Dual frequency altimeter Jason-2 rain flag validation and rain rate estimation

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Abstract

This letter reports the results of case study on Jason-2 rain flag validation and rain rate estimation over North Indian Ocean (NIO) for the first time using novel method of differential attenuation between Ku band and C band backscatter. The rain flag available in Jason-2 Interim Geophysical Data Records (IGDR) were validated by rain events detected using this method. The estimated rain rate was compared with rain rate from collocated Microwave Imager observations on board Tropical Rainfall Measurement Mission (TRMM) and they matched well. Thus the results of the present study accentuate the need to identify extreme weather events like TCs over regional oceans and emphasize the need for better rain flagging which is essential to evade erroneous values in altimetric geophysical parameters.

1. Introduction

Rain is one of the major atmospheric phenomena whose myriad effects in the altimetric return signals from the ocean's surface is least understood due to its high spatial and temporal variability. Earlier studies on the effect of rain in altimeter signals explicated that rain has its impact on all the geophysical parameters derived from the altimeter [1]. These studies indicated that precise identification of the samples affected by rain and flagging them is paramount in maintaining the accuracy of the derived geophysical parameters in subsequent data analysis. Traditionally altimeter data affected by rain are discarded using rain flag based on the measurements by the concurrent passive microwave radiometers. Later, dual frequency altimeters which are primarily aimed to perform ionospheric corrections in the altimetric range measurements are effectively used for rain detection and rain flagging. In this novel method, the rain detection is based on differential attenuation of the altimeter signals between Ku-band and C or S band [2]. Dual frequency rain flagging have been employed operationally in previous altimetric missions like TOPEX/Poseidon, ERS, Envisat-RA and Jason-1 and the recently launched Jason-2 [2-4]. Rain flagging is more essential in regions like Inter Tropical Convergence Zone (ITCZ) and monsoon regions where precipitation is more frequent. Nevertheless, there is still considerable uncertainty as to whether rain events have been totally removed from the data or whether good data are unnecessarily discarded due to incorrect rain flagging. In a recent work, Quartly [1] made an investigation on improving the altimetric rain records of Jason-2 IGDR and suggested different measures to improve the rain detection using initial phase of Jason-2 data. With this backdrop, the present study aims to validate Jason-2 IGDR rain flag over North Indian Ocean, the region which is more prone to heavy rainfall events during monsoon and tropical cyclones. An attempt was also made to compare the rain rate estimated by altimeter with the collocated TMI rainfall data. Section 2 elaborates the data used and methodology employed for rain detection. The rain effects in the geophysical parameters and comparison of estimated rain rate with TMI rain rate is described in section 3 and section 4 summarizes the concluding remarks.

2. Data used and Methodology

2.1. Jason-2

The Ocean Surface Topography Mission (OSTM)/Jason-2 has been successfully launched in June 2008. Jason-2 has a dual frequency Poseidon-3 altimeter operating at two frequencies 13.575 GHz (Ku-band) and 5.3 GHz (C-band). Jason-2 altimeter provides the sea state parameters (wind speed, wave height, etc.) by measuring the slope of the leading edge of the return pulse and the normalized radar backscattering coefficient. The microwave radiometer onboard Jason-2 satellite, the Advanced Microwave Radiometer (AMR) provides the measurement on the liquid water content (LWC) and water vapour. AMR consists of three separate channels at 18.7, 23.8 and 34 GHz which are mainly used for wet tropospheric correction associated with altimeter range correction. Jason-2 altimeter covers the Earth between 66°S and 66°N approximately every 10 days [6]. In the present study JA2 IGDR version D were used to assess the rain flag and the rain rate estimation.

2.2. TMI /TRMM

The TMI sensor is a multichannel dual-polarized Microwave Radiometer (MWR) which has nine channels operating at five frequencies between 10.7 and 85 GHz at different polarizations. TMI provides rainfall rates over the oceans and a detailed description of the rain fall retrieval is given in [6]. Daily binary data files of geophysical parameters were mainly used in this study. They consist of 0.258 by 0.258 gridded maps including observation time, sea surface temperature, wind speed, total water vapour, cloud liquid water, and precipitation rate. TMI data are produced by Remote Sensing Systems and sponsored by the NASA Earth Science MEaSUREs DISCOVER Project.

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2.3. Estimation of Rain rate

The rain flag on the OSTM/Jason-2 IGDR/GDR is set if integrated LWC measured by the AMR is larger than a specified threshold, and if the difference between the expected Ku-band Automatic Gain Control (AGC) (estimated from the C-band AGC which is much less affected by rain) and the measured Ku band AGC, is larger than either a specified threshold or a specified multiple of the uncertainty in the expected Ku-band AGC [3, 6]. The attenuation in the Ku band can be estimated by the difference $\Delta\sigma_0$ between the expected and observed σ_0^{Ku} .

$$\Delta\sigma_0 = f\left(\sigma_0^{\,C}\right) - \sigma_0^{\,Ku} > A \quad .... \quad (1)$$

where f is the mean Ku/C "rain-free" relationship and A is an attenuation threshold set to the minimum of 1.8 times the rms of f and 0.5 dB. The f relation and its rms were estimated as binned averaged of σ_0^{Ku} with respect to σ_0^{C} by step of 0.1 dB using Jason-2 altimeter data over Indian Ocean. Jason-2 rain flag further used LWC with a threshold of 0.4 kg m^{-2} which is being considered as indicative of probable rain [1]. This was also done to eliminate possible false detection of rain especially at low wind speeds for which the backscatter variability is very high. The rainfall rate in mmh^{-1}, R, is calculated from relation [7]

$$R = \left(\frac{\Delta\sigma_0}{2ha}\right)^{1/b} \quad ...... \quad (2)$$

where a and b are coefficients dependent on the frequency of the radar pulse, h is the rain column thickness. The value of h is found to be 5 km within TCs A rainfall rate of 10 mmh^{-1} would lead 0.26 dB and 4.5 dB attenuation at C band and Ku band, respectively.

3. Results and Discussion

Intense rain events are ubiquitous during tropical cyclones over Indian Ocean. Such cyclonic events offer an excellent opportunity to validate the rain flag parameters available in the operational altimetry data records and rain rate estimation. For this purpose, Jason-2 transit through tropical cyclones (TC) during period June 2008 to December 2011 was investigated. Altimeter orbits intersecting TCs were selected using a systematic screening through Joint Typhoon Warning Centre (JTWC) best track fields. The JTWC best track data is available at every 6 hours. The closest Jason-2 orbits in both space and time were considered for the present study. From the systematic screening, only two cases of tropical cyclones (TC) named Laila and Thane through which Jason-2 overflew was chosen. It is found that orbit 40 of cycle 69 made a transit over TC Laila whereas orbit 155 of cycle 128 flew over TC Thane.

3.1. Along track variation of Altimetric Geophysical parameters during TC

Figure 1(a) shows along track variation in the Ku band and C band cross section (σ_0) whereas figure 1(b) shows altimeter wind speed, Ku band significant wave height (Hs-Ku) and AMR measured LWC.

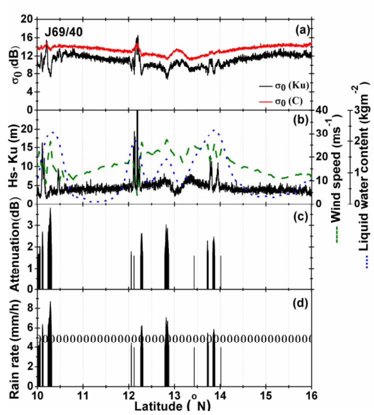

Figure 1: Along track variation in the IGDR products of Jason-2 orbit 40 of cycle 69 (a) Ku band (black line) and C band (red line) cross section, (b) altimeter wind speed (dashed line), Ku band significant wave height (Hs-Ku) (green dashed line) and liquid water content (blue dotted line), (c) Attenuation estimated in the present study from differential backscatter and (d) rain rate. The rain flag bit from IGDR products is also shown here.

It can be seen from fig. (1a) that there was sudden dip in Ku band σ_0 values around 10°N, 10.4°N, 12.2°N, 12.8°N, 13.9°N and 14.2°N latitudes. The corresponding changes in C band σ_0 values were not so pronounced as compared to Ku band σ_0. The sudden changes in Ku band σ_0 values were associated with high liquid water content of more than 2 kgm^{-2} as seen in fig 1(b). The wind speeds around these regions were found to be greater than 20 ms^{-1} [fig. 1(b)]. Hence changes in σ_0 due to lower wind speeds can be neglected. The differential attenuation in Ku band over C band due to rain was estimated using the mean Ku/C rain free relationship as denoted in equation (1) which is depicted in fig 1(c). The estimated attenuation in Ku band was found to be less than 4 dB. Further the rain rate was estimated from attenuation using equation (2). The rain rate estimated from attenuation is displayed in fig 3(d). The rain flag bit obtained from Jason-2 IGDR is also shown here. The estimated rain rate was found to be 8 mmh^{-1} at 10.4°N corresponding to 4 dB attenuation.

The along track variation of Ku band and C band cross section (σ_0) is given in fig 2(a) for the orbit 155. Decrease in Ku band σ_0 around 11°N, 11.5°N, 11.8°N, 14°N and 14.5°N was noticed. The corresponding along track variation in wind speed, Hs-Ku and AMR measured LWC are shown in fig. 2(b). In both orbits it is found that attenuation due to rain was more prominent in Ku band σ_0 than the C band σ_0.

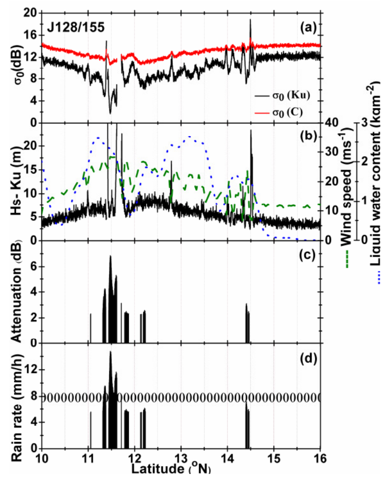

Figure 2: Same as Figure 1, but for Jason-2 orbit 155 of cycle 128

The attenuation in Ku band and rain rate estimated is depicted in figures 2(c) and 2(d) respectively. The rain rate estimated was 15 mmh^{-1} correspond to an attenuation of 7 dB. The rain events around 11°N to 12.5°N were due to the rain bands of TC Thane. A rain event away from TC Thane around 14°N was also observed. The rain flag available in Jason-2 IGDR, shown in fig 2(d) were zero all along this track. The observation of the present study is that the rain flag parameter available in Jason-2 IGDR was always zero during heavy rainfall event associated with TCs. In the present study, in addition to rain flagging based on the differential attenuation, the rain events were also detected using brightness temperature values of three microwave channels 18.7, 23.8 and 34 GHz of AMR as described in [3]. The results of both methods were corroborated each other in identifying the rain events. It is to be noted that operational rain flag of Jason-2 followed the same method [6]. However it failed to identify the rain events which were detected in this study. Hence the present study emphazise the need to relook into the altimeteric rain flag products of Jason-2 over regional oceans.

3.2. Comparison of estimated rain rate with TMI rain rate

In order to validate the rain rate estimated from Jason-2, collocated TMI rainfall observation over BoB was investigated. Jason-2 and TMI crossed the TCs very closely in both space and time. TMI had captured TC Laila exactly an hour later Jason-2 whereas in the case of TC Thane TMI pass was exactly 2 hours after Jason-2 pass. The TMI passes along with Jason-2 orbits were depicted in figures 3(a) and 3(b). The rain rate associated with both cyclonic events as seen by TMI varied from 4 to 16 mmh^{-1}. Apart from the rain events associated with cyclones, isolated rain events were captured by TMI around 11°N in the case of TC Laila and around 14°N in the case of TC Thane, along the path of Jason-2 pass. Both of these isolated rain events were well captured by TMI which were first seen by Jason-2 [figures. 2(d) and 3(d)]. The rain event observed at 10°N by Jason-2 was found to be at 11°N by TMI within an hour which suggests that northward movement of the convective systems. Figure 3(c) and 3(d) respectively illustrates the comparison of rain rate estimated by Jason-2 and TMI for both TCs. As the TMI rain rate data has 0.258X.0258 spatial resolution, the altimeter rain rate was also averaged to match with TMI rain rate. During TC Laila, the rain rate estimated by altimeter was almost equal to the TMI rain rate around latitudes 13.5°N to 14°N. The maximum rain rate observed by both TMI and altimeter was ~5mmh^{-1}. In case of TC Thane, the rain rate estimated by altimeter was found to be lesser than the TMI measured rain rate around 11°N-12°N (fig 4d). The rain rate measured by TMI along Jason-2 orbit varied from 2mmh^{-1} to 12mmh^{-1} whereas the rain rate estimated from Jason-2 varied from 6mmh^{-1} to 12mmh^{-1}. The isolated rain fall event at 14.5°N was equal to the TMI rain rate. In both cases, the rain rates estimated by Jason-2 were in good agreement with TMI. *Tran et al.,* [4] compared the rain rate detected from Envisat RA-2 with collocated TMI and precipitation radar on board TRMM and concluded that the false rain flagging rate by altimeter was 10% low in comparison to TMI and PR rain flag. Their study followed the rain detection algorithm proposed by *Tournadre and Morland* [3]. Thus the present study validated rain rate estimated from Jason-2 with collocated TMI rain rate over NIO for the first time.

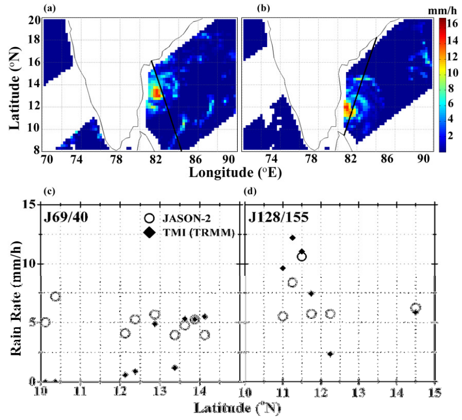

Figure 3: Jason-2 passes overlaid on TMI swath rain fall data (a) orbit 40 of cycle 69 and (b) orbit 155 of cycle 128. Jason-2 estimated rain rate (open circle) and TMI measured rain rate (filled diamond) for (c) orbit 40 of cycle 69, (d) orbit 155 of cycle 128 respectively

4. Concluding Remarks

The differential attenuation between two altimetric frequencies (Ku band and C band) caused by rain was used to validate the rain flag parameters available in Jason-2 IGDR during two major tropical cyclones over NIO. The estimated rain rate from Jason-2 was in good agreement with collocated TMI rain rate. It is obvious to expect that expertise gained in rain detection algorithms for the past few decades would have paved a way to highly accurate rain detection algorithms. However the results of the present study brought out that the rain flag of the recently launched Jason-2 IGDR were not sensitive during both high and low rainfall events. Though it may not look appropriate to comment on the efficacy of Jason-2 IGDR rain flag with only two extreme cases of TCs, the present study makes an appeal to the scientific community which uses this rain flag as a quality check of other geophysical parameters should revisit the rain flag before utilizing these products for oceanographic and climate related studies. In addition to rain flagging, it is envisaged that dual frequency altimeter may shed more light on the characteristics of TCs as well as in complementing finer resolution rain fall data over tropical oceans along with other microwave and IR sensors.

5. References

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