

Study of the relationship between non-dimensional roughness length and wave age, effected by wave directionality

Naoya Suzuki¹, Naoto Ebuchi², Chaofang Zhao^{1;3}, Isao Watabe⁴ and Yasuhiro Sugimori¹

¹Center for Environmental Remote Sensing (CEReS), Chiba University, 1-33 Yayoi Inage Chiba, 263-8522 Japan.

²Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University, Aoba, Sendai 980-8578, Japan.

³Ocean Remote Sensing Laboratory, Ocean University of Qingdao, China.

⁴National Research Institute for Earth Science and Disaster Prevention, Science and Technology Agency, 9-2 Nijigahama, Hiratsuka, Kanagawa, 254-0823 Japan.

Relationship between the non-dimensional roughness length and inverse wave age has been discussed without consideration of wave directions, though wind wave field consists of various directional component waves. In this study we observe wave heights by an array of four wave gauges at the Hiratsuka Tower of (Independent Administrative Institution) National Research Institute for Earth Science and Disaster Prevention (NIED), Japan, and discuss the effect of wave directionality. As a result, the data sets were classified into two different groups according to the directional wave spectrum distribution. In case 1 only swell and wind waves exist and in case 2 there exist wave components from several directions. It is shown that the case of multiple-directional component waves (case 2) may affect the non-dimensional roughness length and friction velocity.

1. Introduction

The sea surface wind stress has generally been estimated using the drag coefficient C_D . Many efforts have recently been made to elucidate the wave dependence of the sea-surface roughness parameter z_0 , which has one-to-one correspondence to C_D under near-neutral conditions. However, there still exists considerable disagreement among investigators for the parameterization of the coefficient, especially for its dependence on wave growth.

In order to estimate the wind stress and roughness length, Charnock's (1955) well known formula,

$$\frac{gz_0}{u^2} = \alpha; \quad (1)$$

has widely been utilized, where g is the acceleration

of gravity, and α is a constant. For the value of α , there seems to be considerable disagreement among authors. For example, Charnock (1955) proposed 0.0068, Smith and Banke (1975) gave 0.0130, Garrat (1977) suggested 0.0144, and Wu (1980) proposed 0.0185. A possible reason for the disagreement might be poor quality and quantity of wind stress measurements. Also effects of waves on the wind stress should be considered explicitly.

Stewart (1974) presented a general form for the wave dependence of the wind stress as a function of wave age,

$$\frac{gz_0}{u^2} = f \left[\frac{C_p}{u} \right]; \quad (2)$$

where C_p is the phase speed of wind waves of the spectral peak frequency. By assuming the lin-

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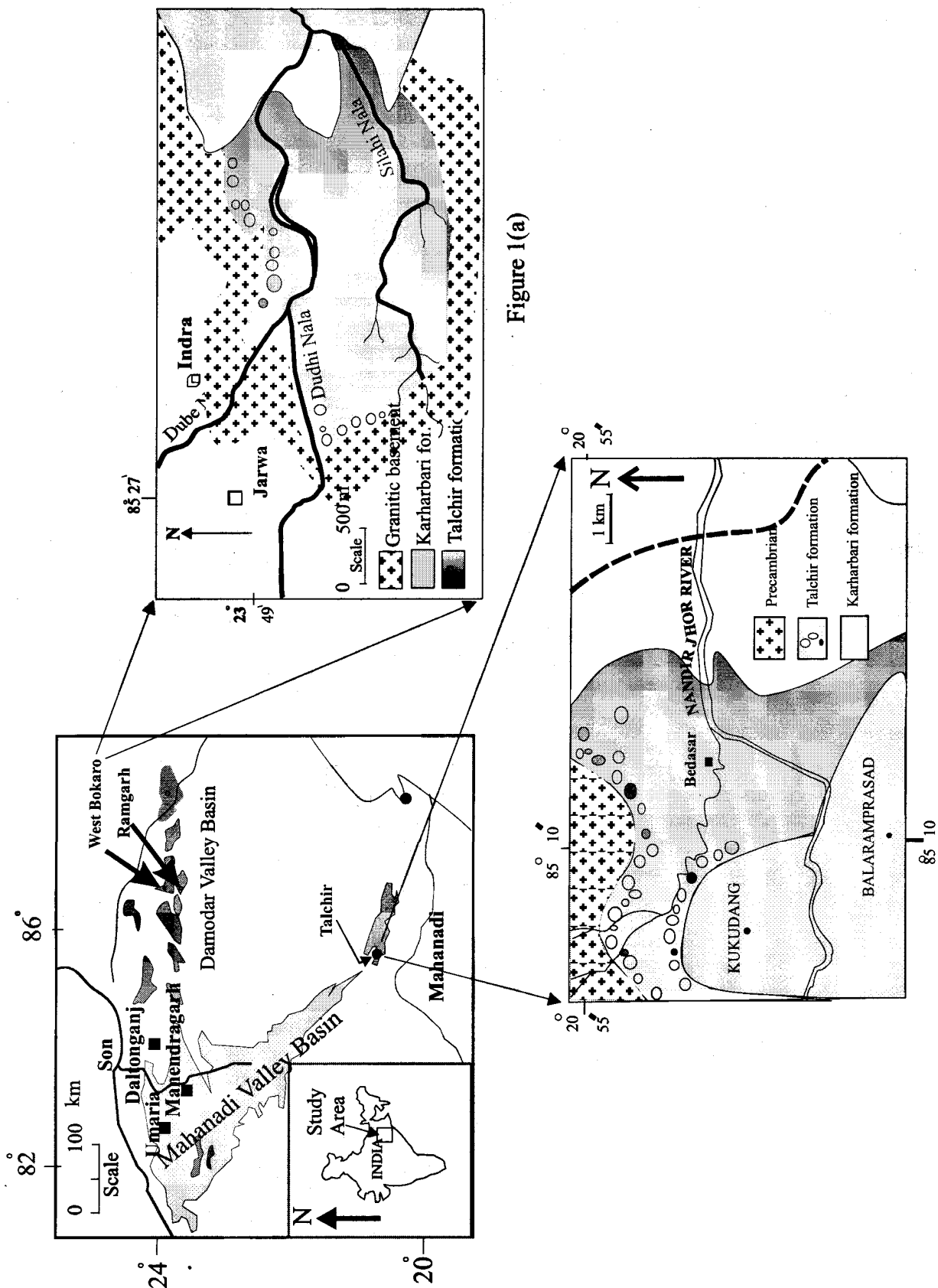


Figure 1(b)

Figure 1(a)

Figure 1. Three major Gondwana basins of peninsular India. Present work is confined to Damodar valley basin (west Bokaro and Ramgarh sub-basins) and Mahanadi valley basin (Talchir sub-basin). (a): Geological map of Talchir basin showing Nandirjhor Nala section.

Table 1. *Salient features of retrieval algorithms.*

Features	MSMR algorithm	Wentz algorithm
1. Type	Statistical technique using Radiative Transfer Simulations (Gohil <i>et al</i> 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	V22, V37, H37
CLW	10V,10H,18V,18H,21V,21H	
SST	18V,18H,21V,21H	V22, V37, H37
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

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

uses all 8 channels and thus is available only in 150 km grid. Table 2 shows the theoretical accuracy of MSMR products.

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

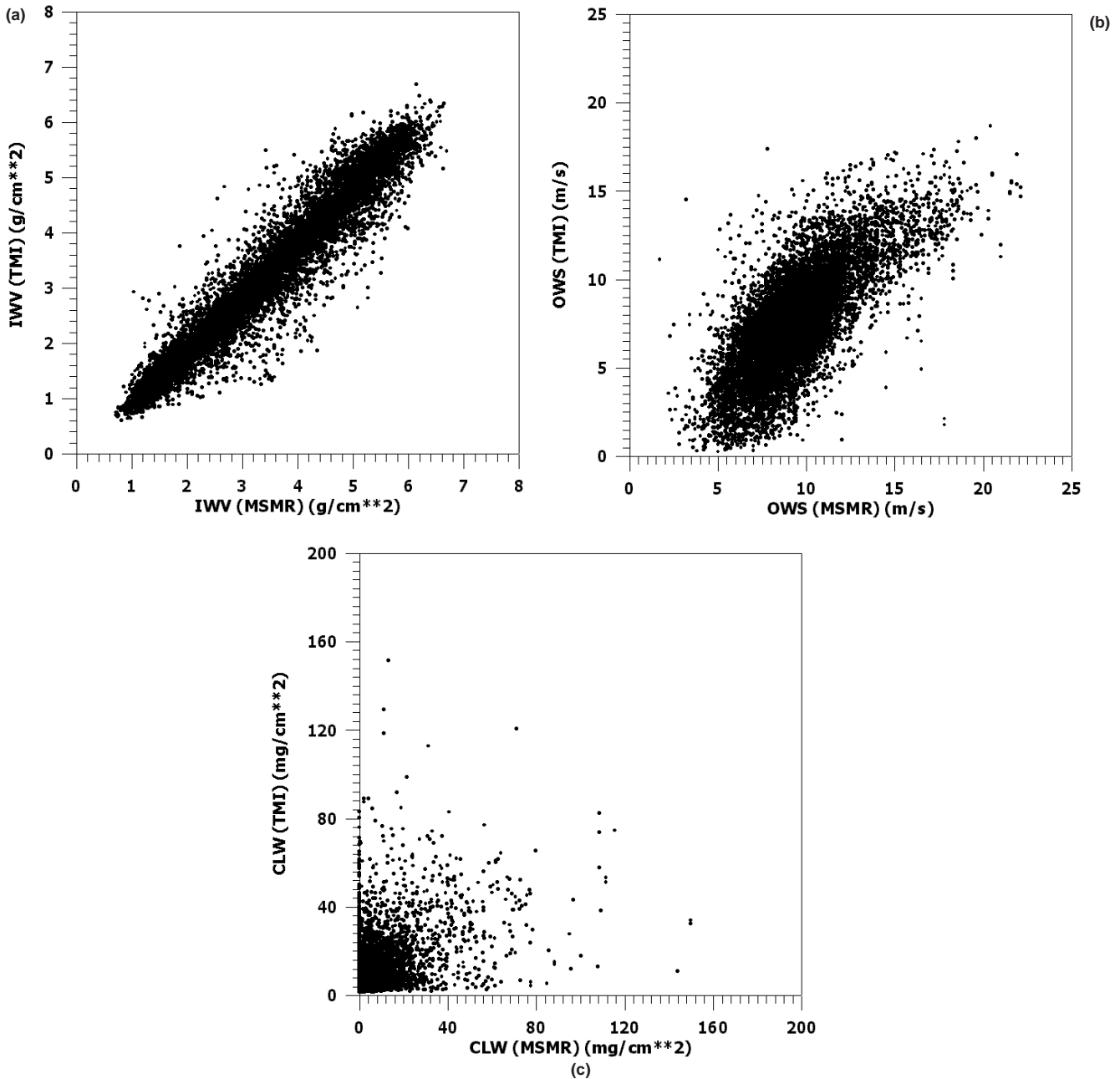


Figure 1. (a) Comparison of colocated and near simultaneous (< 1 hr.) global measurements of Integrated Water Vapour (IWV) from MSMR and TMI for 150 km grid. (b) Same as figure 1(a) but for Ocean Surface Wind Speed (OWS). (c) Same as figure 1(a) but for Cloud Liquid Water (CLW).

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 $\sim 33 \text{ mg cm}^{-2}$.

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