P16.6 A COMPARISON OF RADAR RAINFALL ESTIMATORS DURING THE SOUTH CHINA SEA MONSOON EXPERIMENT (SCSMEX)

[1]T. Keenan*, [2] Zhao Nan, [3]Feng Lei, [4]V. Bringi, [5]J. Nystuen and [1]M. Whimpey

[1]Bureau of Meteorology Research Centre(BMRC), Melbourne, Australia
[2]China Meteorological Agency, Beijing, PRC
[3]National Taiwan University, Tapei, Taiwan
[4]Colorado State University, Fort Collins CO
[5]University of Washington, Seattle, WA

1. INTRODUCTION

As part of the South China Sea Monsoon Experiment (SCSMEX) conducted during May-June 1998, the BMRC **C**-Band dual **POL**arimetric radar (CPOL) was deployed at Dongsha Is (20.7° N 116.72° E) in the northern part of the South China Sea to undertake ground validation studies in support of the Tropical Rainfall Measuring Mission (TRMM). This deployment provided the opportunity to evaluate polarimetric radar rainfall estimators in an essentially oceanic environment. Previous work by May et al., (1999), Le Bouar et al. (2001) has shown that C-Band polarimetric radar rainfall estimators offer considerable promise over more traditional radar estimators based on a Z-R relation, especially at C-band where attenuation issues become important and because they are less susceptible to drop size distribution effects, radar system gain and beam blockage (Zrnic and Ryzhkov, 1996).

2. DATA AND RADAR RAINFALL ESTIMATORS

A significant period of rainfall occurred during SCSMEX with the monsoon onset during the period 15-19 May 1998. This period is employed for these preliminary rainfall validation studies. CPOL gathered volume scan data every ten minutes measuring the following polarimetric variables: horizontal reflectivity (Z_H), the differential reflectivity (Z_{DR}), differential propagation phase shift (ϕ_{DP}) and cross correlation coefficient. The radar data were subjected to quality control procedures based on information from electronic, solar and vertically pointing scans in light rain

The quantitative use of the C-Band power measurements requires use of attenuation-correction procedures and in this study the self consistent method of Bringi et al. (2001) is employed. The total differential propagation phase shift along a path is equivalent to the total path-integrated attenuation and hence can be used as a constraint. The method builds on the “ZPHI” algorithm of Testud et al. (2000) and the technique for correcting Z_{DR} for differential attenuation developed by Smyth and Illingworth (1998). The retrieval of specific attenuation (A_H) by this technique is also useful since it is related by a power law to rain rate (R). A_H is also independent of the radar constant and available at the basic resolution of the radar unlike the specific differential phase (K_{DP}) employed in other polarimetric estimators which is typically averaged over 10-20 range gates.

The power based radar measurements were further checked for internal consistency against values implied by the measured specific differential phase (K_{DP}). The difference between measured and theoretical values (from scattering simulations) of Z_H and Z_{DR} at given K_{DP} values were deduced on a volume by volume basis. The 15-85 percentile values of the observed K_{DP} distribution were employed to compare Z_H and Z_{DR} values. The mean difference for each volume was incorporated into a two hour running mean and these offsets were then applied to bias correct (BC) Z_H and Z_{DR} values. Mean Z_H/Z_{DR} biases were 2.2/0.06 dB (CPOL low). The 2.2 dB figure is consistent with a failure to account for the finite bandwidth loss in the calibration of CPOL. Values without bias correction (NBC) are indicated.

T-matrix scattering simulations based in part on SCSMEX drop size distribution data from Dongsha Is, were used to develop the rainfall estimators summarised in Table 1. CPOL rainfall estimates were derived from the 1.2° elevation tilt undertaken every ten minutes.

Being an oceanic site only a limited amount of direct validation rainfall data were available. Two optical rain gauges (ORG) were located on the PRC Shiyan #3 (20.4°N 116.52°E), and an acoustic rain gauge (ARG) was located on an ATLAS mooring (20.37° N 116.52°E), as shown in Fig. 1. Tipping bucket rain gauges (TBG) on Dongsha Is were too close for direct validation of CPOL rainfall estimates. It is apparent that the ARG was located in a relative minimum of precipitation.

The gauge validation data have different characteristics, as shown in Fig. 2. The four TBGs located on Dongsha Is reported similar rain rate frequencies. The two ship-based ORGs did not report rain rates > 20 mm h^{-1} and had more frequently reported rain in the range 4-10 mmh^{-1}, at least compared to the other gauges. The ARG tended to

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Corresponding author address: Dr T. Keenan, BMRC, GPO Box 1289K, Melbourne, Australia, 3001; email: T.Keenan@bom.gov.au

have less frequent rain rates in the range 1-10 mm h^{-1}, than both the ORG and the TBGs.

It is well known that the measurement of rain on ships is notoriously difficult. Given the lack of high rain rates with the ORG these data have been excluded from this preliminary analysis.

Table 1 Summary of Radar Rainfall Estimators

$$R(K_{DP}) = 32.4 K_{DP}^{0.85} \; for \; Z_H \geq 35; K_{DP} \geq 0.5$$
$$else = R(Z_H)$$
$$R(A_H) = 312 A_H^{0.86} \; for \; Z_H \geq 35; A_H > 0$$
$$else = R(Z_H)$$
$$R(K_{DP}, Z_{DR}) = 60 K_{DP}^{0.93} 10^{0.24 Z_{DR}} \; for \; Z_H \geq 35; K_{DP} \geq 1; Z_{DR} > 1$$
$$else \; R(K_{DP}, Z_{DR}) = R(K_{DP})$$
$$R(A_H, Z_{DR}) = 895 A_H^{0.98} 10^{0.3 Z_{DR}} \; for \; Z_H \geq 35; Z_{DR} > 1$$
$$else \; R(A_H, Z_{DR}) = R(A_H)$$
$$R(Z_H) = 0.015(10^{Z_H/10})^{0.734}$$
$$R(Z_H^{UC}) = 0.015(10^{Z_H^{UC}/10})^{0.734}$$
$$where \; Z_H = attenuation \; corrected \; horizontal \; refelectivity$$
$$and \; Z_H^{UC} = uncorrected \; horizontal \; reflectivity$$

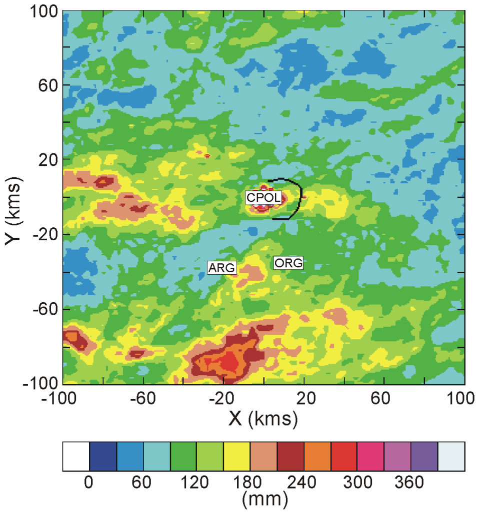

Fig. 1 Accumulated precipitation (BC) for period 15-19 May estimated by R(K$_{DP}$,Z$_{DR}$) with gauge and radar locations.

In order to compare the radar and ARG data, the gauge rain rate data have been averaged over approximately fifteen minutes and the radar over an area of 4 km^2. The mean rain rate (during rain) as measured by the ARG was 5.9 mm h^{-1}. This means the polarimetric rainfall estimators employed in this study often default to the R(Z$_H$) estimator (see Table 1).

3. COMPARISON OF ARG AND POLARIMETRIC ESTIMATORS

Most of the radar rain rate estimators based on polarimetric information employed in this study were consistent as summarised in Table 2. All approaches tended to overestimate the rain rates measured by the ARG although the NBC differences were relatively small with the exception of R(A$_H$). Examination of individual plots, as shown in Fig. 3, indicates the positive bias is partly a result of the ARG indicating no rain when the radar often estimated non-zero values. The BC values showed increased bias.

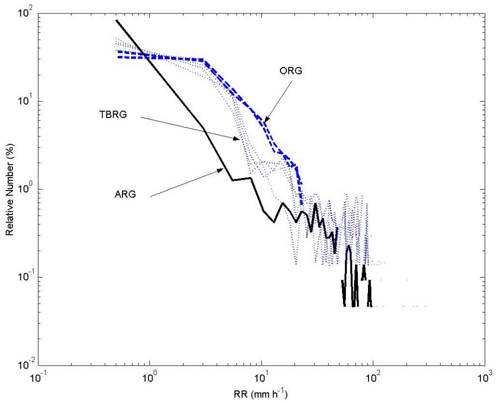

Fig. 2 Comparison of rain rate distributions from acoustic gauge (ARG), optical gauge (ORG) and tipping bucket gauges (TBG) observed during SCSMEX.

R(A$_H$) exhibited the largest positive bias compared to the ARG. With the use of Z$_{DR}$ as an additional discriminator, this bias was reduced significantly.

R(Z$_H$) was equivalent in performance to the polarimetric results. This is in part expected due to the low rain rates of the validation sample. However, R(Z$_H$) employs an attenuation correction based on K$_{DP}$. Without this “polarimetric” contribution, the ARG rain rates are underestimated by 25% as shown (see NBC R(Z$_H$^{UC})) in Table 2. As expected bias values in the R(Z$_H$) estimators increased with BC. This impact of Z$_H$ changes is likely to be responsible for increases in the positive bias of the polarimetric estimators given their dependence on Z$_H$ at low rain rates (Table 1).

Table 2. Comparison of rain rates (NBC/BC) estimated by CPOL and ARG during SCSMEX for the period 15-19 May 1998.

	NB (%)	MAD (mm h^{-1})	MSE (mm h^{-1})	Correlation
R(K$_{DP}$)	5.0/17	0.68/0.74	3.9/3.9	0.81/0.81
R(A$_H$)	22./29.	0.71/0.75	3.7/3.7	0.83/0.83
R(K$_{DP}$,Z$_{DR}$)	-1.7/8.3	0.66/0.72	4.1/4.1	0.78/0.78
R(A$_H$,Z$_{DR}$)	7.0/9.1	0.66/0.70	4.1/4.0	0.79/0.79
R(Z$_H$)	-5.6/31.	0.68/0.77	3.8/3.8	0.82/0.82
R(Z$_H$^{UC})	-25./2.8	0.66/0.72	4.3/3.9	0.78/0.81

NB=Normalised Bias, MAD=Mean Absolute Deviation, MSE=Mean Square Error

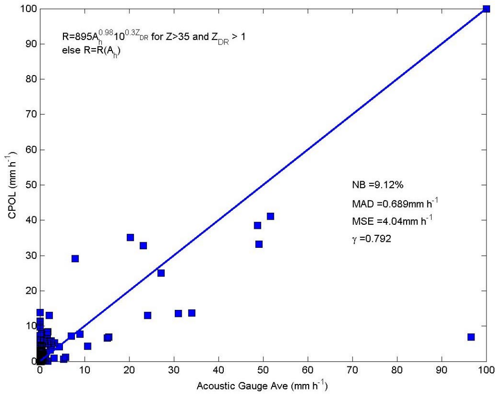

FIG. 3 Comparison of BC R(A_H,Z_{DR}) and ARG rain rates over period 15-19 May, 1998.

A comparison of the NBC accumulated rainfall for various time periods, as summarised in Table 3 shows that the R(Z_H) based approaches underestimated both the ARG rainfall and that estimated from polarimetric approaches. This is consistent with the previous rain rate findings. With BC, the accumulations were biased positively with respect to the ARG totals.

TABLE 3. Comparison of rain accumulations (NBC/BC) estimated by CPOL and ARG during SCSMEX for the period 15-19 May 1998

Period (h)	Technique	NB (%)	MSE (mmh^{-1})	Correlation
1	R(K_{DP})	5.9/20.	1.4/1.5	0.93/0.93
	R(A_H)	27./34.	1.5/1.5	0.93/0.93
	R(K_{DP},Z_{DR})	-2.0/9.9	1.5/1.6	0.92/0.91
	R(A_H,Z_{DR})	8.3/11.	1.7/1.6	0.90/0.91
	R(Z_H^{UC})	-30./3.3	2.2/1.6	0.93/0.93
	R(Z_H)	-6.6/37	1.6/1.6	0.93/0.92
3	R(K_{DP})	5.9/20.	2.6/2.8	0.93/0.92
	R(A_H)	27./34.	3.0/3.1	0.92/0.93
	R(K_{DP},Z_{DR})	-2.0/9.9	2.8/2.9	0.91/0.91
	R(A_H,Z_{DR})	8.3/11.	3.1/3.0	0.90/0.91
	R(Z_H^{UC})	-30./3.3	3.7/2.7	0.93/0.93
	R(Z_H)	-6.6/37	2.9/3.4	0.92/0.91
12	R(K_{DP})	5.9/20.	5.0/6.2	0.94/0.94
	R(A_H)	27./34.	6.7/7.2	0.95/0.95
	R(K_{DP},Z_{DR})	-2.0/9.9	5.5/6.2	0.92/0.91
	R(A_H,Z_{DR})	8.3/11.	6.8/6.6	0.91/0.91
	R(Z_H^{UC})	-30./3.3	6.4/4.7	0.94/0.93
	R(Z_H)	-6.6/37.	4.1/8.4	0.95/0.94
24	R(K_{DP})	5.9/20.	8.1/9.5	0.89/0.87
	R(A_H)	27./34.	9.7/10.5	0.90/0.90
	R(K_{DP},Z_{DR})	-2.0/9.9	9.3/10.1	0.84/0.83
	R(A_H,Z_{DR})	8.3/11.	11./10.7	0.82/0.81
	R(Z_H^{UC})	-30./3.3	11./8.1	0.90/0.88
	R(Z_H)	-6.6/37.	7.5/12.3	0.90/0.88

The MSE values indicate no major difference in deviations or spread of the estimates compared to the ARG for accumulations taken over periods up to three hours

4. STRUCTURE OF SCSMEX PRECIPITATION FIELDS

The total precipitation field for the five day period shows significant spatial variability as shown in Fig. 1. This variability is directly linked to the path of mesoscale systems observed during the monsoon onset. In the mean, the radar estimators exhibited a range dependent decrease in rainfall over the five day period. Without BC this was about –0.2 mm km^{-1} but with BC decreased in magnitude to about -0.13 mm km^{-1}. As a function of range, the BC process also increased the consistency between estimators employing some sort of polarimetric input i.e. the spread was less after BC.

5. SUMMARY

This paper has presented results of a preliminary investigation of the accuracy of various polarimetric and non-polarimetric radar rainfall estimators operating within the oceanic domain of SCSMEX. Limited point validation data were available for this study and conclusions must be tentative. The results imply polarimetric radar approaches offer significant advantages at C-Band in the tropics where attenuation is important. Further work will compare the CPOL estimates to those obtained from the NOAA/TOGA radar located the Shiyan #3 and to those estimated by the TRMM satellite.

6. ACKNOWLEDGEMENTS

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