Intercomparison of IRS-P4-MSMR derived geophysical products with DMSP-SSM/I and TRMM-TMI finished products

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In this paper, MSMR geophysical products like Integrated Water Vapour (IWV), Ocean Surface Wind Speed (OWS) and Cloud Liquid Water (CLW) in different grids of 50, 75 and 150 kms are compared with similar products available from other satellites like DMSP-SSM/I and TRMM-TMI. MSMR derived IWV, OWS and CLW compare well with SSM/I and TMI finished products. Comparison of MSMR derived CLW with that derived from TMI and SSM/I is relatively in less agreement. This is possibly due to the use of 37 GHz in SSM/I and TMI that is highly sensitive to CLW, while 37 GHz channels are not available on MSMR. Monthly comparison of MSMR geophysical products with those from TMI is all carried out for climatological purpose. The monthly comparisons were much better compared to instantaneous comparisons. In this paper, details of the data analysis and comparison results are presented. The usefulness of the MSMR vis-à-vis other sensors is also discussed.

1. Introduction

Integrated Cloud Liquid Water (CLW), Integrated Water Vapour (IWV), Ocean Wind Speed (OWS), and Sea Surface Temperature (SST) are integral components of the ocean observation system. Their spatial and temporal distribution is required for both weather and climatic studies. The Multifrequency Scanning Microwave Radiometer (MSMR) onboard the Indian satellite IRS-P4 (Oceansat-1) has been providing measurements of these geophysical parameters (GPDs) over global oceans since June 1999.

MSMR channel combination was earlier available in SMMR on Seasat/Nimbus-7 in 1978–87. Despite calibration problems, Nimbus provided IWV, OWS and SST for a variety of useful applications. Subsequent to Nimbus was the DMSP (Defense Meteorological Satellite Program) series of satellites, which carried the Special Sensor Microwave Imager (SSM/I) that provided CLW, IWV and OWS over global oceans since 1987. More recently, in 1998 the Tropical Rainfall Measuring Mission (TRMM) satellite was launched with a microwave radiometer (TMI) that provided global measurements of CLW, IWV, OWS and SST. Data from SSM/I and TMI have been very effectively used for rain rate measurements over land and oceans. An extensive comparison of GPDs from SSM/I and TMI has been carried out with *in situ* and other satellites (Hollinger 1990, Alishouse *et al* 1990a and b; Goodberlet *et al* 1990; Varma *et al* 1998; Varma 1999).

For the effective use of the parameters, comparison of MSMR derived GPDs with *in situ*, model observations, and with similar products from other

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Table 1. *Salient features of retrieval algorithms.*

Features		MSMR algorithm	Wentz algorithm
1. Type		Statistical technique using Radiative Transfer Simulations (Gohil *et al* 2000)	Minimization approach between measured and simulated brightness temperatures (Wentz, 1997).
2. Channels for-			
	IWV	18V, 18H, 21V, 21H	V22, V37, H37
	WS	6V,6H,10V,10H,18V,18H,21V,21H 10V,10H,18V,18H,21V,21H	V22, V37, H37
	CLW	18V,18H,21V,21H	V22, V37, H37
	SST	6V,6H,10V,10H,18V,18H,21V,21H	
3. Other inputs in retrieval algorithms		Climate SST and incidence angle	Average SST and incidence angle

satellites is essential. Ali (2000) has presented a comprehensive comparison of all GPDs (except CLW) with *in situ* and analysed fields, and found reasonably good agreement. Varma *et al* (1999) have compared scan mode MSMR derived CLW, IWV and OWS with similar products from SSM/I over the Indian Ocean region. The present study is aimed at inter-comparison of MSMR derived gridded products (except SST) with similar products from SSM/I and TMI over the global oceans.

The difference in MSMR GPDs with respect to SSM/I and TMI are due to the difference in their frequencies at which measurements are made, noise figures and algorithm. The basic features of retrieval algorithm for SSM/I and TMI, and MSMR are shown in table 1, which shows the difference in the basic approach as well as the channels used.

2. Instruments and data

2.1 *IRS-P4 MSMR data*

MSMR on board IRS-P4 (Oceansat-I) provides measurement of brightness temperatures (Tbs) at 6.6, 10, 18 and 21 GHz frequencies in both horizontal and vertical polarisations. IRS-P4 is in a sun synchronous orbit with ascent at equator at 2340 hr and descent at 1140 hr local time. The four operational products available from MSMR are Cloud Liquid Water (CLW), Integrated Water Vapour (IWV), Ocean Surface Wind Speed (OWS) and Sea Surface Temperature (SST). MSMR products are generated in three resolution grids of 150, 75 and 50 kms, respectively. Derivation of CLW and IWV use only high frequency channels, and they are available in all three grids. OWS is available in two grids of 150 and 75 km, with the use of all 8 channels in 150 km grid, and use of 6 channels in 75 km grid (without 6 GHz). Derivation of SST uses all 8 channels and thus is available only in 150 km grid. Table 2 shows the theoretical accuracy of MSMR products.

Table 2. *Theoretical retrieval accuracy of MSMR GPDs.*

Parameter	Tropic	Midlat	Polar
SST (K) (grid 1)	1.52	1.92	1.90
OWS (ms^{-1}) (grid 1)	1.63	1.59	1.51
OWS (ms^{-1}) (grid 2)	2.10	2.00	1.91
IWV ($g\ cm^{-2}$)' (grids 1,2, 3)	0.20	0.18	0.15
CLW ($mg\ cm^{-2}$) (grids 1, 2, 3)	13.0	11.0	9.0

MSMR geophysical data are available daywise (24 hrs) in three grids as mentioned above, with data quality flag.

2.2 *SSM/I and TMI data*

SSM/I is a four frequency, seven channel radiometer. The SSM/I is operated at 19.35, 22.235, 37.0 and 85.5 GHz frequencies. TMI frequencies are almost similar to SSM/I except for additional 10.7 GHz frequency and a 21.3 GHz frequency instead of 22.235 GHz for SSM/I. TMI and SSM/I operate in dual polarizations, V and H, except 22.235 GHz that operates only in V polarization. Three satellites which carry onboard SSM/I, namely F11, F13 and F14, are presently operational in sun-synchronous orbit with equator ascending time at 1925, 1754 and 2046 LST, respectively. On the other hand, TMI onboard TRMM (Tropical Rainfall Measuring Mission) satellite is in a low altitude (218 miles), low inclination, and non-sun-synchronous orbit.

The SSM/I -F13 and -F14 global swath mode data are provided by Global Hydrology Resource Centre (GHRC) of NOAA/USA. The data are available with footprint sampling resolution of 25 km for 19, 22 and 37 GHz channels (called low

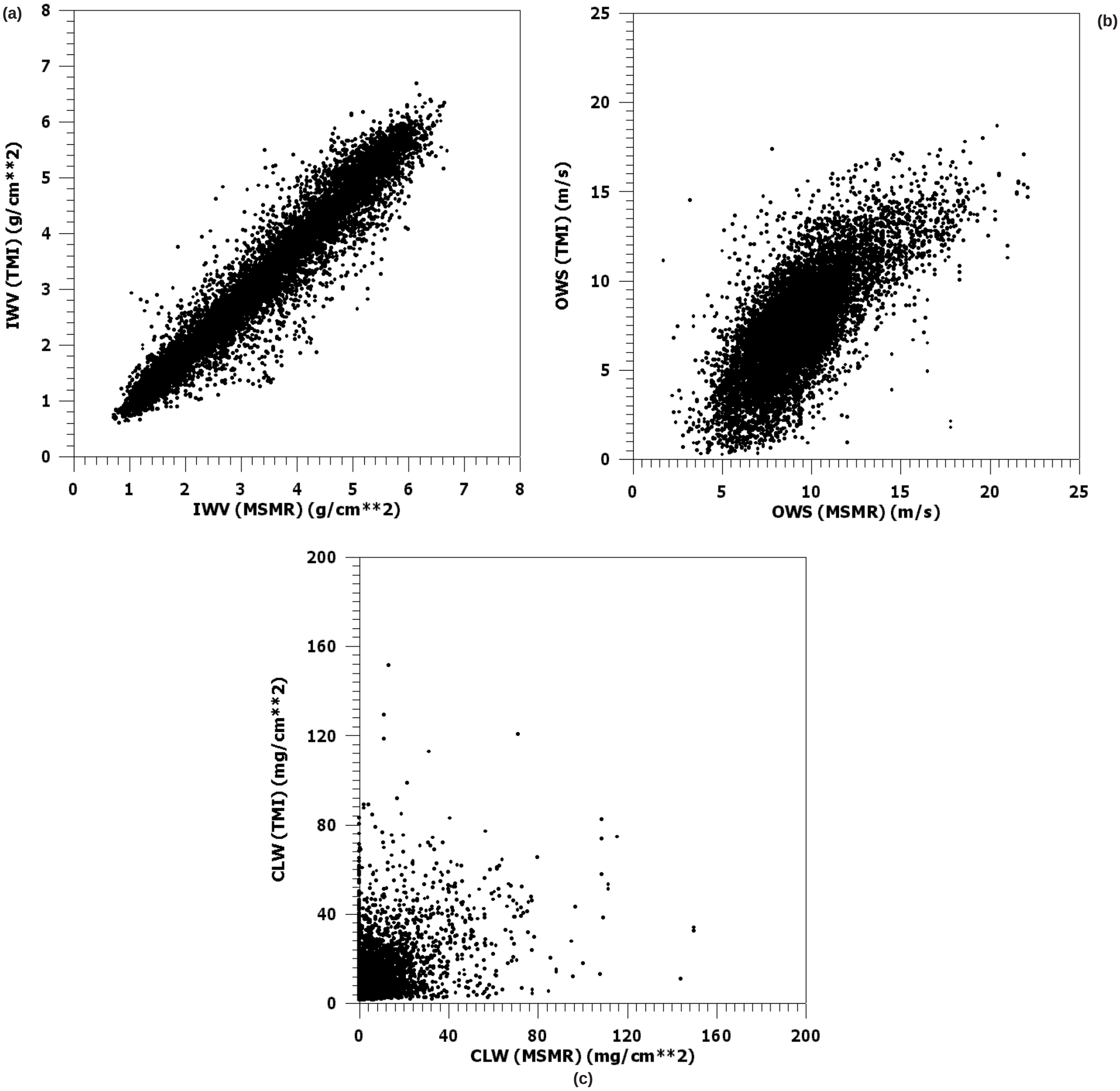

Figure 1. **(a)** Comparison of colocated and near simultaneous (< 1 hr.) global measurements of Integrated Water Vapour (IWV) from MSMR and TMI for 150 km grid. **(b)** Same as figure 1(a) but for Ocean Surface Wind Speed (OWS). **(c)** Same as figure 1(a) but for Cloud Liquid Water (CLW).

frequency channels) and 12.5 km for 85 GHz channels (called high frequency channels) over a swath of 1400 km. The data comprise brightness temperature of all seven channels and three derived geophysical parameters over oceans, viz., CLW, IWV and OWS in addition to the quality flags. A careful examination of OWS values in SSM/I data stream has revealed that OWS values are computed only when CLW is below 13.5 mg cm^{-2}.

The algorithms for TMI finished products are developed by Wentz, and the Wentz products are available from Global Hydrology Resource Centre (GHRC), NASA, USA. In addition to CLW, IWV and OWS, TMI finished product also provided measurements of SST and rain rate. The accuracy of TMI products is not directly available but it is expected that they will have the accuracy of the same order (or even better) as that of SSM/I products. Careful examination of OWS values in TMI data stream indicate that OWS values are provided only when CLW is less than ~ 33 mg cm^{-2}.

Alishouse *et al* (1990b) also noted that SSM/I brightness temperatures are highly correlated with non-precipitating CLW over ocean. Accuracy of

Table 3(a). *Comparison of integrated water vapour: TMI vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
50 km	< 1 hr	27543	0.94	−0.03	0.96	−0.23	0.40	0.46
	< 2 hr	44692	0.94	−0.03	0.96	−0.22	0.40	0.46
	< 3 hr	60859	0.94	−0.02	0.96	−0.20	0.40	0.45
75 km	< 1 hr	26626	0.95	−0.03	0.96	−0.22	0.40	0.46
	< 2 hr	43238	0.94	−0.03	0.96	−0.22	0.40	0.46
	< 3 hr	58898	0.95	−0.02	0.96	−0.20	0.41	0.46
150 km	< 1 hr	10884	0.96	−0.07	0.96	−0.21	0.37	0.43
	< 2 hr	17673	0.96	−0.06	0.96	−0.21	0.38	0.43
	< 3 hr	23953	0.96	−0.05	0.96	−0.19	0.38	0.53

Table 3(b). *Comparison of integrated water vapour: SSM/I F14 vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
50 km	< 2 hr	15245	0.99	−0.23	0.95	−0.26	0.49	0.55
	< 3 hr	97411	0.97	−0.17	0.95	−0.23	0.47	0.52
75 km	< 2 hr	13807	0.99	−0.23	0.95	−0.26	0.50	0.56
	< 3 hr	97750	0.98	−0.16	0.95	−0.23	0.48	0.53
150 km	< 2 hr	5065	1.01	−0.27	0.95	−0.26	0.48	0.54
	< 3 hr	37618	0.99	−0.18	0.95	−0.22	0.45	0.51

Table 4(a). *Comparison of ocean wind speed (m/s): TMI vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
75 km	< 1 hr	24953	0.71	0.87	0.66	−1.81	2.31	2.93
	< 2 hr	40321	0.72	0.77	0.67	−1.85	2.29	2.95
	< 3 hr	54246	0.72	0.76	0.68	−1.87	2.31	2.97
150 km	< 1 hr	10254	0.84	−0.31	0.73	−1.78	2.01	2.68
	< 2 hr	16570	0.85	−0.42	0.73	−1.82	1.99	2.70
	< 3 hr	22196	0.85	−0.41	0.74	−1.84	2.00	2.72

Table 4(b). *Comparison of ocean wind speed (m/s): SSM/I F14 vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
75 km	< 2 hr	9131	0.78	1.10	0.67	−1.01	2.84	3.01
	< 3 hr	66354	0.79	0.63	0.72	−1.41	2.51	2.88
150 km	< 2 hr	3342	0.91	−0.25	0.75	−1.07	2.40	2.63
	< 3 hr	25658	0.88	−0.46	0.77	−1.57	2.18	2.69

Table 5(a). *Comparison of cloud liquid water (mg/cm^2): TMI vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
	< 1 hr	25923	0.42	7.97	0.52	4.42	12.91	13.64
50 km	< 2 hr	42240	0.39	8.14	0.50	4.40	13.18	13.90
	< 3 hr	57530	0.38	8.32	0.49	4.40	13.59	14.29
	< 1 hr	25077	0.36	8.33	0.48	4.57	13.82	14.56
75 km	< 2 hr	40894	0.34	8.45	0.46	4.54	13.99	14.71
	< 3 hr	55716	0.34	8.62	0.45	4.54	14.32	15.03
	< 1 hr	10219	0.44	7.95	0.44	5.39	10.60	11.89
150 km	< 2 hr	16670	0.42	8.00	0.44	5.32	10.65	11.91
	< 3 hr	22616	0.41	8.19	0.42	5.39	10.92	12.18

Table 5(b). *Comparison of cloud liquid water (mg/cm^2): SSMI F14 vs. MSMR.*

Grid	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
50 km	< 2 hr	14980	0.47	8.65	0.40	4.22	19.90	20.35
	< 3 hr	87916	0.44	8.80	0.37	4.51	18.55	19.09
75 km	< 2 hr	11882	0.51	10.13	0.42	6.04	20.37	21.25
	< 3 hr	76868	0.47	10.14	0.38	6.04	19.08	20.02
150 km	< 2 hr	4408	0.55	9.74	0.38	6.64	17.78	18.98
	< 3 hr	29620	0.51	10.04	0.33	6.90	17.55	18.85

CLW from SSM/I is $10\,\mathrm{mg\,cm^{-2}}$ over oceans (Hollinger 1990; Alishouse *et al* 1990b). They further found that 37 GHz is alone a good predicator of CLW with a correlation coefficient of 0.87 between surface and satellite measurements. The accuracy of the IWV over oceans measured from SSM/I is found as $0.2\,\mathrm{g\,cm^{-2}}$ over a range of 0 to $8\,\mathrm{g\,cm^{-2}}$ (Alishouse 1990a; Hollinger 1990). The comparison of SSM/I OWS with *in situ* data has revealed an accuracy of $2\,\mathrm{ms^{-1}}$ over the range of 3 to $25\,\mathrm{ms^{-1}}$ (Goodberlet *et al* 1990). A detailed comparison of SSM/I winds with Geosat-Altimeter and TOPEX-altimeter has been earlier carried out (Varma *et al* 1998; Varma 1999). In all the cases a good correlation is found between two measurements of OWS.

3. Data Analysis and Results

3.1 *Comparison of concurrent observations of IWV, CLW and OWS from MSMR with TMI and SSM/I*

For comparison of IWV, CLW and OWS, we have used global MSMR data on different grids (50, 75 and 150 kms) of 7 days of July, 1999. Data are colocated with near concurrent SSM/I and TMI finished products. As the SSM/I and TMI are available on higher resolution, before analysis, data are averaged on three different MSMR grids. MSMR data over all three grids is colocated with SSM/I and TMI data separately, in $1^\circ \times 1^\circ$ spatial and 1, 2 and 3 hours of temporal bins. If in this space-time bin, more than one data point is found colocated in any bin, average value is computed. Figure 1 (a, b, and c) shows, comparison of IWV, OWS and CLW from MSMR and TMI within 1 hour (i.e., colocated in 1 hour temporal bin) for 150 km grid. Table 3(a) and (b) shows comparison statistics of IWV derived from MSMR with that derived from TMI and SSM/I-F14, respectively. A good comparison of MSMR derived IWV is observed with TMI and SSM/I derived IWV in all the three grids and temporal differences. Table 4(a) and (b) shows comparison statistics of OWS derived from MSMR with that derived from TMI and SSM/I-F14, respectively. OWS from MSMR is available only in 75 km and 150 km grids. In 75 km grid OWS estimation is carried out without the use of 6 GHz channel, whereas in 150 km grid all 8 channels are used for wind estimation. A reasonably good comparison of MSMR derived OWS is observed with TMI and SSM/I derived OWS in both the grids and with different temporal differences. It may be noted here that MSMR OWS is derived with the use of all 8 channels (i.e., in 150 km grid) is better correlated with TMI and MSMR OWS than that measured with only 6 channels (i.e., without the use of 6 GHz channels) in 75 km grid. Tables 5(a) and (b) show comparison statistics of CLW derived from MSMR with

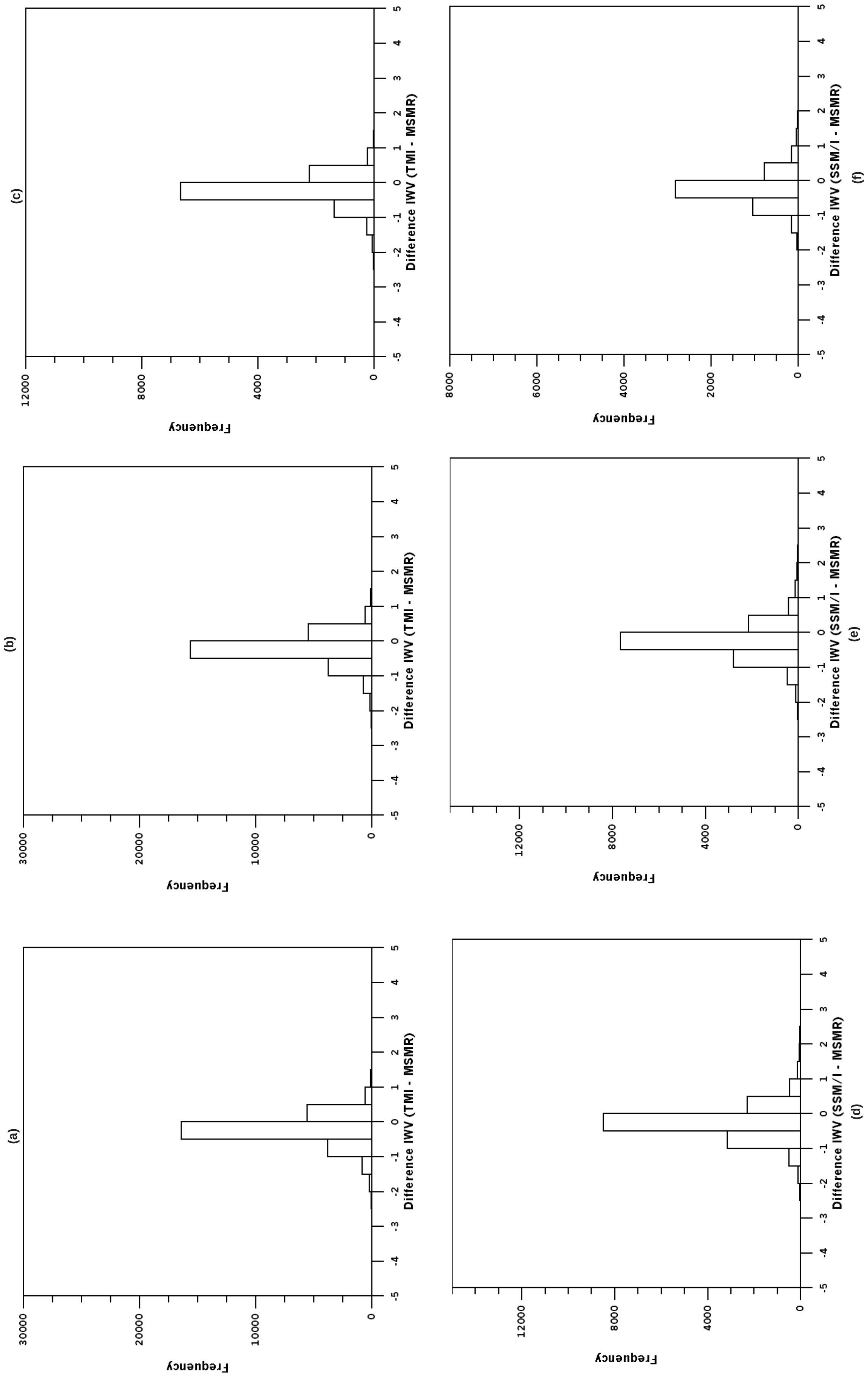

Figure 2. **(a–c)**. Histogram of difference of MSMR and TMI derived colocated and near simultaneous ($<$ 1 hr) IWV values for 50, 75 and 150 km grids, respectively. **(d–f)**. Same as figure 2 (a–c) but for MSMR and SSM/I derived colocated and near simultaneous ($<$ 2 hr) IWV values.

Table 6. *Comparison of IWV, OWS and CLW from TMI and SSM/I-F14.*

Para.	Time	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
IWV	< 1 hr	5153	1.04	−0.26	0.99	−0.09	0.18	0.20
OWS	< 1 hr	4279	0.89	0.61	0.92	−0.21	1.11	1.13
CLW	< 1 hr	4769	1.20	0.25	0.84	2.44	10.60	10.87

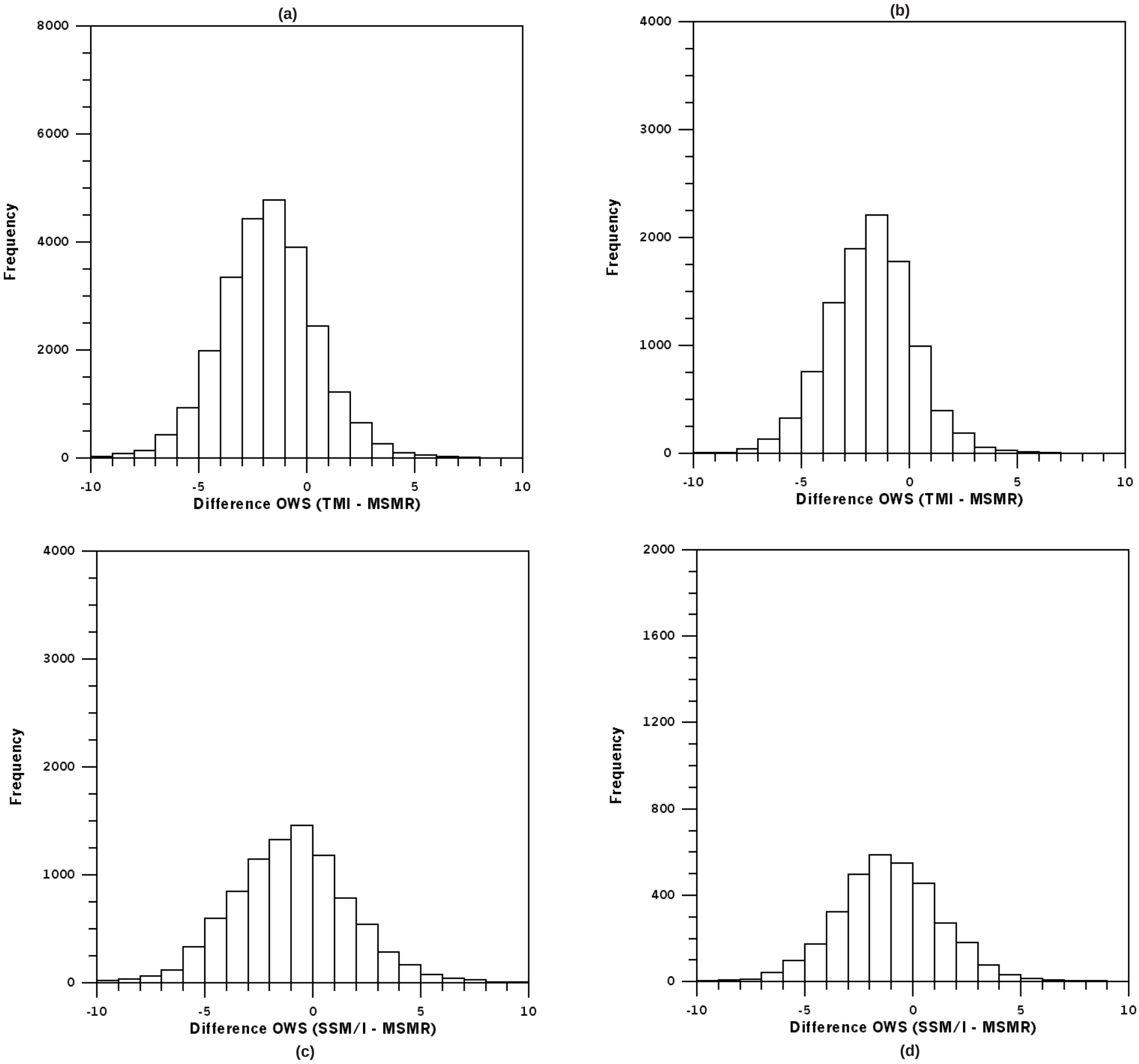

Figure 3. **(a–b)**. Same as figure 2(b–c) but for OWS. **(c–d)**. Same as figure 2(e–f) but for OWS.

that derived from TMI and SSM/I-F14, respectively. The results are not very encouraging. This may be partly because of high spatial and temporal variability of the CLW, and partly because of the absence of 37 GHz channels in MSMR which is highly (about 87%) correlated with the CLW (Alishouse 1990b).

In order to establish the consistency of the present results of MSMR comparison of IWV, OWS and CLW with other sensors, a further study of comparison of these parameters from TMI and SSM/I is also carried out and briefly presented in table 6. It is found that these parameters from TMI and SSM/I match very well with a high value

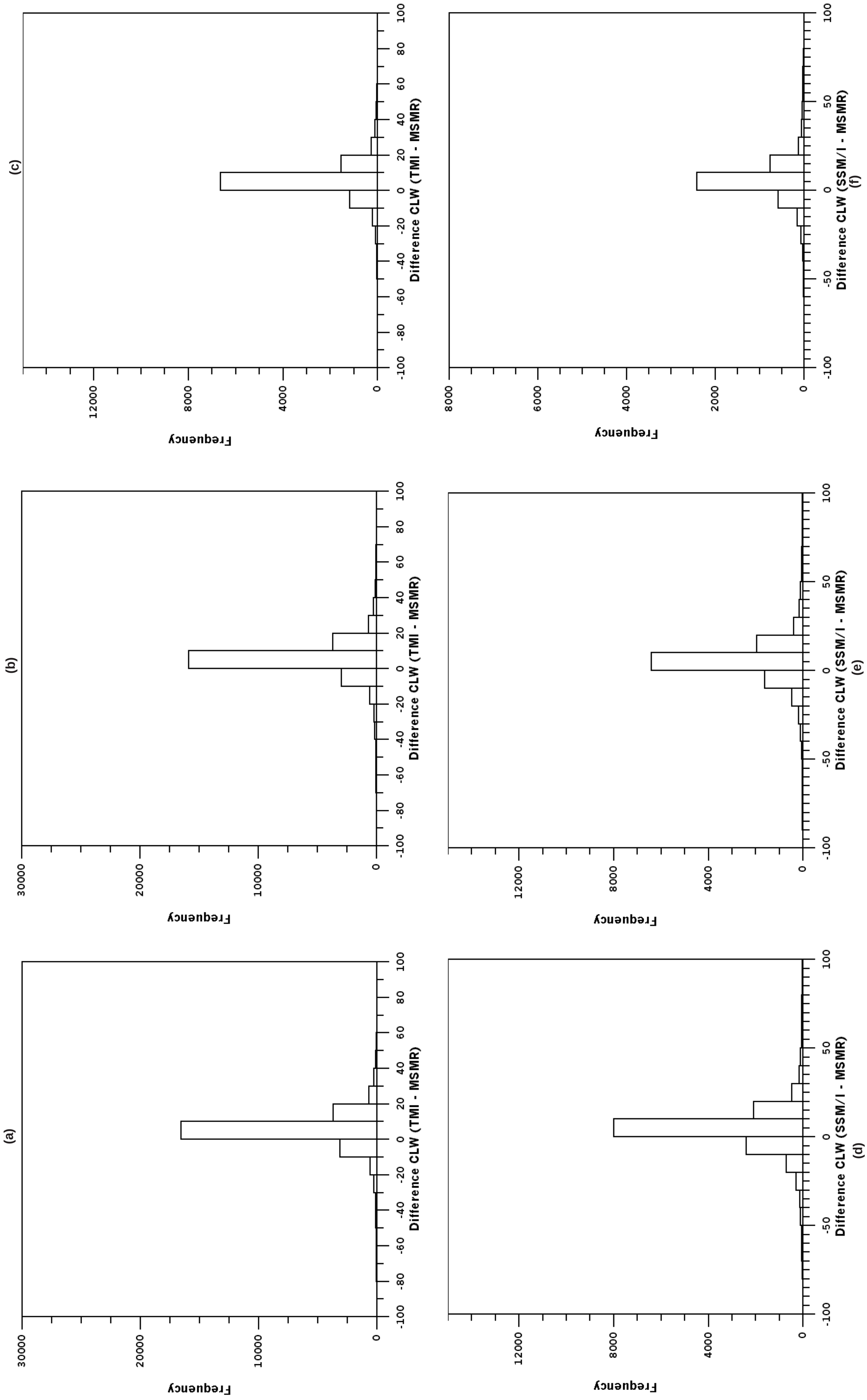

Figure 4. **(a–c)**. Same as figure 2(a–c) but for CLW. **(d–f)**. Same as figure 2(d–f) but for CLW.

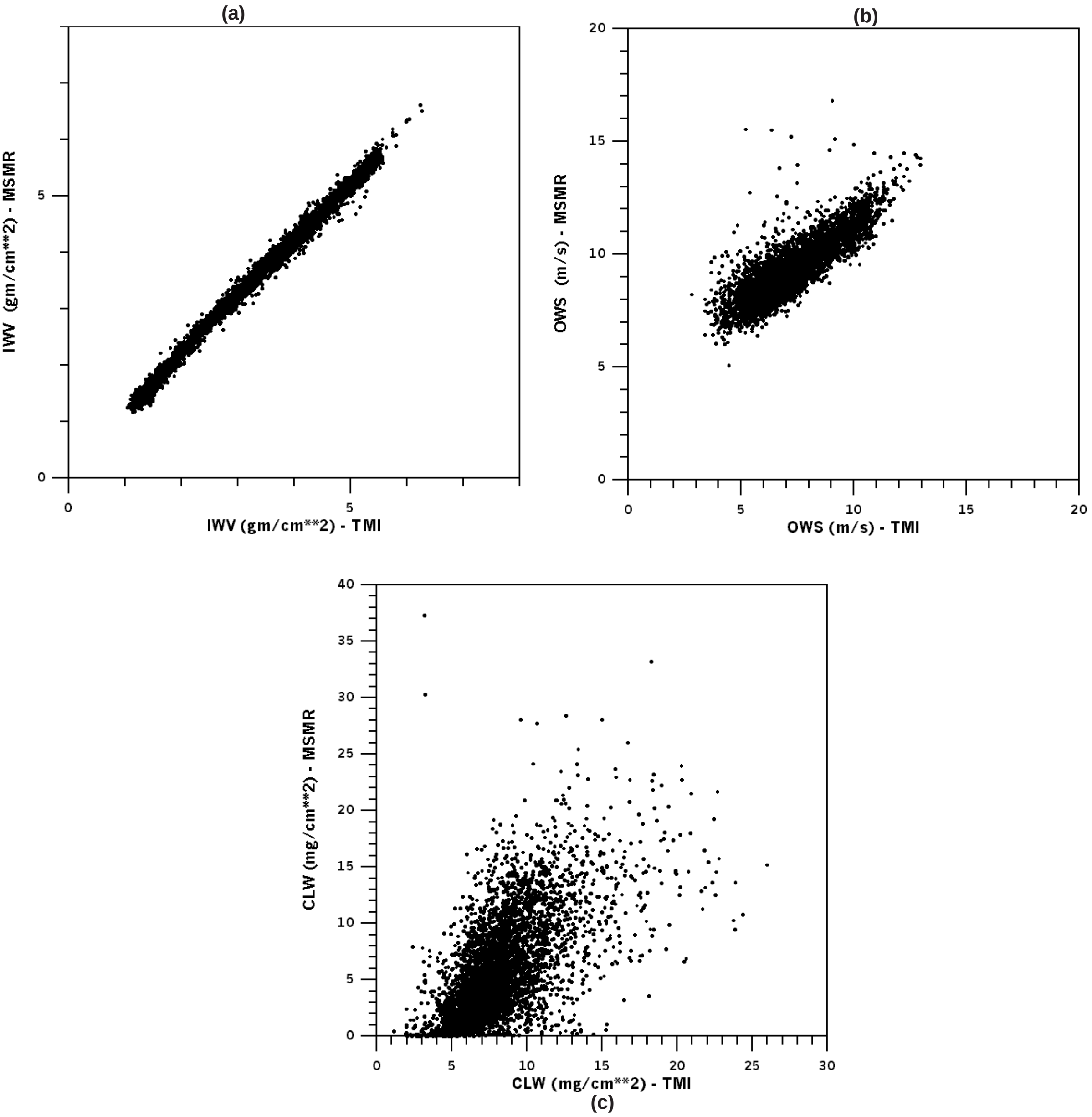

Figure 5. (a–c). Comparison of monthly averaged and grided (2° × 2°) IWV, OWS, and CLW from MSMR and TMI.

Table 7. *Comparison of monthly averaged fields from MSMR and TMI.*

Para.	No. of pts.	Slope	Interc.	R	Bias	S.D. of diff.	rms diff.
IWV	4524	0.99	−0.18	1.00	−0.20	0.10	0.23
OWS	4524	1.05	−2.52	0.84	−2.07	0.89	2.25
CLW	4524	0.40	5.90	0.62	2.33	3.55	4.25

of correlation coefficient, less bias and root mean square (rms) difference. This is since both the TMI and SSM/I have more similarity compared to MSMR.

We have also plotted the difference of IWV, OWS and CLW from TMI and MSMR and from SSM/I and MSMR, in all the grids (figures 2, 3 and 4). It is found that except CLW, IWV and OWS are slightly over estimated by MSMR as compared to TMI and SSM/I. CLW is generally underestimated by MSMR. For IWV about 80% of the points fall within 0.5 gm cm^{-2} of the difference and 96% falls within 1.0 gm cm^{-2} of the difference. Similarly, for OWS within the difference of 3 m/s, 70% points fall without use of the 6 GHz channel, and 73% with the use of the 6 GHz channel. In the case of CLW, about 76% points fall within the difference of 10 mg cm^{-2} from TMI observations.

3.2 *Comparison of monthly fields from MSMR with TMI*

In order to establish the coherence of MSMR derived GPDs on monthly scale that may show its usefulness for climatological studies, we have averaged MSMR and TMI derived parameters on a monthly scale and plotted them in figure 5. MSMR and TMI fields are averaged for the month of August 1999 in a grid of $2^\circ \times 2^\circ$ (latitude–longitude). As expected the monthly fields of MSMR are better compared with TMI. Other statistical details are given in table 7.

4. Conclusions and discussion

MSMR derived IWV values have a very good agreement with TMI and SSM/I derived IWV values with high correlation, low bias and rms difference. Results do not vary significantly with grid size. On the other hand, MSMR derived OWS values in 150 km grid are in better agreement with TMI and SSM/I derived values. This is partly because of the inclusion of 6 GHz brightness temperatures in the retrieval algorithm and partly because of the reduction of noise in large sized grids. MSMR derived CLW is not in good agreement with TMI and SSM/I derived values. This is possibly because of the absence of 37 GHz channels and high variability of the CLW.

Statistics presented in figures reveal that MSMR, in general, over estimates OWS and IWV as compared to TMI and SSM/I. However a critical look at the figures, reveal that lower values of the OWS are under estimated by MSMR and high values are over estimated.

5. Acknowledgement

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