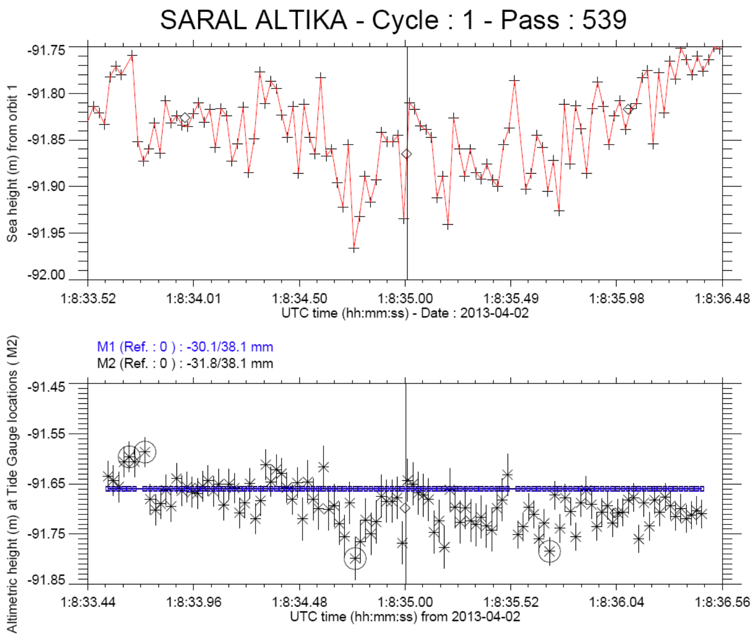
Initial Calibration and Validation results of SARAL/AltiKa



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1. Introduction

Satellite radar altimetry is a technique used in oceanography to measure sea level on a large scale. The data obtained is vital to understanding ocean circulation and its variations. This altimeter uses high frequency (35.75GHz, 500MHz) first time of its kind. This unique technical characteristic of the instrument will offer higher performance both in terms of spatial and vertical resolution. The instrument's more accurate measurements will lead to improved observation of ice, coastal areas, in-land waters and wave height. The SARAL/AltiKa project is a collaboration between France and India in the environment monitoring domain. SARAL/AltiKa flies on ENVISAT orbit, to ensure a continuity of altimetry observations for the long term. On the other hand, the local time of passage over the equator is different due to specific cover requirements for the ARGOS instruments constellation. SARAL was successfully launched on 25th February 2012 and reached its final orbir on 13th March 2013.

The calibration and validation of altimetric missions is the process of quantitatively defining and assessing the altimetric system's response (in other words, the sea state bias, wet tropospheric path delay, marine geoid, tides, geographically correlated errors, etc.) to known and conrtolled signal inputs, determined by independent means. This can be achieved by using dedicated research infrastructures, together with distributed tide gauges to consistently and reliably determine (1) the absolute altimeter biases for each of these various satellite altimeters and (2) the relative biases among missions. Another approach for calibration is to use a tide gauge network, equiped with GPS receivers, in order to simultaneously measure sea surface heights and positions in the same reference frame, while the altimetric heights are recorded by the satellite in the ocean. While dedicated calibration sites detect absolute biases, the drift estimate of an altimeter is accurately determined by the global tide gauge analysis.

In the world, there are five permanent sites for providing absolute calibration of satellite altimeters, three of which are located in Europe (Gavdos in Greece, Corsica in France-operated by CNES, Ibiza in Spain), one in the USA (Harvest Oil platform, Californa-operated by JPL) and one in Australia (Bass Strait, Tasmania). These sites, some of which have been operational since early 1992, produce absolute biases and drifts for overflying satellite measurements. Nonetheless, calibration results depend on the local conditions, standards and specifications applied, duration of measurements and geographical location of the calibration sites.

The objective of this document is to bring out the inital results obtained for SARAL AltiKa in terms of its absolute calibration over Kavaratti calibration site and its derived geo-physical data records validation using globally available *in-situ* observations. Our initail findings are encouraging for AltiKa products except for the satellite derived wind speed which needs to be improved in order to meet the specifications. Inter satellite sensor comparion with Jason-2 are also reported.

2. Radar gauges at Kavaratti site

Near Kavaratti Island, the Jason-2 (red line), AltiKa (yellow line) (Figure 1) and the implantation possibility of Radar gauge have lead us to augment additional radar gauge (the tide stations are shown in Figure 2) in connection to developing a site for altimeter calibration (Babu et al., 2010 & 2013). Both the altimeter passes are on the west side of the Island. A perliminary geodetic survey was first performed in October 2012. Benchmark points, near the radar gauge station, have been established using six days of continuous GPS operation. Coordinates of this point are expressed in the International terresterial reference frame (ITRF) using Trimble geodetic receiver/antenna. Finally, height differences between tide gauges (TG1, and TG2) and their respective geodetic marker have been determined by optical leveling method.

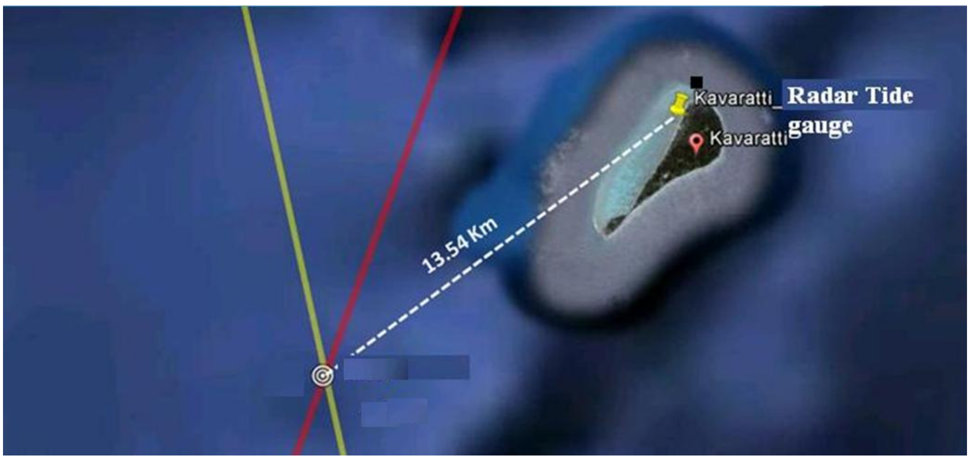


Figure 1: The experimental plan for Saral AltiKa calibration over Kavaratti Island

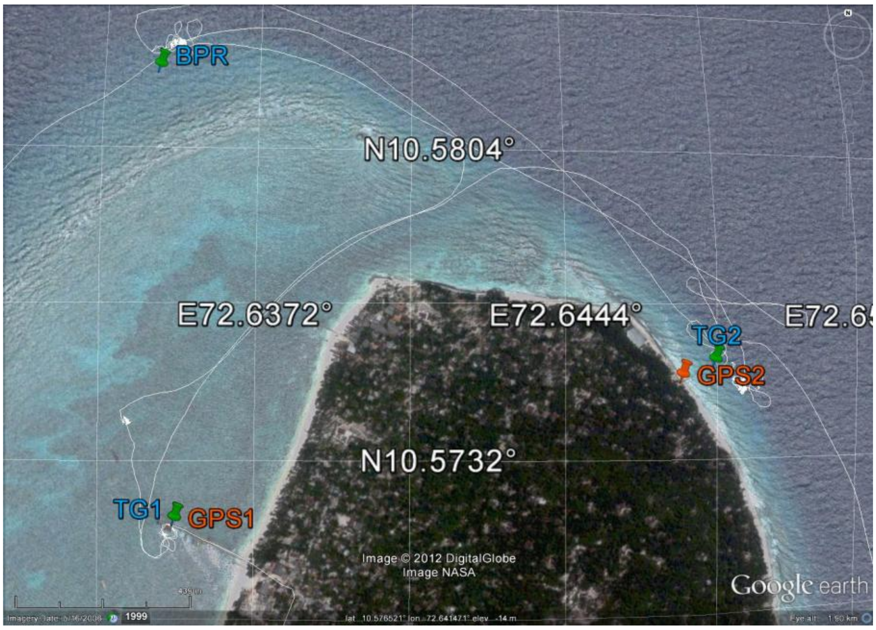


Figure 2: Positions of the instruments at main Jetty (GPS1 and TG1), at NIOT Jetty (GPS2 and TG2) and at offshore BPR mooring. The white track displays the temporal positions of the GPS buoy. October, 2012 experiment design.

Downlooking aerial microwave radars are incorporated at TG1 and TG2 location. The data sets are at 5min interval with an accuracy of ±1cm. The measurement range capability and accuracy for these gauges is given in Table 1.

Table 1: Radar tide gauge specifications

Sensor	**Range**	**Accuracy**	**Sampling interval**	**Data transfer**
Radar level sensor (OTT, Germany)	0 - 30m	±1 cm	5 minutes	GSM modem

3. SARAL/AltiKa Data products

SARAL/AltiKa provides three types of data sets : Operational Geophysical Data Record (OGDR), Interim Geophysical Data Record (IGDR), and Geophysical Data Record (GDR). Different levels of products are :

Level 0: Data as acquired by satellite

Level 1: It consists of extraction of raw measurements from telemetry packets, decoding and conversion of all parameters for further instruments and geo-physical processing. The altimeter echoes/waveforms are time tagged and the radial component of the orbit is generated and associated with measurements. In case of radiometer data, antenna temperatures for each channel are generated.

Level 1b: At this level, processing is done by computing all instrumental corrections and applying them to instrument measurements. Now data is in the altimeter parameters and the radiometer brightness temperatures with instrumental and internal calibration corrections applied.

Level 2: Geo-physical processing is done at this level. Altimeter waveforms are processed (on ground re-tracking) to estimate relevant physical parameters such as altimeter range, backscattering coefficient (σ^0), significant wave height (SWH), thermal noise and square of the off-nadir angle. All environmental and geo-physical correction are applied on the data in this step and data is interpreted in terms of sea surface height, wind speed etc.

Level 3: Objectively analyzed gridded products of sea level anomaly, wind and significant wave height.

The level-2 products of this mission will be calibrated and validated using controlled Cal-Val site over Indian region by us. The level-2 product specifications are given in Table 2 for reference (taken from Saral/AltiKa Products Handbook). All these family contains sea surface height, wind speed, and significant height, and also other parameters.

Table 2: Level -2 Saral/AltiKa products for Cal-Val exercise

	OGDR Family	IGDR Family	GRD Family	GOALS
Sea surface height (cm)	30.5cm (req.)	5.3 cm(req.)	4.6 cm(req.)	2.8cm
Significant wave height (m)	10% (0.5m)	10% (0.4m)	10% (0.4m)	5%(0.25)
Wind speed (m/s)	2m/s	1.7m/s	1.7m/s	1m/s
Latency period	3 – 5 Hours	< 1.5 days	~40days	

4. Methodology and absolute calibration

The instruments carried by the SARAL make the following measurements: altimeter range, ocean significant wave height, ocean radar backscattering cross section, ionospheric electron content in the nadir direction, tropospheric water content, and position relative to the GPS satellites. Also a DORIS system onboard the satellites along with a ground based network of DORIS stations provide the precise location and speed of the satellite as it measures the ocean surface. The satellite ranges are measured in Ka band and corrected for various instruments effects for the path delay in the atmosphere through which the radar pulses and for the nature of the reflecting sea surface using the following expression :

Corrected range = Range + Wet troposphere correction + Dry troposphere correction + Ionosphere correction + Sea state bias ---- (1)

Finally, a sea surface height (SSH) is produced above the reference ellipsoid after subtracting the corrected range from the satellite altitude :

SSH = altitude - Corrected range ----- (2)

The calibration principle is to compute the difference between the sea surface height (SSH) measured with the altimeter and the SSH recorded by the Radar gauge. These two SSHs are located at two distant points. The link between the two SSHs is partly the geoid slope from offshore altimetric measurement to tide gauge locations. Initially, high-rate (20Hz) altimetric sea heights are corrected from Geoid slope by computing the Geiod height differences from the altimetric data location to each tide gauge location. At each altimetric data location, the mean Geiod height is computed inside the footprint area which size is defined by Chelton et al. 1989. This permits being closer to the altimeter measurement principle and minimizes the internal residual errors of the Geoid map.

In the second step, tide gauge data are interpolated at the high-rate altimetric data time using a linear regression over a time span of 30min centred on the time of closest approach. The mean values of sea height differences and the associated standard deviations are then computed for each tide gauge. The sea-height bias is thus defined by the following: altimeter sea height-in situ sea height. For example, a positive sea-height bias means that the altimetric sea height is erroneously high or the altimeter is measuring too short.

The altimeter sea surface height bias can then be expressed as:

$$Bias = [Sea\ level_{Alt} – Sea\ level_{Tg}] – [Geoid_{Alt} – Geoid_{Tg}] \quad ---- \quad (3)$$

Where, the sea level information for both data types, recorded at the same time of satellite near-overpass of the gauge are measured within the same geocentric reference frame. The flowchart of the method adopted is given in Figure 4.

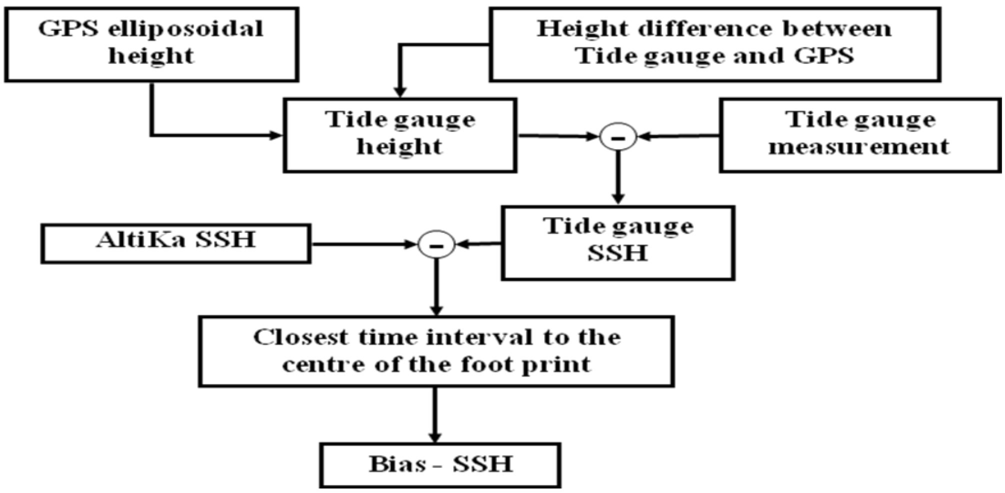
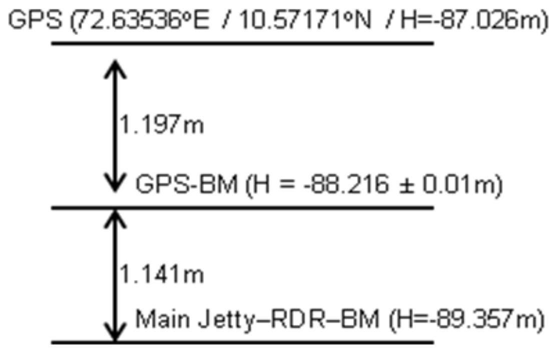


Figure 4: Flowchart of absolute calibration of Altimeter using tide gauge observations

Referencing of radar tide gauge to Earth ellipsoid

Main jetty Radar tide gauge (RDR)

The GPS-base receiver was installed inside the main jetty hut (10^o 34.303'N; 72^o 38.119'E) and configured at 1Hz sampling with a 5^o elevation mask. The slant height was measured between the side and the top of the bench mark (SL=127cm). The radius of the antenna is R=16.98cm then the height of the bottom of antenna mark to the top of the bench mark is $H^2=(SL^2-R^2)$=124.101cm. After correction of the distance from antenna mark to antenna reference point (ARP), the height distance between the bench mark and the ARP is 119.671cm. Height difference between the reference benchmark to radar antenna level was measured through sprit leveller and scale, this was found to be 1.141m. The ellipsoidal difference between the SARAL crossover point to tide gauge location is estimated to 0.70051558m The GPS solutions are obtained through GAMIT processing software. The GPS processing was carried out by Pascal of CNES. Using these levelling information and radar gauge raw data sets, the absolute sea surface height is computed.



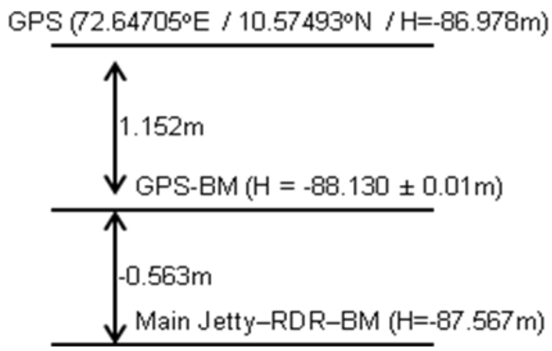
Other ancillary parameter for computing absolute sea surface height using benchmark reference are given below :

D_tg_gps = 1.141m - 0.02m
D_tg_capt = 0.0 (additional offset of the sensor)
hwgs84 = -88.21586m (from GAMIT)
delta_ellips = 0.70051558m

Absolute_SSH_RDR = hwgs84 + delta_ellips - (D_tg_gps - D_tg_capt) - hraw*1e^{-2}

NIOT jetty radar tide gauge (RDR)

Similar GPS survey and computation are carried out for NIOT radar tide gauge station. The levelling information are given below :



Other ancillary parameter for computing absolute sea surface height at NIOT Radar tide gauge using benchmark reference are :

$$D\_tg\_gps = -0.563 - 0.02$$
$$D\_tg\_capt = 0.0 \text{ (additional offset of the sensor)}$$
$$hwgs84 = -88.21586\text{m (from GAMIT)}$$
$$delta\_ellips = 0.70051558$$

$$htopex = hwgs84 + delta\_ellips$$
$$absolute\_SSH\_TP = htopex - (D\_tg\_gps - D\_tg\_capt) - hraw*1e^{-2}$$

Based on the absolute calibration methodology as explained above, the absolute calibration of SARAL/AltiKa altimeter is carried out over Kavaratti calibration site on 2nd April 2013(over pass). Figure 5a gives absolute calibration of SARAL/AltiKa on 2nd April 2013 - OGDR product. The left panels show the SSH as derived by satellite altimeter (top left panel) and tide gauges (bottom left panel). The right panel is Earth Geoid Model derived Geoid height for normalization of distance among altimeter foot print and tide gauge observation at the time of overhead pass.

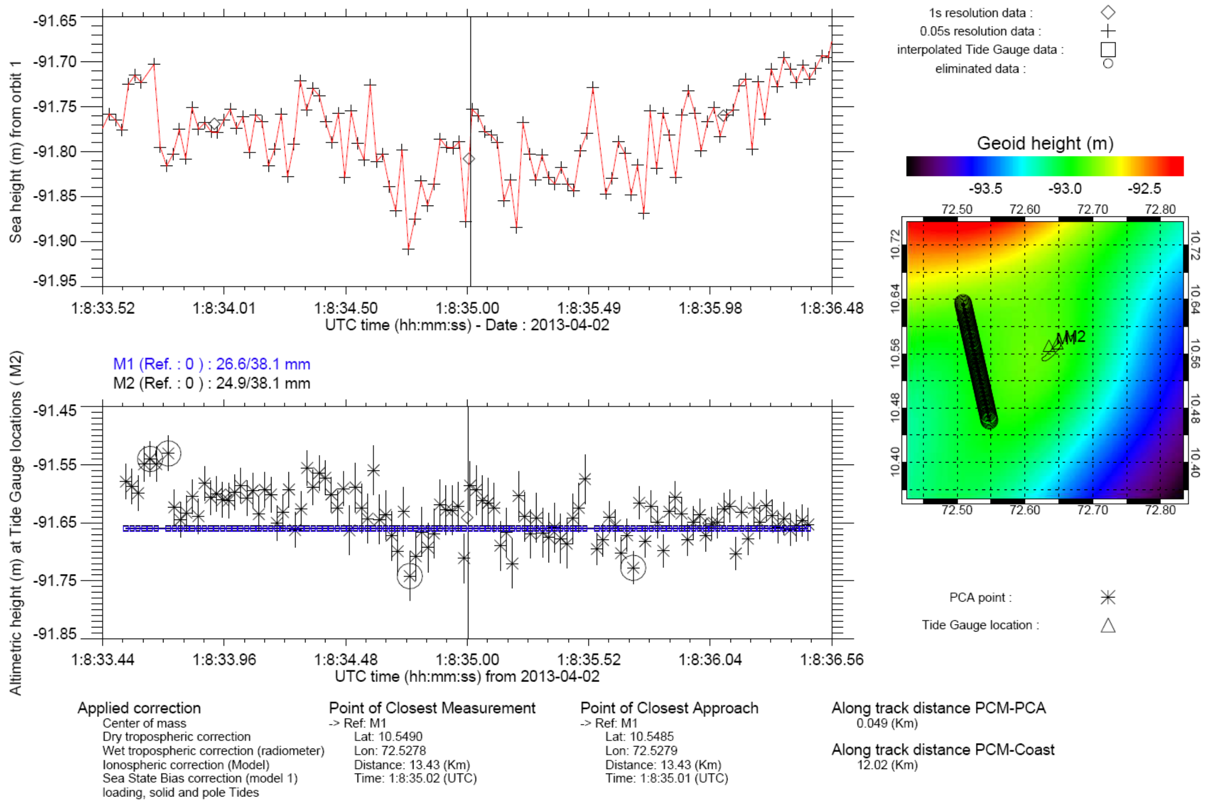


Figure 5a: Absolute calibration of SARAL/AltiKa on 2nd April 2013 - OGDR product

The mean SSH bias for OGDR product at main jetty and NIOT jetty are found to be 2.66cm and 2.94cm respectively.

Figure 5b gives absolute calibration of SARAL/AltiKa on 2nd April 2013 - IGDR product. The mean SSH bias for IGDR product at main jetty and NIOT jetty are found to be -3.01cm and -3.18cm respectively.

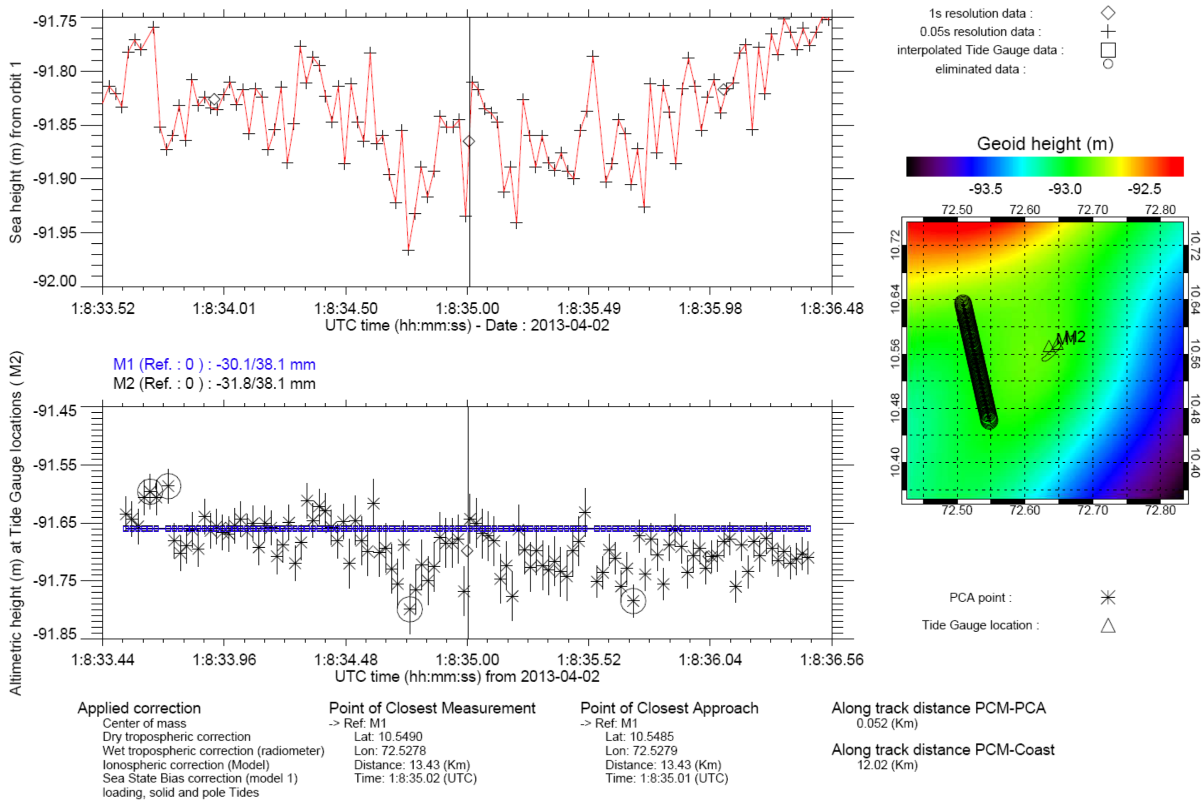


Figure 5b: Absolute calibration of SARAL/AltiKa on 2nd April 2013 - IGDR product

5. SARAL/AltiKa geo-physical product validation

The accuracy of Geo-physical products depends on the accuracy of altimeter measurements as well as the error involvement in the geo-physical model function for retrieval. The complicated relations between the altimeter echo and the different geophysical parameters like sea surface height, wind etc. depends on the accuracy of measurements of time delay between the transmitted and the received pulses. The time delay however elongated due to interaction of the return pulse with the air molecules water vapour etc. Further, the sea surface height varies under effect of the pressure changes and tides due to gravitational attraction of sun and moon. Inaccuracies involved in the geoid height measurements in association with all the above mentioned phenomena introduce a considerable amount of error in the instrument measurements. However, effects of many of these phenomena are reduced by introducing various correction terms that includes predominantly the dry atmospheric corrections, wet atmospheric corrections, inverse barometric effects, sea state bias, tides etc. Validation of these parameters is therefore required to find whether the errors in data are within required range so that it can find its application for various studies.

5.1 Approach/methodology and data used for validation

Data Used for the validation exercise are as follows :

1. *Jason-2 (SLA, SWH and Wind Speed) taken from Radar Altimeter Database System(RADS).*
2. *SARAL/AltiKa (SLA, SWH and Wind Speed)taken from MOSDAC*
3. *NDBC Buoy (SWH and Wind speed) from NDBC NOAA.*

The validation procedure involves the following steps (Suchandra et al., 2010) one by one as data comes :

- Removal of data out of range: The data is plotted simply to find out the values that are out of known range.
- The long term validation has provided the monthly average range of values for all geophysical parameters. This is compared to the data to see the climatological consistency of the data.
- Comparison of the SARAL/AltiKa data with available buoy and Jason-2 observations.

Collocation of satellite and in-situ measurement:

The satellite measurement over the globe would not be exactly collocated with the buoy locations. For this reason, the measurements have to be made collocated in terms of space and time. For our comparison, we have set the limitations for the collocated data set to a maximum time window of 30 min between the satellite pass and the in-situ measurement and a maximum distance of 50km.

Normalization of the buoy wind field:

In radar altimetry, the algorithms used for wind speed retrieval estimates wind speed at typical height of 10m above the surface and is represented as U_{10}. This is typically to avoid the lowest layer of the Planetary Boundary Layer (PBL) commonly called the surface layer where the small scale turbulent eddies are formed due to the molecular viscosity of the air. This surface layer extends typically up to height of 10ms on any convectively active day. Therefore, the 10 meters height is referred as the level of neutral stability. Most anemometers used for the wind speed measurements are however mounted at different heights, and has be normalized. Anemometer attached to buoys is located typically between 3m and 5m above the hull. Thus the buoy data has to be firstly converted into the 10m wind speed and it is done mathematically by using the following equation.

$$\frac{U_z}{U_{10}} = \left(\frac{z}{10}\right)^{1.3} \qquad \text{---- (4)}$$

(z = anemometer height in m, U_z = measured wind speed m/s, U_{10} = wind speed in 10m m/s).

Statistical comparison:

The collocated satellite and the in-situ measurements of SWH, the wind (from buoy) and SSH (from the tide gauges) are compared with each other using the statistical techniques. Bias, Root Mean Square Error (RMSE), mean, standard deviations and Correlation Coefficient (CC) would be calculated to find out the relation between the measurement and the observation.

5.2 Validation results

The SARAL/AltiKa OGDR and IGDR data is regularly kept by MOSDAC and is received by the CAL/VAL team. The Jason-2 data has been used for the purpose of inter-comparison and has been taken from radar altimeter data base system. NDBC data used for validation exercise has been taken from the NDBC /NOAA site. The SARAL/ Altika data has been collocated with the Jason-2 and NDBC buoy data at a spatial distance of 50 Km and temporal scale of 30 min. The collocated geo-physical parameters are then analyzed. Consistency checks have been carried out and the statistics has been generated on an overall and daily basis. The OGDR data was first received from 13th March 2013 and from then, continuous validation has been carried out with Jason-2 until 24th when Jason-2 suddenly stopped working. The data of this concurrent phase was very important to check overall performance of SARAL/AltiKa in-flight stage. Figure 6 shows the comparison of SARAL/Altika SLA at both OGDR and IGDR level with Jaosn-2. Clearly, the overall biases in SLA are as low as 9 cm to 10 cm which is pretty low when we talk about OGDR level as the mission requirement for SLA accuracies at OGDR level was 30 -35 cm. However at IGDR level, the RMSE is slightly more. Figure 7 shows the same for SWH. The bias in OGDR and IGDR are 1.06 and 1.04 m respectively. However, some outliers are seen in the scatter which can be probably due to the coastal contaminations in Jason 2. Figure 8 and 9 shows the daily variation in statistics in OGDR and IGDR data for SLA and SWH respectively. Clearly, the average and standard deviation match fairly between the Jason-2 and AltiKa. There is a slight rise in the RMSE of SLA with time and it was noticed from 20 March 2013. By 20 March 2013, the RMSE was up to ~16 cm. The RMSE for SWH was consistent was between 0.5 to 0.91 m. Figure 10 shows the percentage improvement between the OGDR and IGDR levels. Clearly, the improvement was consistent until 19 March 2013 and afterwards, the improvement was cut down. The validation of the SARAL/AltiKa data has also being carried out using the NDBC buoy data and the results are shown for the SWH at OGDR and IGDR levels. The coefficient of determination shows that at both levels of the SARAL/AltiKa, data is in good agreement with the actual observations of SWH. The RMSE is approximately 0.28 m which is again within the mission requirement. On an average, till date the overall quality of SARAL/AltiKa data is good. At OGDR level, the achieved accuracies are well within mission requirement. The improvement in IGDR level is however less and is only seen in SSHA. The validation carried out with in-situ observations shows that SWH is of very high quality (Figure 11).

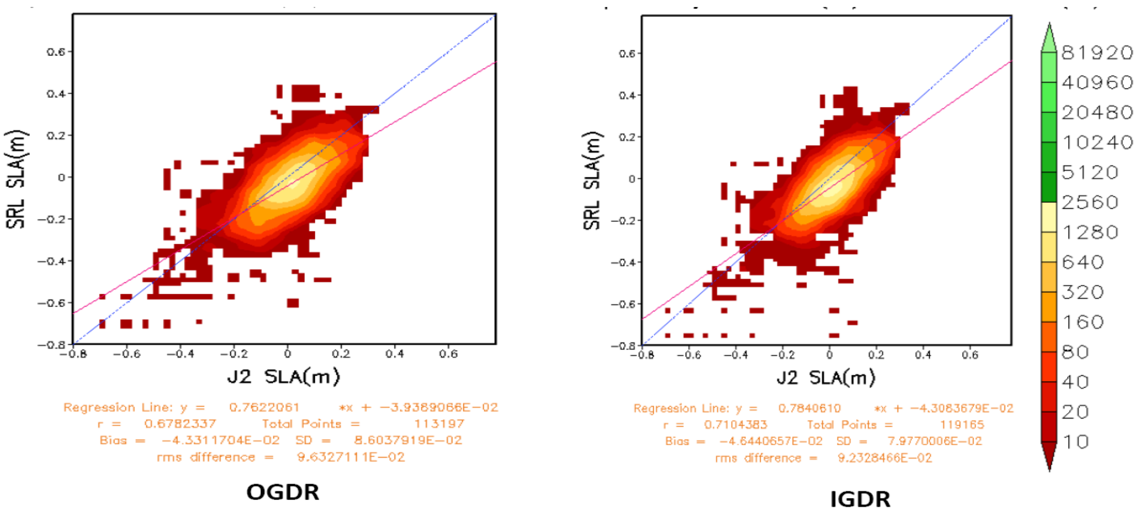


Figure 6: Inter comparison of SARAL/AltiKa SLA with Jason-2 SLA from March 13 - 30, 2013

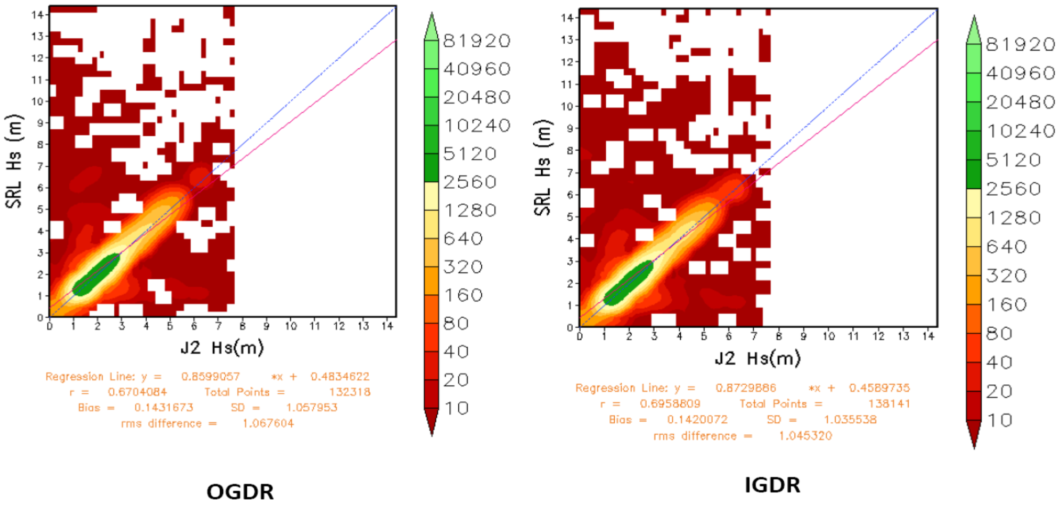


Figure 7: Inter comparison of SARAL/AltiKa SWH with Jason-2 SLA from March 13-30, 2013

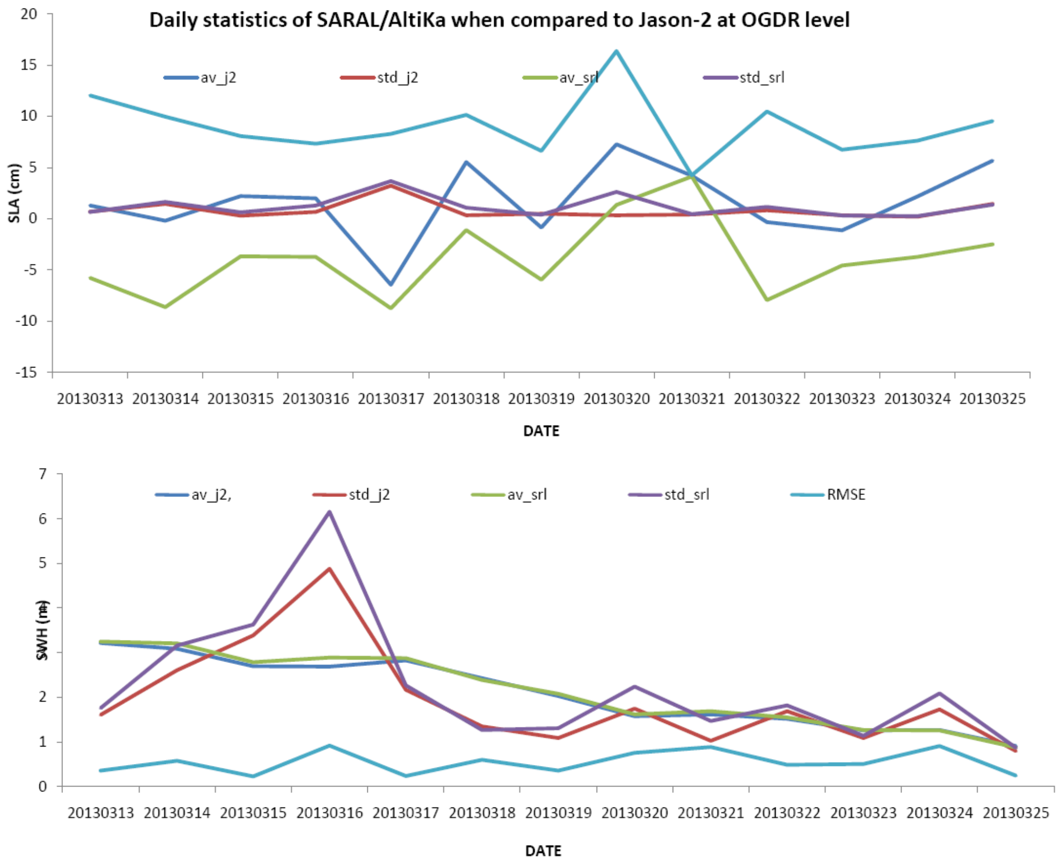


Figure 8: Daily inter comparison of SARAL/AltiKa SLA and SWH with Jason-2 at OGDR level from March 13-30, 2013

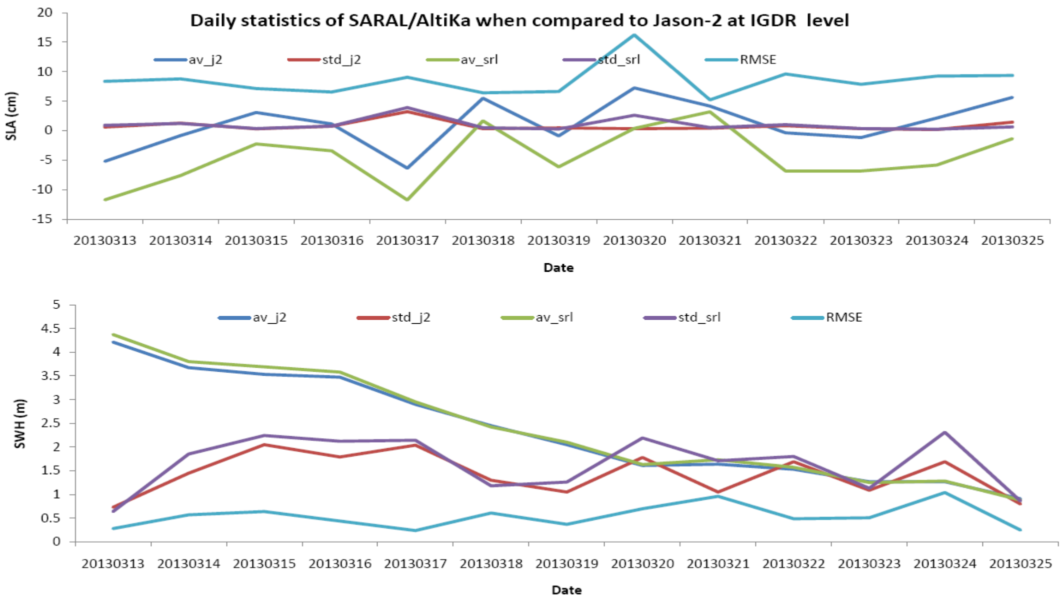
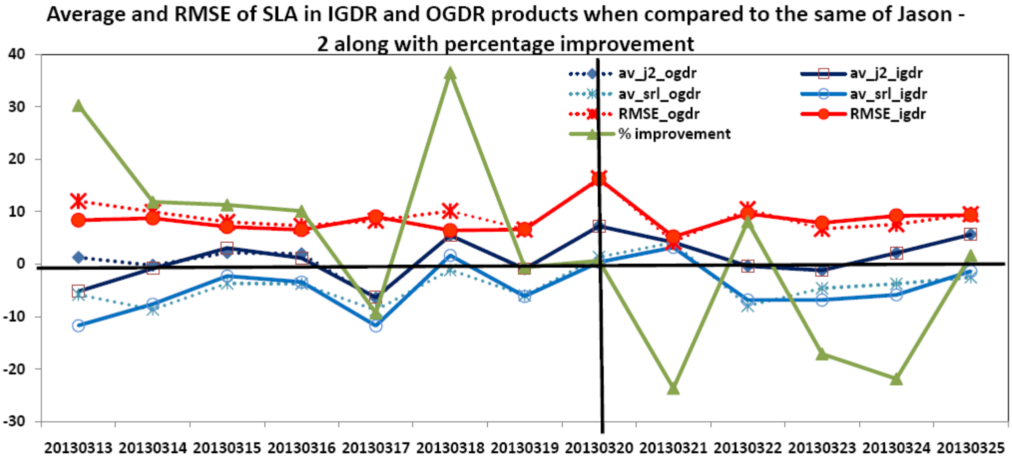


Figure 9: Daily inter comparison of SARAL/AltiKa SLA and SWH with Jason-2 at IGDR level from March 13-30, 2013

Improvement between OGDR and IGDR products



Gross statistics of SARAL/AltiKa when compared to Jason-2 at OGDR level (13-24, March,2013)

	No of points	av_j2,	std_j2	av_srl	std_srl	RMSE
sla (cm)	9491	1.39	9.3	-3.29	10.83	8.8
swh(m)	10795	2.43	1.05	2.5	1.13	0.62
wsp(m/s)	11175	7.18	4.09	20.79	6.62	14.37

Gross statistics of SARAL/AltiKa when compared to Jason-2 at IGDR level (13-24 Mar 2013)

	No of points	av_j2,	std_j2	av_srl	std_srl	RMSE
sla (cm)	10013	1.34	9.25	-3.72	10.52	8.5
swh(m)	11306	2.5	1.09	2.58	1.19	0.66
wsp(m/s)	11689	7.32	4.13	21	6.59	14.42

Figure 10: Improvements between OGDR and IGDR levels of SARAL/AltiKa from March 13-30,2013

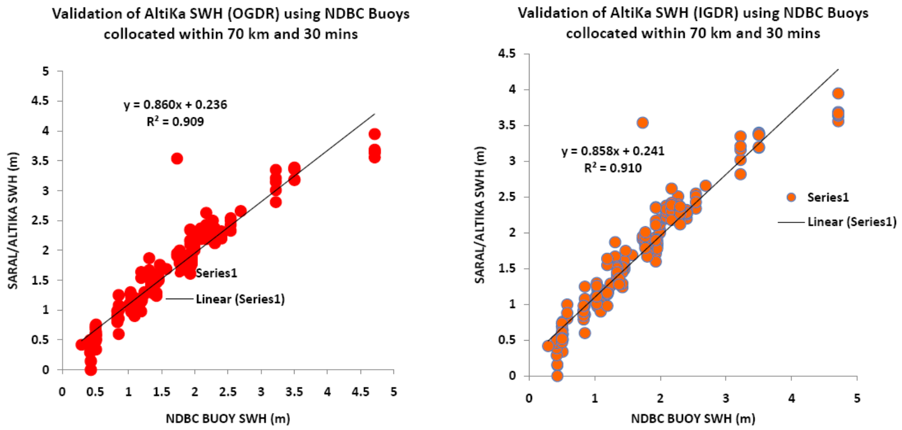


Figure 11: Validation of SARAL SWH at OGDR and IGDR levels using the NDBC buoy observations

6. Conclusion

This report brings out the initial calibration and validation results of SARAL/AltiKa over Kavaratti calibration site and validation against Jason-2 and NDBC buoy observations. The absolute bias against in-situ tide gauge measurements are very encouraging (as they are meeting the mission requirement). The validation carried out with in-situ observations shows that SWH is of very high quality. The retrieved wind speed is very high as compared to Jason-2. The additional validation parameter (sea level anomaly) is having a RMS error of 8.8/8.5 in OGDR/IGDR products respectively.

Cal/Val site	Saral/AltiKa OGDR bias	Saral/AltiKa IGDR bias
Kavaratti Main jetty	2.66 cm	-3.01 cm
Kavaratti NIOT jetty	2.49 cm	-3.18 cm

	No. of points	Jason -2		SARAL/ AltiKa (OGDR)		RMSE
		Mean	**Std. dev**	**Mean**	**Std. dev**	
SLA (cm)	9491	1.39	9.3	-3.29	10.83	8.8
SWH (m)	10795	2.43	1.05	2.5	1.13	0.62
WS (m/s)	11175	7.18	4.09	20.79	6.62	14.37

	No. of points	Jason -2		SARAL/ AltiKa (IGDR)		RMSE
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