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Validation of SWH and SSHA from SARAL/AltiKa Using Jason-2 and In-Situ Observations

SUCHANDRA AICH BHOWMICK, 1 RASHMI SHARMA, 2
K. N. BABU, 1 A. K. SHUKLA, 1 RAJ KUMAR, 1
R. VENKATESAN, 3 R. M. GAIOILA, 1
PASCAL BONNEFOND, 4 AND NICOLAS PICOT 5

1Space Application Centre, Ahmedabad, India
2India Space Research Organization, Ahmedabad, India
3National Institute of Ocean Technology (NIOT), Chennai, India
4Observatoire de la Cote d’Azur, Valbonne, France
5Centre National d’Etudes Spatiales (CNES), Toulouse, France

The focus of this study is the validation of significant wave height (SWH) and sea surface height anomaly (SSHA) obtained from the first Ka-band altimeter AltiKa onboard SARAL (Satellite for ARGOS and Altimeters). It is a collaborative mission of the Indian Space Research Organization and Centre National d’Etudes Spatiales (CNES). This is done using in-situ observations from buoy and Jason-2 measurements. Validation using buoy observations are at particular locations while that using Jason-2 altimeter is an attempt towards global validation of Altika products. The results clearly indicate that the SARAL/AltiKa provide high-quality data and the errors are within a predefined range of accuracy. A parallel validation of SWH from other altimeters, which monitored ocean since last decade, like EnviSAT and Jason-2 was also performed with buoy observations. The results clearly show that the accuracy of AltiKa SWH is much better than EnviSAT and comparable to reference mission Jason-2. The accuracy is quite good for the calm sea while in the rough seas the accuracy degrades some. The inter-comparison of SARAL/AltiKa SSHA with Jason-2 indicates a fair match between them. These validation exercises demonstrate the high quality of AltiKa products, usable for practical applications.

The focus of this study is the validation of significant wave height (SWH) and sea surface height anomaly (SSHA) obtained from the first Ka-band altimeter AltiKa onboard SARAL (Satellite for ARGOS and Altimeters). It is a collaborative mission of the Indian Space Research Organization and Centre National d’Etudes Spatiales (CNES). This is done using in-situ observations from buoy and Jason-2 measurements. Validation using buoy observations are at particular locations while that using Jason-2 altimeter is an attempt towards global validation of Altika products. The results clearly indicate that the SARAL/AltiKa provide high-quality data and the errors are within a predefined range of accuracy. A parallel validation of SWH from other altimeters, which monitored ocean since last decade, like EnviSAT and Jason-2 was also performed with buoy observations. The results clearly show that the accuracy of AltiKa SWH is much better than EnviSAT and comparable to reference mission Jason-2. The accuracy is quite good for the calm sea while in the rough seas the accuracy degrades some. The inter-comparison of SARAL/AltiKa SSHA with Jason-2 indicates a fair match between them. These validation exercises demonstrate the high quality of AltiKa products, usable for practical applications.

Keywords EnviSAT, Jason-2, Ka-band, NDBC buoy, SARAL/Altika, validation

1. Introduction

Nadir-looking satellite altimeters are space borne instruments dedicated for monitoring ocean. Altimeters contributed significantly towards operational oceanography and enhanced our understanding of physical oceanography and climate (Cazenave and Narem 2004; Bindoff et al. 2007). Altimeters have evolved over the past decade in terms of resolution and data quality to cater to these objectives in an improved manner. Altimeters have a rich history in which oceans have been observed at Ku-band using SKYLAB,
GEOS, SEASAT, TOPEX/POSEIDON, GFO, JASON-1, JASON-2, EnviSAT, and so forth. However, spatial resolution achieved by Ku-band altimeters is often not sufficient for studying the coastal oceans. Higher resolution is required for this purpose. For this reason, efforts were initiated towards high frequency radar altimetry. This also allows a smaller payload, easy to integrate on the satellite. AltiKa onboard SARAL (Satellite for ARgos and AltiKa) is the first attempt at such high frequency altimetry and was made possible by the joint efforts of Indian Space Research Organization (ISRO) and Centre National d’Etudes Spatiales (CNES), France. The satellite was launched on 25 February 2013. Apart from AltiKa, SARAL carries a dual frequency radiometer for wet tropospheric range corrections, Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) for the precise orbitography, and Laser Retro reflector Array (LRA) for the purpose of Precise Orbit Determination (POD). The nominal frequency at which AltiKa operates is 35.75GHz. AltiKa is dedicated to play a complementary role to Jason-2 as a partner in Global Constellation of Ocean Surface Topography missions (OSTM). It fills the gap between ENVISAT and SENTINEL3. The aim of this mission is to provide improved performance both in terms of spatial and vertical resolution. This mission would provide accurate global measurements of sea surface height (SSH), significant wave height (SWH), and wind speed for developing operational/physical oceanography and understanding of climate. The accuracy of these geo-physical products, however, depends on the accuracy of altimeter measurements. Calibration and validation of geo-physical products is one of the vital components in this regard. Primary objective of calibration and validation is to characterize performance of each component of measuring system to provide warning about instrumental behaviour and to assess the quality/accuracies of the products.

Several studies have been carried out earlier emphasizing the requirement of calibration and validation of satellite altimeters such as Topex, Jason, and ERS series (Mastenbroek et al. 1994; Abdalla et al. 2010; Ablain et al. 2010). In the present study, the sea surface height anomaly (SSHA) and SWH estimated from SARAL/AltiKa have been monitored and validated against buoy and Jason-2 data. Previously a detailed study on this field was available in the AltiKa annual report (Philipps et al. 2013). However, this study is a short summary showing validation efforts carried out at ISRO. It aims to study the improvement achieved by AltiKa in estimation of SWH and SSHA. The SWH available from AltiKa has been compared to the buoy observations from the National Data Buoy Centre (NDBC) and to the Jason-2 SWH estimates whereas the SSHA has been compared only with Jason-2 SSHA. Primary purpose of this exercise was to estimate accuracies of SWH and SSHA from AltiKa. Analysis of errors at various sea-states and its geographical distribution have indicated nominal instrument behavior and improvements achieved by Ka band over Ku band. Results indicate not only the high quality of SARAL/AltiKa data with accuracies well within the predefined ranges (Table 1) but also show that AltiKa is a sure boon for the study of sea ice and ocean dynamics at calm sea state.

2. Data Used and Study Area

In the last 10 years, scientists received huge resource of altimeter data for operational oceanography, understanding of ocean dynamics, and global climate. Altimeters helped in many decision making for a better tomorrow. Reference missions like ENVISAT and Jason-2 have successfully monitored ocean in the last 10 years. AltiKa, is the latest addition to this class. Thus discussions on accuracies of
SARAL/AltiKa products would be incomplete without addressing continuous improvement in altimeter measurements by its ancestors. Therefore, keeping SARAL/AltiKa (2013) on focus, Jason-2 in 2009 and EnviSAT in 2005 are chosen at intervals of four years, when quality of their products is evaluated to see the way, generations of altimeters has evolved with better accuracies and technologies in last decade. The SWH from SARAL/AltiKa, Jason-2, and EnviSAT have been validated independently using NDBC buoy data for the years 2013, 2009, and 2005, respectively, to carry out a comparative analysis of these altimeters. However, this in-situ validation is limited. These observations are at irregularly scattered point locations over the ocean, thus they do not represent the global accuracies of the products. Therefore, Jason-2 SWH and SSHA are inter-compared with the same quantities from SARAL/AltiKa to determine the relative performance of SARAL with respect to the reference mission Jason-2. Details of the data used are listed in the next section. The inter-comparison of AltiKa and Jason-2 is conducted for global oceans between 66°S to 66°N and 0–360°E.

2.1. In-situ Data

The buoys provide accurate measurements of ocean surface wind, wave etc. Space-borne altimeters mostly rely on buoy observations for verification of their estimates. However, an organized network of buoys is still rare over the global oceans. Indian waters are most poorly observed specially near the coasts. There are almost 640 buoys deployed by NOAA in shallow water and deep water ocean regions that provide accurate ocean state information at high temporal resolution. This data are available from NDBC (ftp://data.ndbc.noaa.gov/data/stdmet) monthly and are used to validate ALtiKa observations. This number varies every month. The density of observation from these buoys is profound near either U.S. coast. Figure 1 shows the location of densely populated NDBC buoy network during 2009 near the United States. Many of these buoys are near to the coasts and many are located at estuaries. These locations have intense land ocean contaminations in altimeter data. Thus, almost 300 buoys are removed from the analysis in order to avoid these contaminations. This analysis considers only approximately 300 buoy points for validating AltiKa and other altimeters. This number is further reduced since many of the buoys are located much away from the altimeter pass. Finally, the number of buoy observations that effectively contributes towards this validation exercise is almost 120–128. In this study the hourly wave observations are used for the purpose of validating SWH estimates from EnviSAT Radar Altimeter (2005), OSTM/Jason-2 data (2009), and SARAL/AltiKa (2013).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>OGDR</th>
<th>IGDR</th>
<th>GDR</th>
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<tr>
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<td>4.6</td>
<td>2.8</td>
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<tr>
<td>SWH (m)</td>
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<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Wind Speed(m/s)</td>
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<td>1.7</td>
<td>1.7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1
Predefined ranges of accuracies for SARAL/AltiKa mission

SARAL/AltiKa products would be incomplete without addressing continuous improvement in altimeter measurements by its ancestors. Therefore, keeping SARAL/AltiKa (2013) on focus, Jason-2 in 2009 and EnviSAT in 2005 are chosen at intervals of four years, when quality of their products is evaluated to see the way, generations of altimeters has evolved with better accuracies and technologies in last decade. The SWH from SARAL/AltiKa, Jason-2, and EnviSAT have been validated independently using NDBC buoy data for the years 2013, 2009, and 2005, respectively, to carry out a comparative analysis of these altimeters. However, this in-situ validation is limited. These observations are at irregularly scattered point locations over the ocean, thus they do not represent the global accuracies of the products. Therefore, Jason-2 SWH and SSHA are inter-compared with the same quantities from SARAL/AltiKa to determine the relative performance of SARAL with respect to the reference mission Jason-2. Details of the data used are listed in the next section. The inter-comparison of AltiKa and Jason-2 is conducted for global oceans between 66°S to 66°N and 0–360°E.

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2.2. Satellite Altimeter Data

2.2.1. SARAL/AltiKa. SARAL is a joint ISRO-CNES mission, launched from Sriharikota High Altitude Range (SHAR), India, using a Polar Satellite Launch Vehicle (PSLV). It was placed in a sun-synchronous orbit at an inclination of 98.55° at a height of 814 km. It has a repeat cycle of 35 days, which is exactly the same as EnviSAT. AltiKa was proposed in 2001 (Verron et al. 2001). AltiKa, like its predecessors, is destined for ocean monitoring from space. However, it is significantly different from the previous altimeters in terms of accuracy. Traditionally in the 1–18 GHz range of frequency in which most altimeters before AltiKa worked, the incoming signal from the satellites is severely attenuated in the ionosphere. This attenuation is inversely related to radar frequency; that is, the attenuation is higher at lower frequency. However, SARAL/AltiKa uses exceptionally high frequency of 35GHz at Ka band. This not only minimizes the ionospheric attenuation but also enhances the spatial resolution since the footprint size is smaller in this case. As mentioned before, this high resolution is useful for coastal studies. There is, however, an associated disadvantage of high rain attenuation of signals at this wavelength range. Nevertheless, sophisticated data processing minimized data loss due to rain attenuation from AltiKa (SARAL Newsletter 2013).

The primary geophysical parameters that are available from SARAL/AltiKa are the SWH, Sea Level Anomaly (SLA) and wind speed. In this study the SWH and SSHA have been used. The SWH and SSHA data from AltiKa from 13 March–31 December 2013 have been validated in this study. The data are made available by ISRO and are available
from the Meteorology and Oceanography Data Archival Center (MOSDAC; www.mosdac.gov.in). For validation of the SWH the operational geophysical data records or OGDR level data are used. For the SSHA, the operational (OGDR), interim (IGDR), and final level (GDR) products are used.

2.2.2. Jason-2. The OSTM/Jason-2 satellite is a joint NASA, NOAA, EUMETSAT, and CNES project, which is a part of Ocean Surface Topography Mission. It was placed into polar non-sun-synchronous orbit on 20 June 2008 by a United Launch Alliance Delta-II rocket from Vandenberg Air Force Base (VAFB), California. OSTM/Jason-2 is designed to match or exceed the performance of its predecessors Topex/Poseidon and Jason-1. It has the same orbit as the previous two, namely a circular orbit at a height of 1336 km and 66° inclination angle covering 95% of ice-free ocean. The repeat cycle of Jason-2 is 10 days. The payloads include the dual frequency Poseidon-3 altimeter for ocean state monitoring, along with Advanced Microwave Radiometer (AMR) for the wet tropospheric range correction, Global Positioning System Payload (GPSP), and DORIS instrument for the determination of precise orbit. OSTM/Jason-2 Poseidon-3 altimeter is a dual frequency altimeter operating at Ku band (13.6 GHz) and C band (5.3 GHz) frequencies. In this study the similar collocated wave height and SSHA data from Jason 2 and AltiKa have been used for validating the latter for 2013. Jason-2 data for 2009 have also been validated using the NDBC buoy. The data are available through ftp://nodc.noaa.gov/pub/data.nodc/Jason-2. To compare the SWH and SARAL, an OGDR-level product of Jason-2 is used. For SSHA, all three levels are used (OGDR, IGDR, and GDR).

2.2.3. EnviSAT. EnviSAT radar altimeter was based on the heritage of ERS-1 satellite. It is a nadir-looking, dual-frequency, pulse-limited radar altimeter onboard EnviSAT satellite. EnviSAT was launched on 1 March 2002 in a sun-synchronous, polar orbit at inclination of 98.55°, with a lifetime of five years. The orbital height of EnviSAT was 800 km. It operates at the nominal frequency of 13.575 GHz in Ku-band as a compromise to affordable antenna dimensions and attenuation due to the ionosphere. It also operates at the S-band at 3.2 GHz for the purpose of ionospheric correction, rain detection, and flagging. The EnviSAT has a repeat cycle of 35 days. It measures ocean surface wind and SWH at both the frequencies. The satellite completed its dedicated and fruitful life in 2012. In this study the SWH at Ku-band from GDR data has been compared using NDBC buoy data for 2005 when it was operational. This data are collected from radar altimeter database system RADS through www.rads.tudelft.nl/rads/data.

3. Methodology

The SWH from EnviSAT (2005), Jason (2009), and SARAL/AltiKa (2013) has been collocated with the NDBC buoy observations of respective years at spatio-temporal window of 20 Km and 30 min. The choice of this spatio-temporal window is not straightforward. Sateeshan et al. (2007), while validating the QuikSCAT winds with in-situ measurements, observed that temporal window of 30 min and a spatial search radius of 0.25 degree (25 km) is appropriate for collocation of satellite and in-situ wind measurements. Since waves are created by winds, similar variability is expected in waves as in winds. Thus the collocation criterion is chosen to be spatially comparable or less than that of wind.

Considerable data editing has been performed to remove outliers from this collocated data set. To do this, standard deviations of the differences between the buoy and altimeter
measurements have been computed. All data with differences within three times the standard deviations (3sigma) have been considered for analysis. This includes almost 96.5% of the total number of co-located points for EnviSAT, 97.76% for SARAL, and 97.99% for Jason-2. The locations of the outliers have been determined to guess possible reasons about large deviations in their values compared to observations. Figure 2d shows the location of outliers (that has been removed from the analysis) where AltiKa estimates are deviated from observed SWH due to intense land contamination. Clearly these outliers are in extreme proximity to land and in many cases lies in water masses surrounded by

Figure 2. Validation of the SWH data from (a) EnviSAT (2005), (b) Jason-2 (2009) and (c) SARAL/AltiKA (2013) using the NDBC buoy observations. (d) The location of the buoys where the removed outliers are obtained in SARAL/AltiKa data. (e) Comparison of instrument noise in Jason-2 and SARAL as function of SWH in cm.
land from three sides. However, the number of outliers in SARAL/AltiKa are much less
than EnviSAT.

The filtered collocated data, of three individual altimeters with corresponding buoy
data hence prepared is used for further analysis. The statistics is computed from them to
diagnose errors in the SWH measurements of these three altimeters. Further the analysis
of errors has been performed at various sea states. The sea state has been determined
using the threshold criterion based on observations. If the observed wave height is
between 0 and 1.25 m, the sea is considered to be affected by slight disturbances; if it
is between 1.26 and 2.5 m, the sea is termed as moderate; and if it exceeds 2.5 m the sea
is rough. This nomenclature follows Indian Meteorological Department’s criteria for
defining sea state. This analysis provides an assessment of overall improvement of data
quality in SARAL/AltiKa compared with its previous Ku-band altimeters in calm sea
state. Performance of these altimeter instruments at various sea states has also emerged
from this analysis.

Similar collocation has been performed on SWH and SSHA data of SARAL/AltiKa
and Jason-2. Similar data editing has been followed on these samples as well. Statistics
are computed on these data sets, which include the daily and monthly variations in rela-
tive root mean square errors (RMSE) and standard deviations. The daily monitoring of
RMSEs in SWH has been carried out to observe possible changes in instrument behavior
if any. The inter-comparison of SSHA and SWH with similar quantities of Jason-2 is fur-
ther been done to evaluate the SARAL/AltiKa with respect to the reference mission of
Jason-2.

4. Results and Discussions

An analysis of collocated datasets of observed and measured SWH from AltiKa (2013),
Jason-2 (2009), and EnviSAT (2005) shows that the AltiKa SWH is a good match with
the buoy observations (Figures 2a, b, c). Also, there is significant improvement in the
SARAL/AltiKa SWH compared with EnviSAT, which has the same orbit. The root mean
square error in AltiKa is as low as 0.22 m and correlation is as high as 0.96; it is almost
equal to that of reference mission of Jason-2 (RMSE = 0.28 m and correlation = 0.96). It
is much better than EnviSAT (RMSE = 0.48 m and correlation = 0.91). However, the
bias in SWH of AltiKa is 0.115 m higher than that of Jason-2 (0.016 m). Yet it appears to
be much better than that of EnviSAT (0.4 m). This increase in bias of AltiKa compared
with Jason-2 is mainly due to the fact that AltiKa mildly overestimates the wave height in
rough sea conditions. This can be seen in Table 2, which shows the variation in RMSE at
different bins of SWH based on the observed sea state. However, at calm and moderate
sea states, AltiKa provides excellent estimates of SWH. It is much improved compared
with Jason-2 and EnviSAT. This may be because the bandwidth and temporal sampling

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<tr>
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<tbody>
<tr>
<td>Slight (0–1.26m)</td>
<td>1.39</td>
<td>0.70</td>
<td>0.52</td>
</tr>
<tr>
<td>Moderate (1.26–2.50m)</td>
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<td>0.44</td>
<td>0.45</td>
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<tr>
<td>Rough (&gt;2.5m)</td>
<td>0.50</td>
<td>0.41</td>
<td>0.56</td>
</tr>
</tbody>
</table>
for Ku band altimeters like Jason-2 (320 MHz and 20 Hz) are lower than the one of SARAL/AltiKa (500 MHz and 40 Hz) which considerably reduces the noise in AltiKa. At calm sea state reduction of noise helps in better estimation of SWH. However, in rough sea it causes a mild overestimation. Figure 2e showing the noise component in Jason-2 and AltiKa as function of the SWH (cm) clearly indicates the better performance of SARAL/AltiKa at a calm sea state.

The SARAL/AltiKa data have also been intercompared with collocated Jason-2 altimeter data at similar spatio-temporal windows. Figures 3a and b show the variation of SWH from AltiKa and Jason-2 over the tropical region and in the belt from 30–66° north and south of the equator. It is evident from these figures that SARAL/AltiKa SWH matches Jason-2 at the midlatitude belt with higher correlation of 0.96 as compared to the tropics where the correlation is 0.82. In mid-latitude, Jason-2 overestimates the wave heights beyond 65 degrees of both the northern and southern hemispheres. The main reason behind this could be the fact that this area is dominated by sea ice and the sea is calm.

![Figure 3](image-url)

**Figure 3.** Inter-comparison of the SWH data from Jason-2 and SARAL/AltiKA (2013) over (a) tropical belt and (b) mid-latitudes and beyond (c) Location where SARAL/AltiKa SWH does not match Jason-2 (red cross where Jason-2 exceeds SARAL and green triangles where SARAL exceeds Jason-2).
Thus, the SWH is overestimated due to sea ice contaminations in Jason-2 waveforms. However, in Ka band AltiKa, the pulse repetition frequency (PRF) is more, which reduces the noise significantly. Thus inspite of having a lowering in return signal it can be picked up very well by the AltiKa and it provides better estimates of the SWH.

On the other hand, the SARAL overestimates the waves at the tropics at much lower waves observed by Jason-2. These mismatches can be attributed to the presence of rain and its effect on Ka-band signals. SARAL has certain issues with the rain attenuations, leading to disturbed waveforms. But in low wind-dominated regions near the tropics where the ocean is expected to be calm, AltiKa measurements seems to be reasonable compared with Jason-2, which overestimates the waves. Overall the SARAL performance is excellent over calm to moderate sea conditions and sea ice-dominated areas. After removing the outliers indicated in Figure 3c from the collocated data sets of SARAL and Jason-2, the statistics improves dramatically showing excellent match between the duo and with an improved RMSE of 0.32 m (Figure 4).

The daily and monthly RMSE with respect to Jason-2 are computed operationally at ISRO to monitor the changes in behavior of the instrument, if any. The evolution of errors in SWH computed daily shows certain spikes with rise in the RMSEs between Jason-2 and SARAL. On most occasions, the time of spikes matches the dates when the various satellite maneuvers have taken place in SARAL, as shown in Figure 5a. However, the monthly variations in errors (Figure 5b) between AltiKa and Jason-2 remain mostly within the predefined ranges of required accuracies for wave heights. In August 2013, however, the standard deviation of Jason-2 SWH was higher than AltiKa, thus a mild hike in RMSE has been observed.

![Figure 4](image_url). Inter-comparison of the SWH data from Jason-2 and SARAL/AltiKa (2013) after removal of outliers.
Similar collocated data sets of AltiKa and Jason-2 SSHA have been analyzed for OGDR, IGDR, and GDR levels and are shown in Figures 6a, b, and c, respectively, with their corresponding statistics. For SSH all three levels have been chosen because at GDR level SSHA is supposed to be the best estimate with all sorts of altimeteric corrections. The accuracies at all three stages of SSHA are thus very different from one another, as seen in Figure 6 (RMSE are 7.08, 5.50, and 4.6 cm, respectively, for OGDR, IGDR, and GDR levels). The RMSE, bias, and correlation coefficients at all three levels are shown in Table 3. The high correlation at all three levels shows a good match between the Jason-2 and Altika SSHA. The root mean square errors indicate that the SSHA data meets the required accuracy for the mission as mentioned in Table 1. The standard deviation in both data sets for Jason-2 and SARAL is shown in Figure 7 and indicates a good match among the data sets. The standard deviation in the SARAL operational product (OGDR) is high for the month of July due to the major inclination maneuvering during this phase of 2013.

A negative bias is observed at the GDR, IGDR and OGDR levels of AltiKa with respect to Jason-2. This bias is 5.26 cm, 6.06 cm, and 7.08 cm, respectively (Table 3). The differences in the biases at O/I/GDR levels implies that this may be coming from the orbit and/or from corrections applicable to the altimeter data. A detailed analysis of dependence of this bias on collocation distance and latitude has also being carried out (not shown here) but it has been observed that this bias is independent of collocation
distance and is uniformly distributed globally. Similar bias is also observed during absolute calibration of AltiKa at Corsica and Kavaratti, reported by Bonnefond et al. (2014) and Babu et al. (2014), respectively. Thus, the reason for this bias is still under investigation.

Although Altika and Jason-2 are different, the SSHA of the duo matches well. Overall bias removed RMSE of 7.07 cm, 5.50 cm, and 4.60 cm at OGDR, IGDR, and GDR level.

![Figure 6](image.png)

**Figure 6.** Inter-comparison of the SLA data from Jason-2 and SARAL/AltiKa (2013) collocated at a spatial distance of 20 km at (a) OGDR (b) IGDR and (c) GDR level.

<table>
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<td>IGDR</td>
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<tr>
<td>GDR</td>
<td>5.26</td>
<td>0.90</td>
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</tbody>
</table>

**Table 3**

Statistics of the Altika SSHA respect of Jason-2 SSHA before and after application of high frequency noise filter.
levels of AltiKa SSHA imply an excellent quality of data, which is in accordance to the mission requirement (Table 1). The study indicates an unprecedented performance of SARAL/Altika in precisely measuring ocean parameters to centimetric level accuracy. Thus AltiKa is instrumental in capturing several meso-scale and microscale ocean processes, useful for operational oceanographic applications.

5. Conclusion

Newly launched SARAL/Altika is a milestone in the history of altimeters. With higher frequency, enhanced data rate, and temporal sampling, it can observe the earth with better horizontal and vertical resolutions. In this study a detailed validation exercise performed at ISRO has been discussed. The validation exercise involved huge data sets from NDBC buoys and Jason-2 data products. The analysis of the errors in various sea states and its latitudinal dependences has been carried out using standard statistical procedure. The results show that SARAL/Altika is providing data of excellent quality with an accuracy that is well within the mission requirement and approaching the mission goal. The performance of the system is excellent. However, it performs much better in calm sea states and over sea ice regions as compared to other altimeters.

Acknowledgements

The authors congratulate CNES, France, and ISRO for developing SARAL/Altika. The authors would like to thank the director, SAC, and deputy director, EPSA, for their great support and encouragement for this work. This article would not be complete without suggestions and helps rendered by Prof. S. K. Basu.

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