Quantitative Precipitation Estimation over Ocean Using Bayesian Approach from Microwave Observations during the Typhoon Season

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ABSTRACT

This study is to estimate rainfall over oceans around Taiwan using Bayesian approach during the Typhoon season. Simulated brightness temperatures of Tropical Rainfall Measurement Mission (TRMM) Microwave Image (TMI) are obtained through a 3-D microwave radiative transfer model inputting the outputs of the Weather Research and Forecast (WRF) Model. Considering the complicated physical processes between rainfall and microwave measurements, the normalized polarization index P (Petty, 1994) is used in this study and the rainfall algorithm is then established by the Bayesian approach. High resolution Infrared data, collocated within the FOV of the pixel of TMI, are also employed to eliminate the beam-filling problem.

The preliminary result shows the retrieval rainfall pattern is similar to those of GPROF (Goddard Profiling Algorithm) and our previous statistical retrieval result, but the rainfall intensity is greater in this study. The rainfall retrievals have also been validated with rain gauge data. The result also shows that the rainfall seems to be overestimated by the Bayesian approach for weak precipitation system and slightly underestimated for heavy precipitation system. Some evidences show that the amount of snow and ice seems to be overestimated by the current version of WRF model compared with observations. Therefore, more efforts are needed to treat the outputs of the cloud-resolving model and to simulate more reasonable brightness temperatures of TMI in order to obtain acceptable rainfall retrievals.

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PURPOSE

To use Bayesian approach for estimating the rainfall of typhoon over ocean. The disasters are caused by mostly severe rainfall like the typhoons of KAEMI and BILIS generated on July 2006. In order to reduce the damage to livelihoods and economies caused by heavy rainfall suddenly, the accurate rainfall retrievals of typhoon are an important mission for researching in the future.

DATA SETS

1. TMI passive microwave measurements/ TRMM
2. Goddard Cumulus Ensemble (GCE) 3D model data.
3. The Weather Research and Forecasting (WRF) Model simulation data.
4. Rainfall accumulation (mm) over one hour from island rain gauges. (JMA)

REFERENCES

- Chiu, J. C., G. W. Petty, 2006: Bayesian Retrieval of Complete Posterior PDFs of Oceanic Rain Rate from Microwave Observations. J. Appl. Meteor. Climatol., 45, 1073-1095.
- Amerault, Clark; Zou, Xiaolei,2006 ：Comparison of Model-Produced and Observed Microwave Radiances and Estimation of Background Error Covariances for Hydrometeor Variables within Hurricanes. Mon. Wea. Rev., 134, 745-758.
- Di Michele, S., A. Tassa, A. Mugnai, F. S. Marzano, P. Bauer, and J. P. V. P. Baptista, 2005: Bayesian algorithm for microwavebased precipitation retrieval: Description and application to TMI measurements over ocean. IEEE Trans. Geosci. Remote Sens., 43, pp. 778–791.
- Evans, K. F., J. Turk, T. Wong, and G. L. Stephens, 1995: Bayesian approach to microwave precipitation profile retrieval. J. Appl. Meteor., 34, pp. 260–279.
- Kummerow, C., Hong, Y., Olson, W. S., Yang, S., Adler, R. F., McCollum, J., Ferraro, R., Petty, G., Shin, D. B., and Wilheit, T. T., 2001: "The evaluation of the Goddard Profiling Algorithm (GPROF) for rainfall estimation from passive microwave sensors", J. Appl. Meteor.,Vol. 40, pp. 1801-1820.
- Olson, W. S., and Coauthors, 2006: Precipitation and latent heating distributions from satellite passive microwave radiometry. Part I: Improved method and uncertainties. J. Appl. Meteor. Climatol., 45, pp. 702–720.

SUMMARY AND FUTURE WORK

1. Simulations used to build conditional probabilities were squall line cases in the KWAJEX. we showed that simulations and observations have similar statistics, although they are not similar in horizontal structures of rain clouds. We also found that the cloud model generated more data points with heavy rain rates that were not frequently sampled by TMI observations.
2. We used attenuation index as the observed variable in our method. Unlike brightness temperature, attenuation index has a monotonic relationship with RR, and is less sensitive to background noises from water vapor, wind speed and sea surface temperature.
3. Validations of our new Bayesian approach were conducted against retrievals from PR, GPROF, and MLRS methods, and measurements from rain gauges located on Japanese islands. Fifteen typhoons that passed over rain gauges in 2004 were selected. We found that our Bayesian retrievals and PR RR show significant similarity in horizontal distributions of precipitation. Quantitative results also demonstrate that our retrievals agree well with rain gauge measurements, showing the highest correlation (0.95) and the smallest root-mean squared error (~ 2 mm hr-1).
4. It is desired to include more typhoon simulations in our database and to investigate how much extra information could be added in. We have started simulations using the Weather Research and Forecasting (WRF) model. More regional and global validations in simulations and retrievals are on going research.

PHYSICAL THEOREM

POLARIZATION CHARACTERISTIC

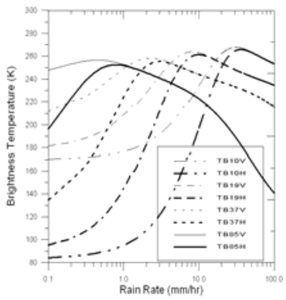

Fig. 3 Idealized TBs versus surface rain rate over ocean for TMI channels of 10, 19.35, 37, and 85GHz.

ATTENUATION INDEX

$$P = \frac{T_v - T_h}{T_{v,o} - T_{h,o}}$$ Petty (1995)

SCATTERING INDEX

$$S = P * T_{V,O} + (1 - P) * T_C - T_V$$

v : vertical polarization h : horizontal polarization Tc: 273°K

v,o & h,o : the brightness temperature under cloud free

BAYESIAN APPROACH

unknown → $f(R|p) = \frac{f(p|R) * f(R)}{\int f(p|R) * f(R) dR}$ ← given ← normalized

Conditional PDF (Chiu, 2006)

$$f(p|R) = f(p_{37}|R) * f(p_{19}|p_{37},R) * f(p_{10}|p_{19},p_{37},R)$$

$$f(p_{37}|R) \propto p_{37}(a - p_{37})\exp\left[-\frac{1}{2\sigma_3^2}(p_{37} - \mu_3)^2\right]$$

$$f(p_{19}|p_{37},R) \propto p_{19}(a - p_{19})\exp\left[-\frac{1}{2\sigma_2^2}(p_{19} - \mu_2)^2\right]$$

$$f(p_{10}|p_{19},p_{37},R) \propto p_{10}(a - p_{10})\exp\left[-\frac{1}{2\sigma_1^2}(p_{10} - \mu_1)^2\right]$$

3-D 4 STREAMS FAST RADIATIVE TRANSFER MODEL TO SIMULATE BRIGHTNESS TEMPERATURE

PROF. Liu (2006)

SIMULATED BRIGHTNESS TEMPERATURE – GCE data

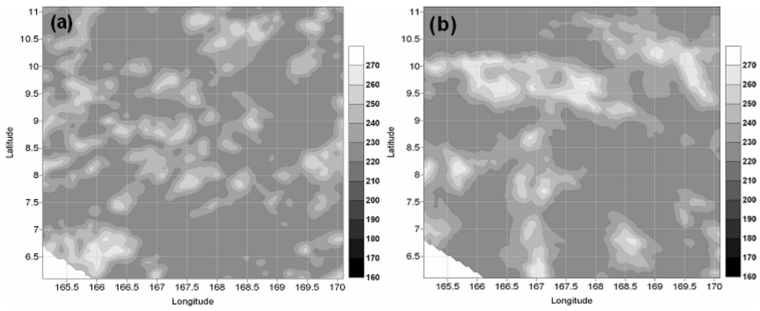

Fig. 4 Vertically polarized brightness temperatures at 37 GHz from (a) model simulations and (b) TRMM/TMI measurements for the Kwajalein Experiment on 10 August 1999. Simulations based on outputs of the cloud-resolving model at 1300 UTC, while TMI observations taken at 1256 UTC.

SIMULATED BRIGHTNESS TEMPERATURE – WRF data

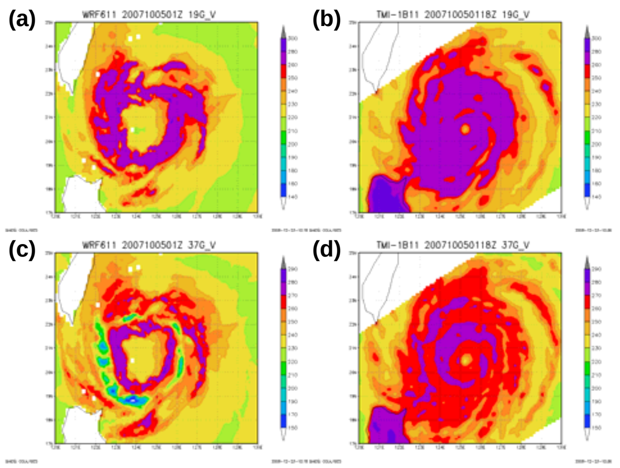

Fig. 5 Vertically polarized brightness temperatures at 19, 37 GHz from (a)WRF 19 GHZ simulation (b) TRMM/TMI 19 GHZ measurements (c) WRF 37 GHZ simulation (d) TRMM/TMI 37 GHZ measurement. Simulations based on outputs of the WRF model at 0100 UTC, while TMI observations taken at 0118 UTC.

COMPARISON WITH OBSERVATIONS AND SIMULATION-GCE

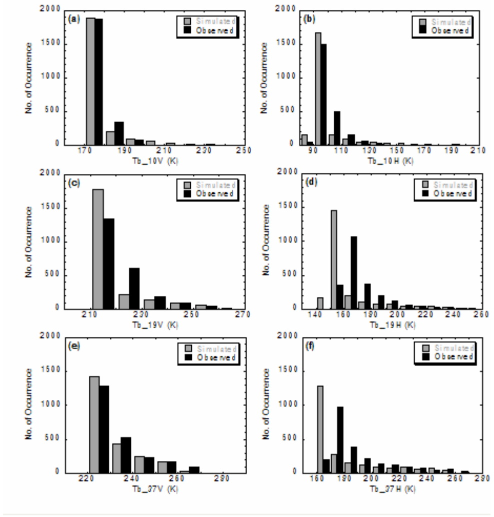

Fig. 1 Histograms of (a) TB10V, (b) TB10H, (c) TB19V, (d) TB19H, (e) TB37V, and (f) TB37H, from simulations (grey) and TMI observations (black). The bin size of the histograms is 10 K.

WRF SIMULATIONS COMPARED WITH OBSERVATIONS

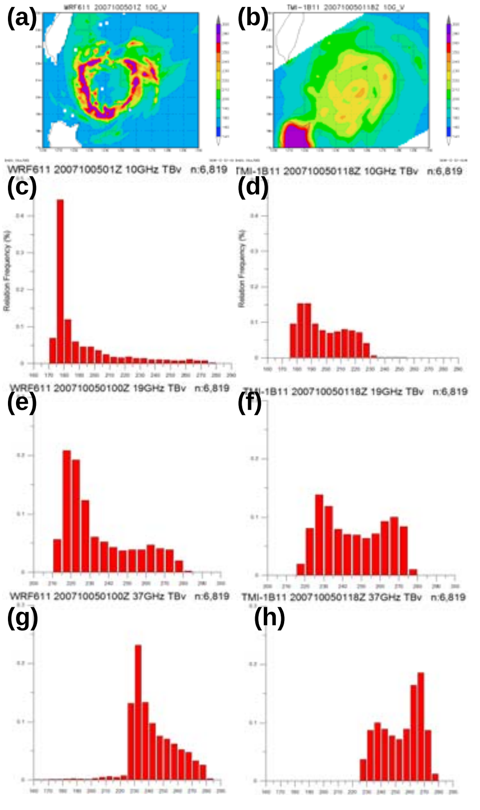

Fig. 2 2007 KROSA Typhoon (a) TB10V simulation (b) TB10V observation (c) histogram of TB10V simulation (d) histogram of TB10V observation (e) histogram of TB19V simulation (f) histogram of TB19V observation (g) histogram of TB37V simulation (h) histogram of TB37V observation.

VALIDATION

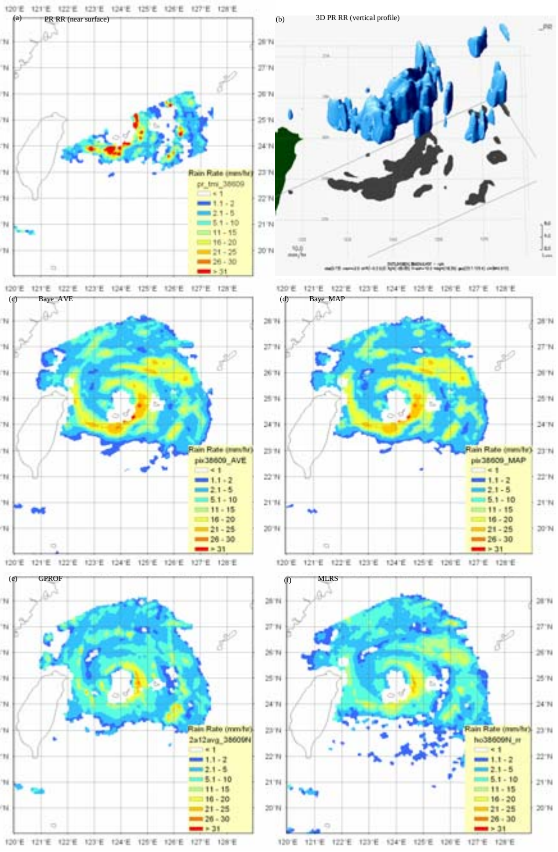

Fig. 6 Rain rates (a) and 3D vertical profiles (b) of Typhoon AERE retrieved from PR for orbit No. 38609 at 0151 UTC on 24 August 2004. In (b), we also shade areas that correspond to PR surface rain rate greater than 10 mm hr-1. Rain rates in (a) are compared to those retrieved from (c) Baye_AVE, (d) Baye_MAP, (e) the Goddard Profiling Algorithm (GPROF), and (f) a multi-channel linear regression statistical method (MLRS). Baye_AVE and Baye_MAP are both derived from our Bayesian method, representing the average and the maximum value of the posterior probability, respectively.

COMPARISON BETWEEN WRF DATABASE AND GCE DATABASE

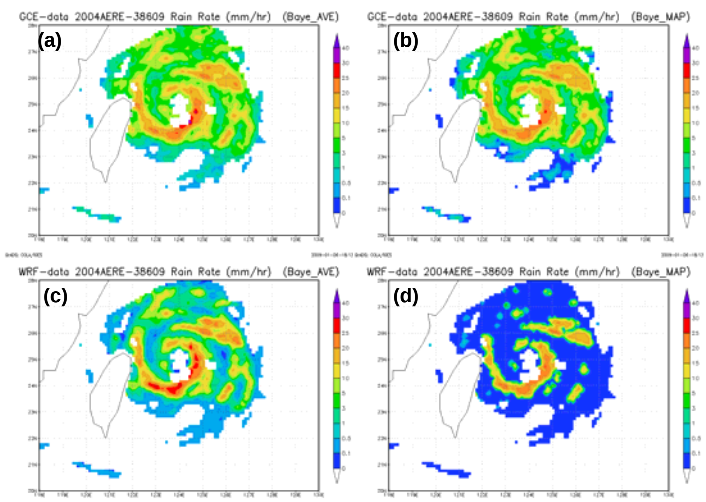

Fig. 7 2004 Typhoon AERE retrieved rain rates with (a) GCE database and Baye_AVE, (b) GCE database and Baye_MAP, (c) WRF database and Baye_AVE, (d) WRF database and Baye_MAP.

VALIDATION POINT- JAPANESE ISLANDS

No.	Rain gauge	Station No.	Location	Altitude (m)
1.	IRABU	93011	24.82˚N, 125.17˚E	10
2.	MIYAKOJIMA	93041	24.79˚N, 125.27˚E	40
3.	GUSUKUBE	93051	24.74˚N, 125.41˚E	55
4.	TARAMA	93061	24.66˚N, 124.69˚E	16
5.	IBARUMA	94001	24.50˚N, 124.28˚E	15
6.	KABIRA	94036	24.46˚N, 124.14˚E	7
7.	YONAGUNIJIMA	94017	24.46˚N, 123.01˚E	30
8.	IRIOMOTEJIMA	94061	24.38˚N, 123.74˚E	9
9.	ISHIGAKIJIMA	94081	24.33˚N, 124.16˚E	6
10.	OOHARA	94101	24.26˚N, 123.87˚E	28
11.	HATERUMA	94116	24.05˚N, 123.76˚E	38

Table 1 The locations of rain gauges on isolated islands in Japan.

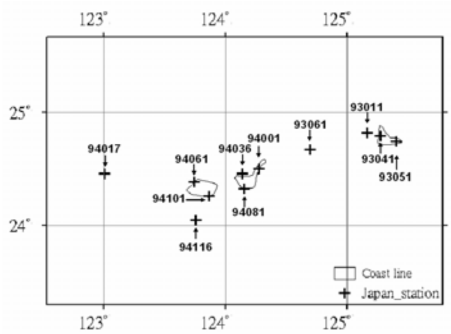

Fig. 8 A map of the 11 Japanese rain gauge stations.

VALIDATION CASES- FIVE TYPHOON

No.	Name of Typhoon	Time of data	Max. wind speed (m s-1)	Pressure (hPa)	No. of Overpass
1	CONSON	2004 0609~0610	47	960	2
2	MINDULLE	2004 0701~0703	62	940	4
3	AERE	2004 0823~0825	42	955	5
4	HAIMA	2004 0911~0912	15	992	4
5	NOCK-TEN	2004 1025~1026	55	945	1

Table 2 Five typhoon cases for validating rain rate retrievals against rain gauge measurements.