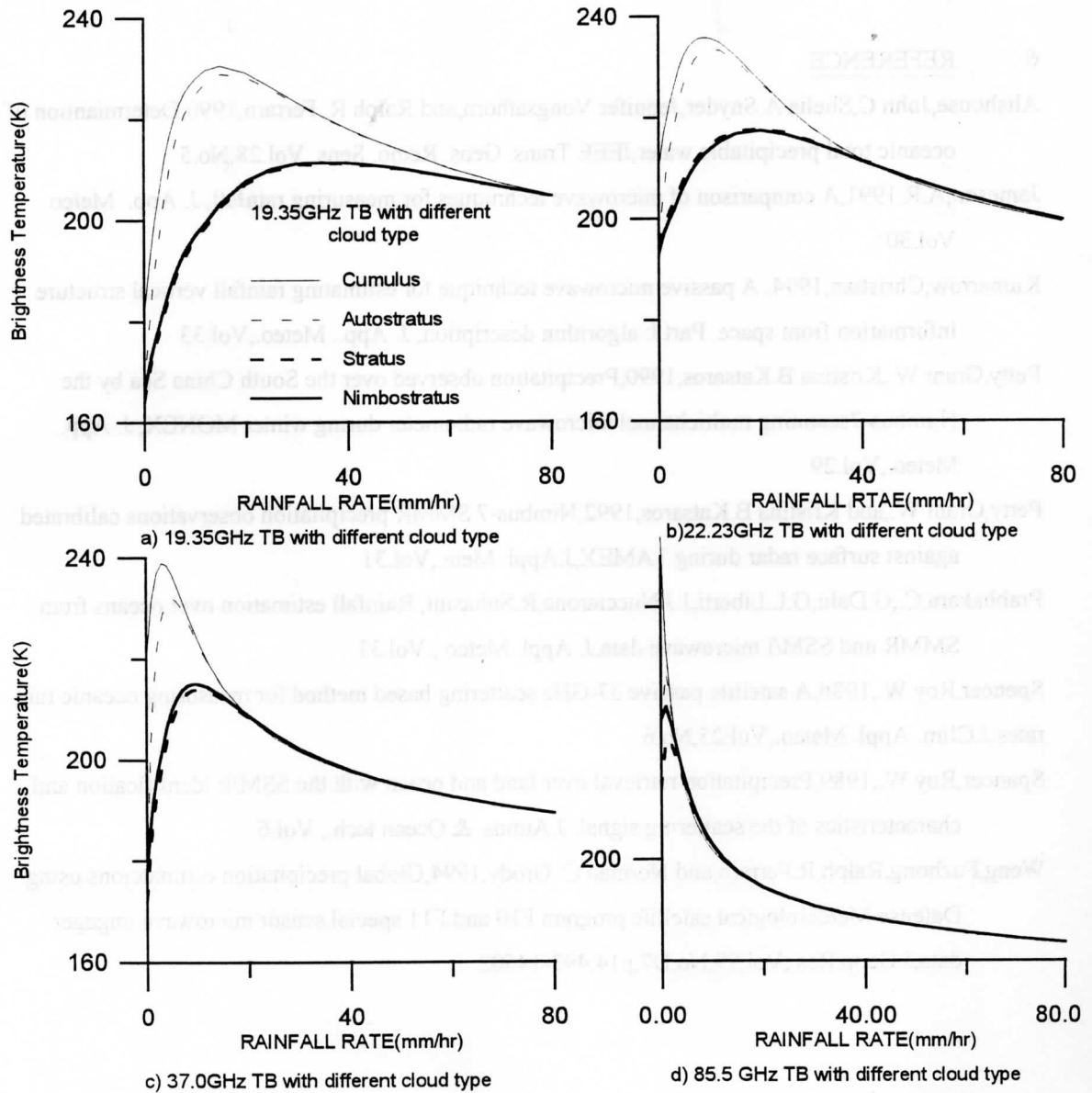


Fig.1 The relationship between rainfall rate and SSM/I each channel brightness temperature with different cloud types. Thin solid line is Cumulus, thin dashed line is Autostratus, thick dashed line is Stratus, thick solid line is Nimbostratus.

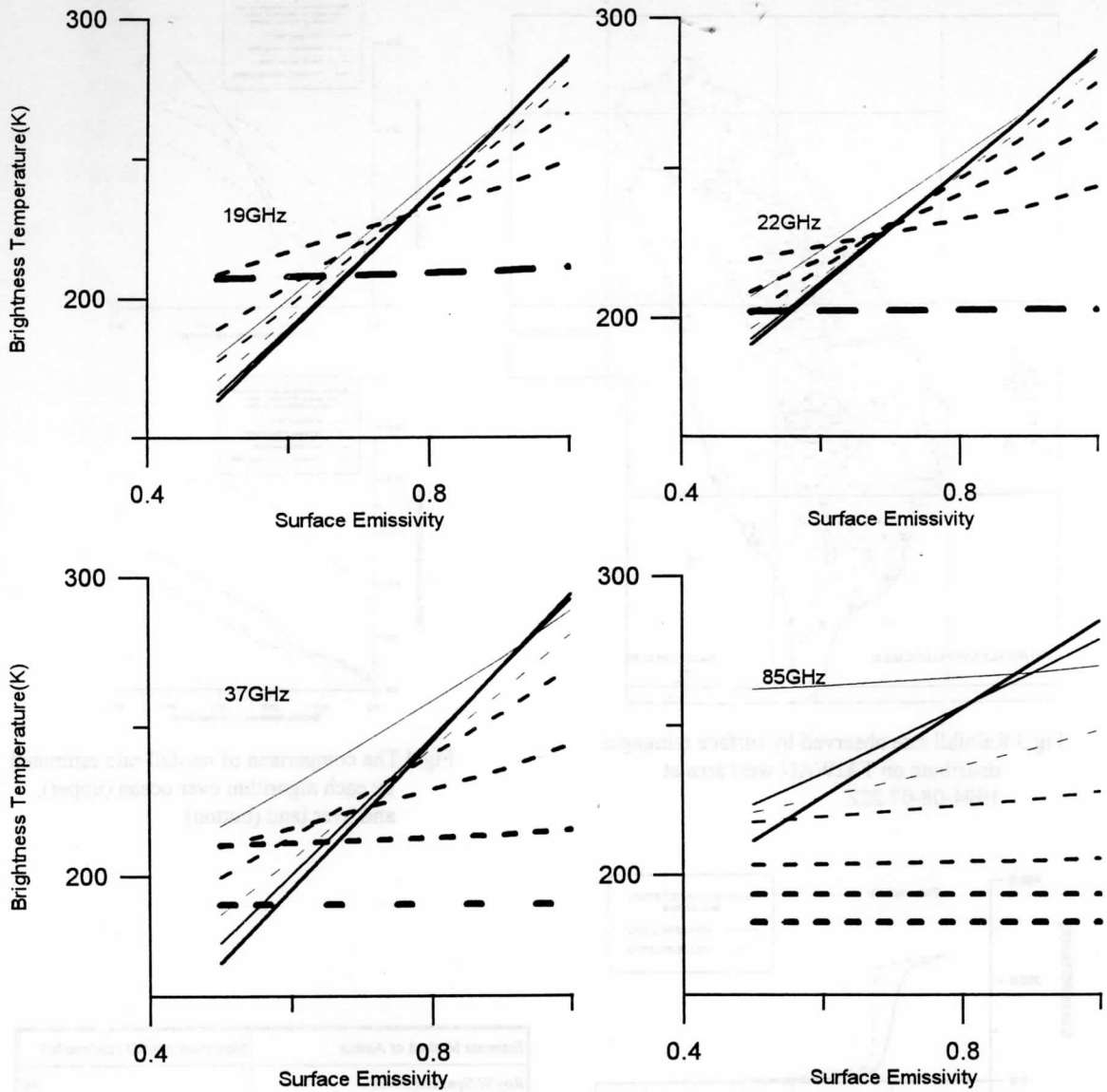


Fig.2 The relationship between surface emissivity and SSM/I channel's brightness Temperature with different cloud type and rainfall rates

cloud types and rainfall rate

- Cumulus
- Altostratus
- Stratus
- - - 2.0mm/hr rainfall (As)
- - - 5.0mm/hr rainfall (Ns)
- - - 12.5mm/hr rainfall (NS)
- - - 25.0mm/hr rainfall (Cu)
- • 75.0mm/hr rainfall (Cu)



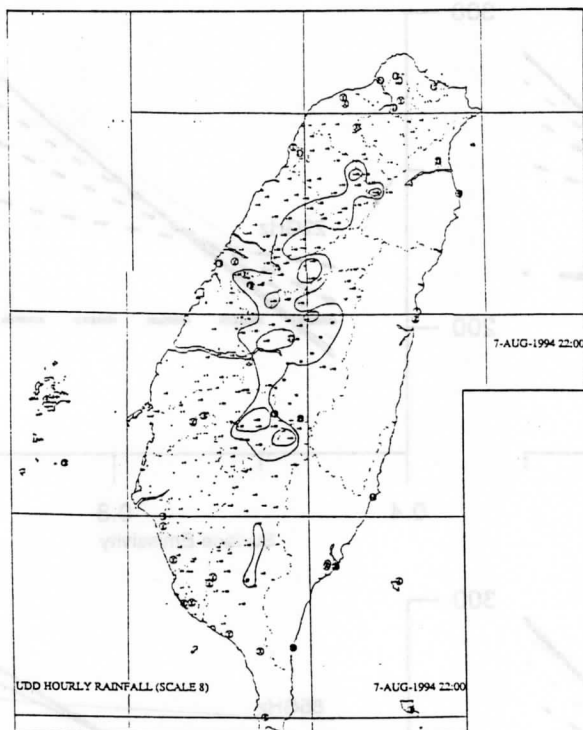


Fig.3 Rainfall rate observed by surface rain gauges distribute on TAIWAN west area at 1994-08-07 22Z

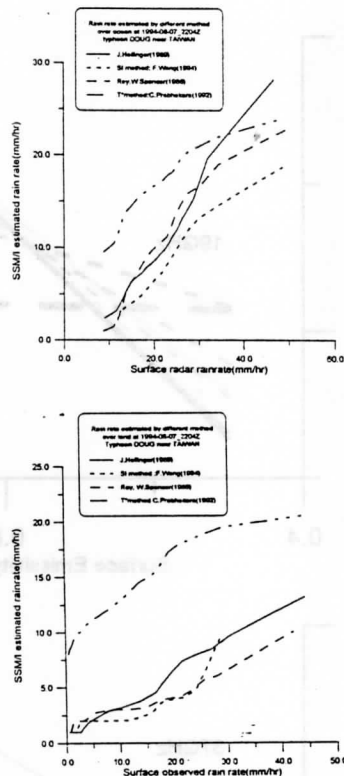


Fig.4 The comparison of rainfall rate estimated by each algorithm over ocean (upper), and over land (button)

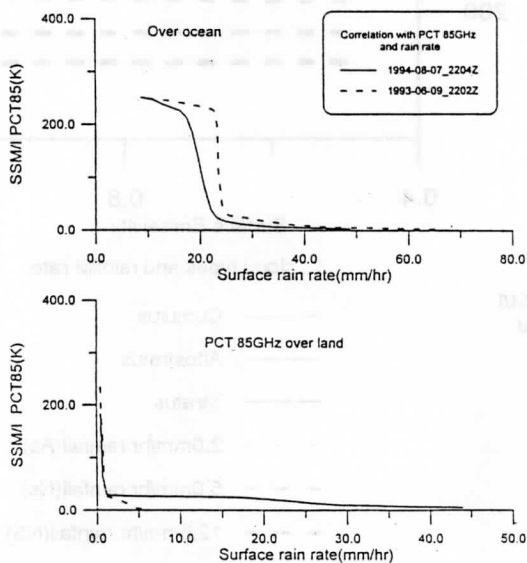


Fig.5 The relationship between PCT and rainfall rate over ocean (upper) and over land(button)

Estimate Method or Author	Maximum rainfall rate(mm/hr)
Roy.W.Spencer(1986)	40
J.Hollinger etc(1989)	50.4
John.C.alihouse etc(1990)	1.9
T* method by C.Prabhakara(1992)	31.28
Grandirate V.Rao(1990)	7.51
Scattering Index method By F.weng(1994)	43.78
Radar maximum rain rate	64.6
Radar maximum rain rate	48.7

Table 1. The result of maximum rainfall rate that using different retrieval method to Typhoon DOUG and maximum rain observed on surface

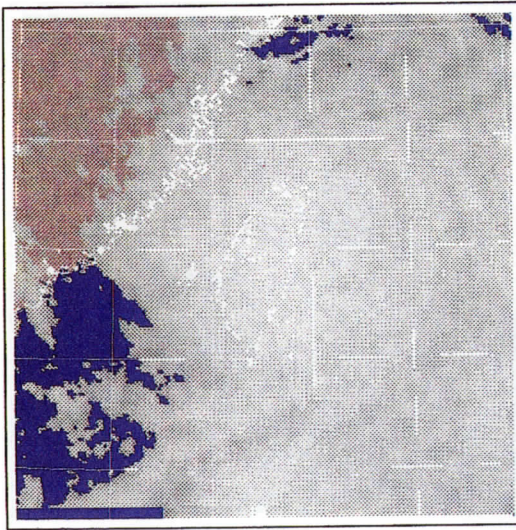


Image 1 1994-08-07\_21Z GMS-04 IR Image

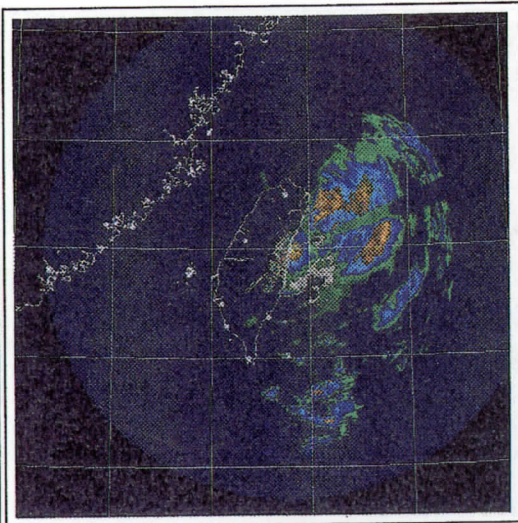
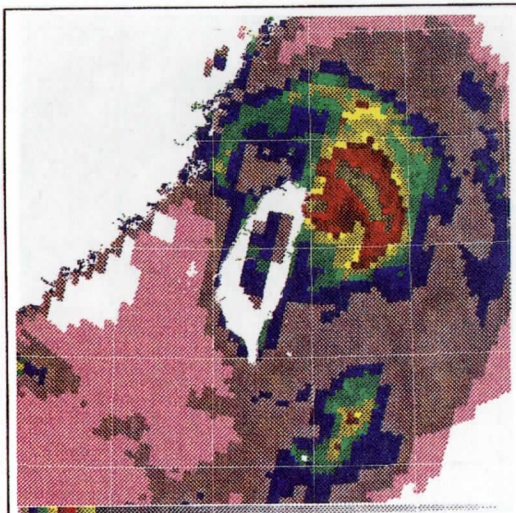
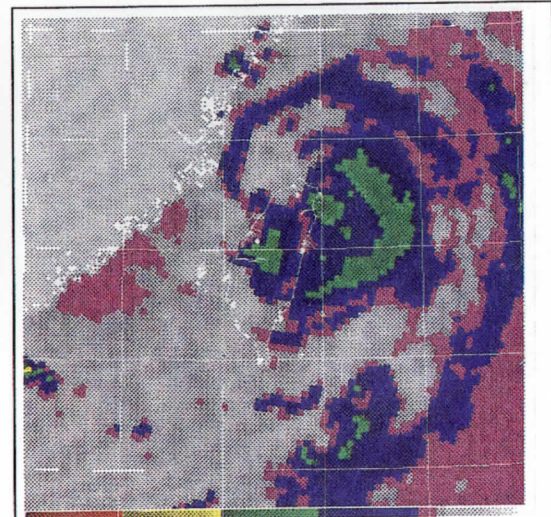


Image 2 1994-08-07\_2204 Hualien Radar reflectivity (DBZ)  
elevation angle = 0



0 40

Image 3 1994-08-07\_2204Z SSMI-11 rain rate  
estimated by Hollinger algorithm,  
Rain rate maximum = 50.4 mm/hr



100 200 300K

Image 4 1994-08-07\_2204\_SSMI-11 85 GHz-H  
Brightness Temperature Image (K)

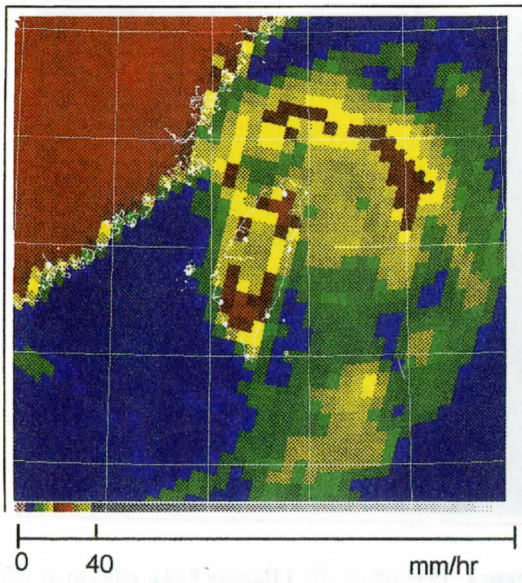


Image 5 1994-08-07\_2204\_SSMI-11 Rain rate estimated by T-star algorithm, Rain rate maximum = 40.0 mm/hr

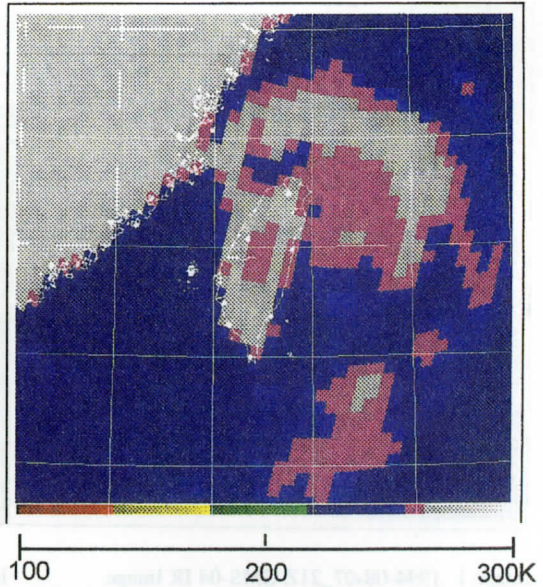


Image 6 1994-08-07\_2204\_SSMI-11 37 GHz-V Brightness Temperature image (K)

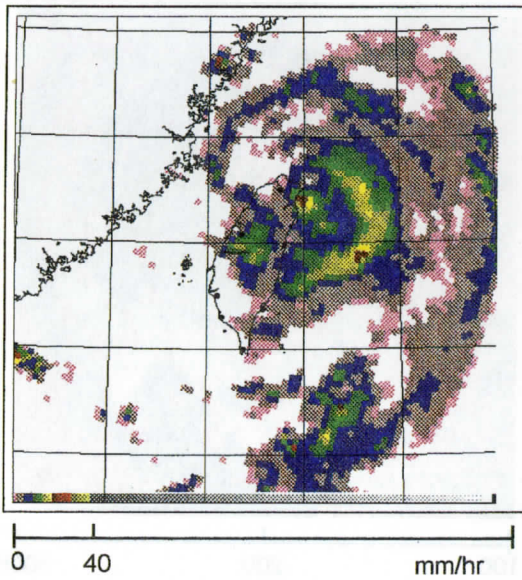


Image 7 1994-08-07\_2204Z SSMI-11 Rain rate estimated by Scattering Index algorithm, Rain rate maximum = 43.8 mm/hr

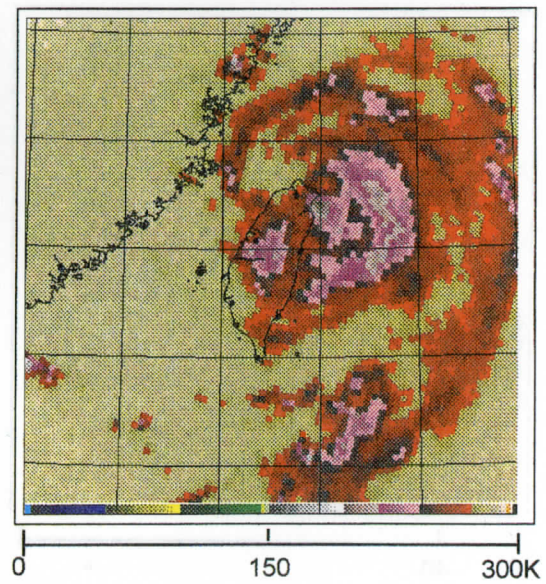


Image 8 1994-08-07\_2204\_SSMI-11 PCT\_85 Brightness Temperature (K)

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