Moving closer to the coast by SARAL/AltiKa: Geophysical Product for Indian Mainland Region

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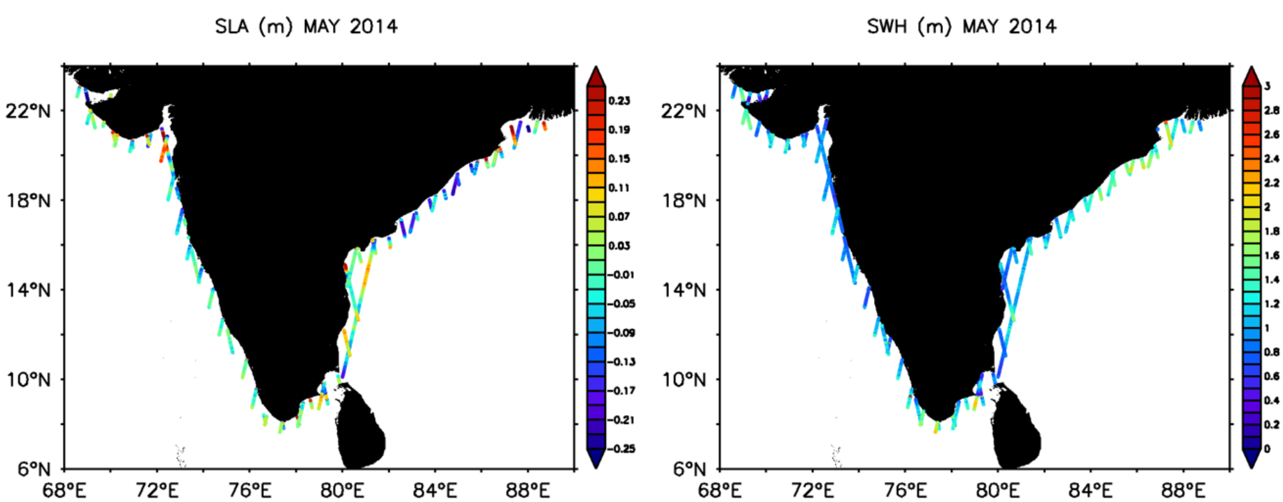
User Handbook



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1 Introduction

SARAL-AltiKa is the ISRO-CNES joint collaborative project. SARAL is an acronym for "SAtellite for ARgos and ALtiKa" with two payloads namely AltiKa, a Ka-band (35-GHz) radar altimeter and ARGOS, a data collection platform for a variety of physical and biological data from ocean in-situ instruments like Ocean buoys etc. SARAL realizes ocean radar altimetry through a suite of altimetry payloads which includes the DORIS and LRA instruments for precise orbit determination (POD); a dual-frequency microwave radiometer (MWR) at 24/37GHz for water vapor correction. At 35 GHz, not only is the ionospheric contamination of the pulse echo negligible, it also gives a better vertical resolution of about 0.3m for wave estimation and a compact, light-weight instrument for greater portability.

The objectives of AltiKa mission are: To realize precise, repetitive global measurements of sea surface for studying mesoscale variability, developing coastal oceanography, inland waters and ice sheets monitoring and understanding of climate change.

This document is User Handbook for the "**Moving closer to the coast by SARAL/AltiKa: Geophysical Product for Indian Mainland Region**". This product was conceived in the framework of deriving high resolution "Coastal Product" project under SARAL/AltiKa mission. This coastal product is an experimental product derived from SARAL/AltiKa S-IGDR tracks. The document provides an insight to coastal product and various algorithms used in its derivation. It is advised that user refer the SARAL/AltiKa product handbook (SARAL/AltiKa User Handbook, Dec, 2013), as present document is an add-on with specific retrackers and quality flags for 40-Hz data processing.

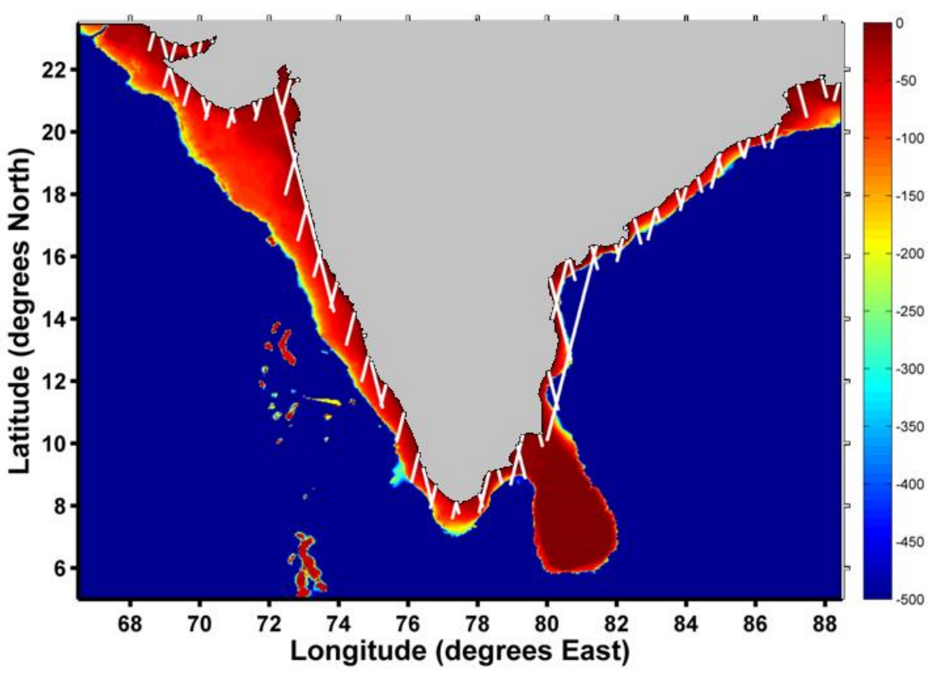

Figure 1. Different tracks of SARAL AltiKa (in white) near Indian coast used in the study. Tracks are overlaid on ocean bathymetry. Along-track coastal 40-Hz products are derived up to 50 km from the coast.

1.1 Overview of the product

In Open Ocean, the altimetric echo follows a standard shape, with steeply rising leading edge followed by a trailing edge with gradually diminishing power. This standard shape is in agreement with the theoretical Brown model (Brown 1977) and hence can be easily modeled. Output of the Brown model is sea surface height (SSH), significant wave height (SWH) and backscatter coefficient (Sigma (0)). Sea surface height anomaly (SSHA) is further computed from SSH. The waveforms measured in the coastal area do not conform to the theoretical Brown model due to land contamination and inaccurate geophysical corrections. Special data processing efforts are needed for coastal region. SARAL/AltiKa coastal product is concerned with providing the geo-physical parameters SSHA, SSH, SWH and Wind Speed from the retracking algorithms BETA5, BETA9 and BAGP at 40-Hz data rate. The distance between the consecutive points in the 40-Hz data is approximately 180 meters. Geophysical products have been computed along the tracks of SARAL/AltiKa in the coastal regions of Indian Mainland. The tracks are shown in Fig. 1 in white. List of tracks are provided (in ascending order) here:

0010, 0023, 0038, 0051, 0066, 0081, 0096, 0109, 0124, 0137, 0152, 0182, 0195, 0210, 0223, 0238, 0281, 0296, 0309, 0324, 0367, 0382, 0395, 0410, 0423, 0453, 0468, 0481, 0496, 0509, 0524, 0539, 0554, 0567, 0582, 0595, 0610, 0640, 0653, 0668, 0681, 0696, 0726, 0739, 0754, 0767, 0782, 0825, 0840, 0853, 0868, 0911, 0926, 0939, 0954, 0967, 0997

Users can use links in *http://www.aviso.altimetry.fr/en/data/tools/pass-locator.html* to locate the SARAL/AltiKa tracks. Users can refer SARAL/AltiKa User Handbook (Dec, 2013) for more information about the tracks.

Apart from SSH, SSHA, SWH and wind speed some other useful parameters in the coastal parameters which are useful for users are also provided. These are listed below:

1) Backscatter Coefficient (Sigma (0)) from different retracking algorithms
2) Quality parameters of the retracker and retracking flag
3) Waveform shape classification
4) Distance from the coast and land flag
5) Interpolated corrections
6) Ocean retracker is also provided from standard S-IGDR product.

This product is experimental and similar in approach to the **PISTACH** product (Refer PISTACH User Handbook, Oct, 2010) for Jason-2 altimeter.

2. Domain and data format

The domain of the coastal product is for the Indian mainland coastal region (~50 km from the coast) as shown in Fig. 1. Maximum and minimum latitude and longitude are given below.

geospatial_lat_min = 05N

geospatial_lat_max = 24N

geospatial_lon_min = 68E

geospatial_lon_max = 90E

The output is provided in the NETCDF file format. Output files are named in the following manner

SRL_CCC_TTTT_yyyymmddHHMMSS_yyyymmddHHMMSS_INDIANCOAST_SIGDR_VER1.1.nc

CCC is the cycle number and TTTT is the track number.

First yyyymmddHHMMSS is the start time of the file.

second yyyymmddHHMMSS is the end time of the file.

3. Processing involved in the coastal product and parameters provided

Prior to describing, the processing involved in deriving coastal products, it will be useful to understand the procedure involved in the computation of geo physical parameters from altimeter in the open ocean. In the following sections we first discuss the open ocean altimeter data processing.

3.1 Altimeter Data Processing for Open Ocean

Basic measurement of an altimeter is in form of a time series known as waveform in which power is distributed along various measuring gates of an altimeter as depicted in Figure 2. These gates arise due to signal processing and decide the vertical resolution of the altimeter. A model is fitted to the altimeter waveform, and the model parameters provide the geophysical parameters or their corrections. Fitted model is shown as blue curve in the same Figure. This process of modeling the altimetric waveform is known as retracking and the specific model used for retracking is known as a retracker. A theoretical model (known as MLE4 retracker), based on the scattering of a radar pulse from the sea-surface, was formulated by Brown (1977) and is extensively used for open ocean waveform retracking.

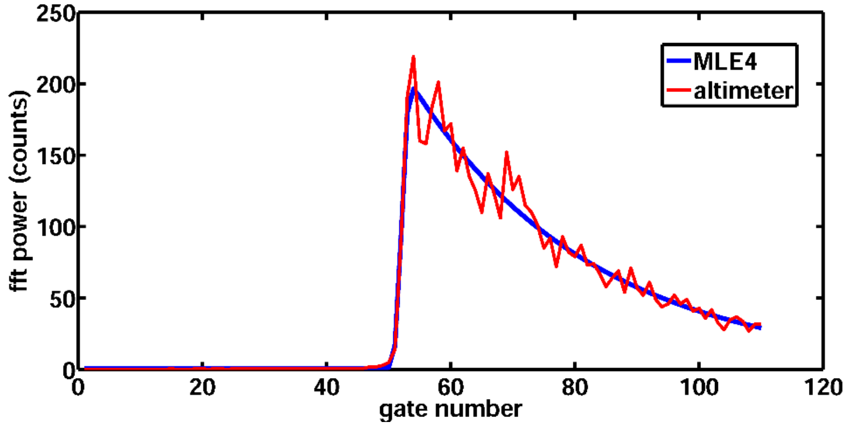

Figure 2. A typical open ocean waveform from SARAL/AltiKa (red) and fitted waveform by the MLE4 retracker in blue

To the first order, this model is given as by Amarouche et al. (2004)

$$W(t) = \left(\frac{A}{2}\right) exp(-v)\,[1 + erf(u)]$$

where

$$u = \frac{t - t_0 - \alpha\sigma_c^2}{\sqrt{2}\sigma_c}, \quad v = \alpha\left(t - t_0 - \frac{\alpha}{2}\sigma_c^2\right) \qquad (3.1)$$

$$\alpha = \delta - \frac{\beta^2}{4}$$

$$\beta = (4/\gamma)(c/h)1/2 sin\,(2\xi)\,, \delta = (4/\gamma)(c/h)cos(2\xi)$$

c is speed of light

h is the height of the satellite platform, $\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-z^2} dz$

$\gamma = (1/2)\ln 2 \sin^2\theta_{-3dB}$, θ_{-3dB} being the half-power antenna beam width.

A is the amplitude scaling term of the waveform.

ξ is the satellite antenna mispointing angle

σ_c is the composite rise-time

t_0 is the midpoint of the leading edge with reference to a fixed tracker bin. This bin is 52 for SARAL/AltiKa.

$$\sigma_c^2 = \sigma_p^2 + \left(\frac{2}{c} \ \sigma_s \right)^2$$

$$\text{SWH} = \ 4\sigma_s$$

where σ_p is radar antenna parameter and σ_s is the RMS surface elevation .

Brown Model and the retrieved parameters are shown in Figure. 3. Note that thermal noise is also present in the actual altimetric waveforms.

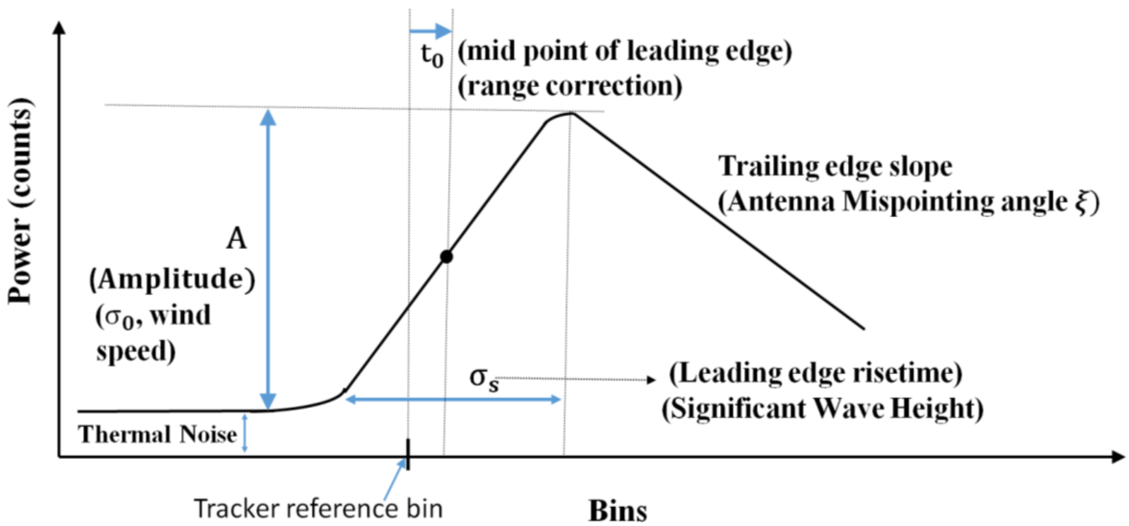

Figure 3. Brown model and the related retrieved parameters.

Fitting the waveform model with the altimetric waveform is done using the Maximum Likelihood Estimator (MLE) technique explained in Amarouche et al. (2004). After fitting the theoretical model to the altimetric waveform three basic parameters are computed as described in the following sub-sections.

3.1.1 Computation of Sea Surface Height Anomaly

Parameter t_0 computed from equation 3.1 gives retracking correction to the range calculated by the onboard tracker on the satellite. The range is also corrected for the geophysical and the instrument corrections.

Corrected Altimeter Range = Tracker Range + t_0 + geophysical corrections + instrument corrections.

Altimeter range is then subtracted from the Altitude of satellite to give the SSH. Geophysical corrections in the altimeter will be discussed in the Section 5.

SSH = Altitude - Corrected Altimeter Range

Sea Surface Height Anomaly (SSHA) is then calculated by subtracting Mean Sea Surface (MSS). MSS is the long term mean of the Sea Surface Height calculated by averaging the SSH by the previous satellite altimeters.

SSHA = SSH - MSS

3.1.2 Computation of Significant Wave Height

σ_c from equation 3.1 is the composite rise time of the waveform. This parameter is obtained by fitting the waveform with the theoretical model. Antenna characteristic σ_p is already known. So we can compute σ_s which is root mean square (RMS) surface elevation.

$$\left(\frac{2}{c} \sigma_s \right)^2 = \sigma_c^2 - \sigma_p^2$$

where c is speed of light

SWH is approximated as four times the RMS elevation σ_s.

$$SWH = 4\sigma_s$$

3.1.3 Computation of Wind Speed

Wind speed is obtained generally using empirical relationships based on backscatter coefficient σ_0 which is obtained by the $'A'$ term in the equation 3.1 as follows

$$\boldsymbol{\sigma_0}(\boldsymbol{dB}) = \mathbf{10log}(\boldsymbol{A}) + \boldsymbol{scaling\ factor} + \boldsymbol{atmospeheric\ correction} + \boldsymbol{instrument\ corrections}$$

Scaling factor accounts for all the parameters of the radar equation except the amplitude of the waveform. σ_0 is also accounted for the atmospheric correction due to propagation in medium and the instrument corrections.

The wind speed is calculated in S-IGDR by using one dimensional model given by Lillibridge et al. (2014) which is a function of backscatter coefficient. Equations for calculating wind speed using one dimensional model are shown below

$$U_m = \begin{cases} \alpha - \beta\sigma_0 & if\ \sigma_0 \leq \sigma_b \\ \gamma\ exp(-\delta\sigma_0) & if\ \sigma_0 > \sigma_b \end{cases} \tag{3.2}$$

where $\alpha = 34.2$, $\beta = 2.48$, $\gamma = 720$, $\delta = 0.42$ and $\sigma_b = 11.4$

Wind speed = $U_m + 1.4\ {U_m}^{0.096}\ exp(-0.32{U_m}^{1.096})$

One dimensional model from eqn. (3.2) is used for calculating wind speed from backscatter coefficient obtained from all the retracking algorithms.

Note: In general, the geophysical parameters are calculated at 40-Hz and then averaged over 1-Hz by using some filtering procedure. But in coastal regions 1-Hz resolution which is approx. 7 km, is not very useful to provide the resolution needed for most of the coastal applications. 40-Hz data can be noisy due to limited averaging. Therefore, 40-Hz data can be used for research purposes in coastal regions. It is suggested that the 40-Hz data should be filtered and averaged according to the specific applications.

Geophysical parameters computed from the Ocean retracker as provided in the S-IGDR product are also provided. The list of these parameters is given below:

SSHA :: **ssha_mle4_40hz**

SSH :: **ssh_mle4_40hz**

SWH :: **swh_mle4_40hz**

WIND SPEED :: **wind_speed_mle4_40hz**

3.2 Retracking algorithms used in the coastal product

Although eqn. 3.1 (ocean model) works well in the Open Ocean, in the coastal areas this model fails due to incursion of the land in the footprint of the altimeter as shown in Figure 4. In order to encounter this contamination, specific retracking algorithms are used in the coastal regions.

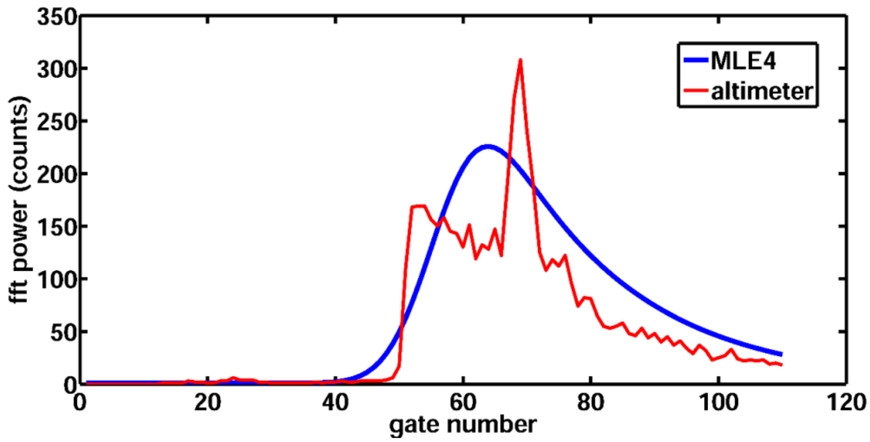

Figure 4. Sample waveform in the Coastal Ocean from SARAL/AltiKa (red) and fitted with the Open Ocean model (blue).

In coastal product we have provided three types of retrackers which are useful for the retrieval of parameters in the coastal region. These retrackers are discussed in the following sections.

3.2.1 Beta retracker with exponential edge

Martin et al. (1983) developed a retracking algorithm for processing altimeter waveforms over continental ice sheets. This algorithm was used to retrack all SEASAT radar altimeter waveforms. This retracker was found useful in many coastal studies eg. Deng (2003)

The algorithm fits a 5 or 9-parameter function to the altimeter waveform. The first function is for fitting returns with single ramp in the trailing edge while the second one is used to fit returns with double ramps in the trailing edge. Single-ramp returns are modeled by 5-parameter model (Figure 5). The functional form for which is given in the equation below:

$$W(t) = \beta_1 + \beta_2(1 + \beta_5 Q)P(\frac{t-\beta_3}{\beta_4}) \quad (3.3)$$

where

$$Q = \begin{cases} 0 & \text{for } t < \beta_3 + 0.5\beta_4 \\ t - (\beta_3 + 0.5\beta_4) & \text{for } t > \beta_3 + 0.5\beta_4 \end{cases} \quad (3.4)$$

$$P(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} exp\left(\frac{-q^2}{2}\right) dq \quad (3.5)$$

The unknown parameters related to a waveform are:

1) β_1 : Thermal noise level of waveform
2) β_2 : Return signal amplitude
3) β_3 : Midpoint on the leading edge of the waveform
4) β_4 : Return waveform rise-time
5) β_5 : Slope of the trailing edge

β_4 (the rise-time) is equivalent to σ_c, the composite rise-time. The formula used to derive the SWH from the rise time is:

$$\left.\begin{array}{l} \sigma_c^2 = \sigma_p^2 + (\frac{2}{c}\sigma_s)^2 \\ \text{where c is speed of light} \\ SWH = 4\sigma_s \end{array}\right\} \quad (3.6)$$

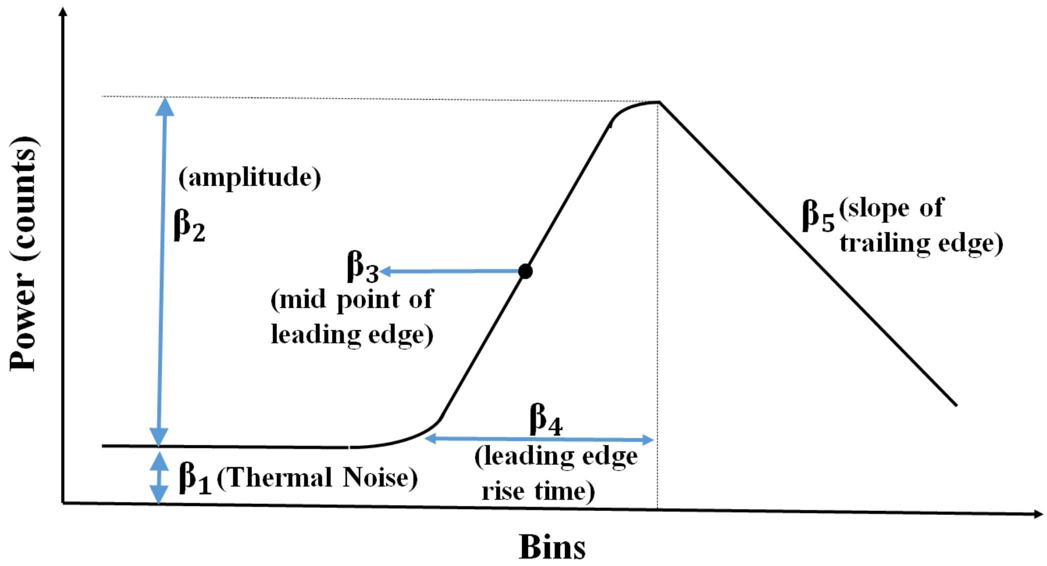

Figure 5. Cartoon showing different parameters in the 5 parameter BETA retracker.

In eqn. (3.6), σ_c is written instead of β_4 to denote the composite rise-time. Please note that σ_c is composite rise time and is slightly different from σ_s which is RMS of surface elevation. Simple form of eqn. 3.3 helps in encountering the contamination in the waveforms.

9 parameter form of eqn. (3.3) is given as

$$W(t) = \beta_1 + \beta_2(1 + \beta_5 Q_1)P(\frac{t-\beta_3}{\beta_4}) + \beta_6(1 + \beta_9 Q_2)P(\frac{t-\beta_7}{\beta_8}) \quad (3.7)$$

where P is same as in eqn. 3.5 and

Q_1 and Q_2 are analogous to eqn. 3.4 as

$$Q_1 = \begin{cases} 0 & \text{for } t < \beta_3 + 0.5\beta_4 \\ t - (\beta_3 + 0.5\beta_4) & \text{for } t > \beta_3 + 0.5\beta_4 \end{cases} \quad (3.8)$$

$$Q_2 = \begin{cases} 0 & \text{for } t < \beta_7 + 0.5\beta_8 \\ t - (\beta_7 + 0.5\beta_8) & \text{for } t > \beta_7 + 0.5\beta_8 \end{cases}$$

where β_6, β_7, β_8 and β_9 are the parameters of the second ramp in the waveform.

1) β_6: Return signal amplitude of the second ramp
2) β_7 : Midpoint on the leading edge of second ramp in the waveform

3) β_8 : Rise-time of the second ramp in the waveform

4) β_9 : Slope of the trailing edge of the second ramp in the waveform.

Various parameters in 9 parameter BETA retracker are shown in Figure 6.

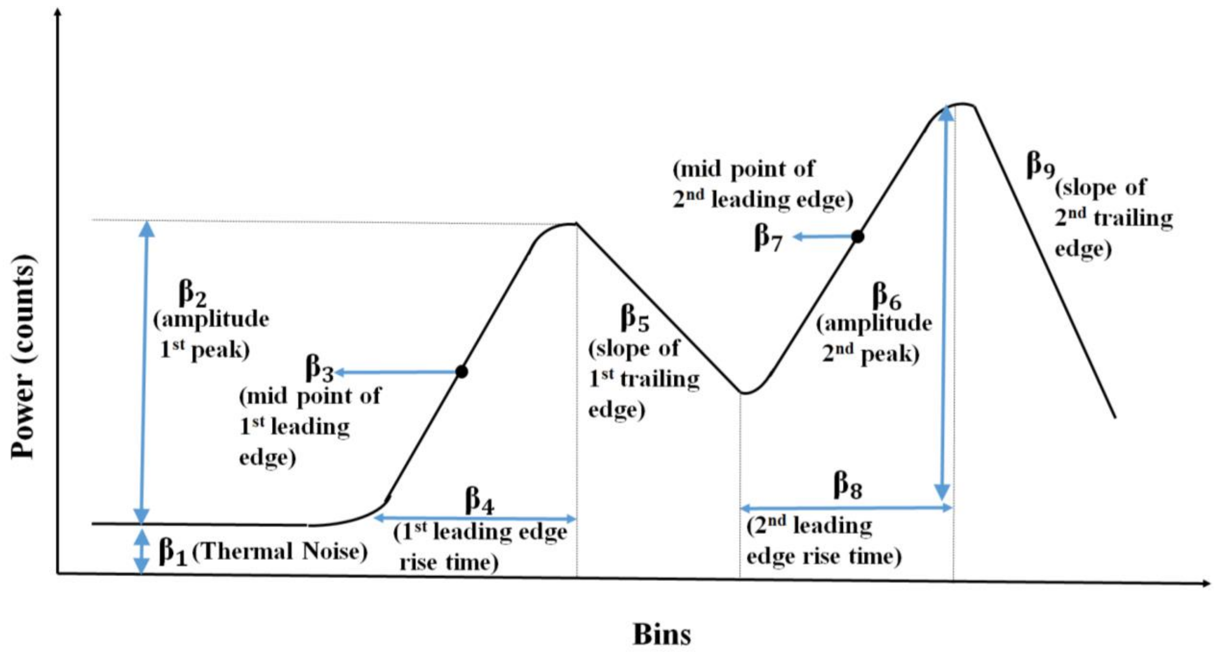

Figure 6. Cartoon showing different parameters in the 9 parameter BETA retracker.

Deng and Featherstone (2006) gave a different expression than eq. (3.2) with exponential trailing edge for 5 parameters which is given as

$$W(t) = \beta_1 + \beta_2 \exp(-\beta_5 Q) P(\frac{t-\beta_3}{\beta_4}) \tag{3.9}$$

where P is same as in eqn. 3.4 and

$$Q = \begin{cases} 0 & \text{for } t < \beta_3 - 2\beta_4 \\ t - (\beta_3 + 0.5\beta_4) & \text{for } t > \beta_3 - 2\beta_4 \end{cases} \tag{3.10}$$

9 parameter form of eqn. (3.9) is given as

$$W(t) = \beta_{1+}\beta_2 \exp(-\beta_5 Q_1) P\left(\frac{t-\beta_3}{\beta_4}\right)(t) + \beta_6 \exp(-\beta_9 Q_2) P(\frac{t-\beta_7}{\beta_8}) \tag{3.11}$$

where P is same as in eqn. 3.5 and

Q_1 and Q_2 are analogous to eqn. 3.10 as

$$Q_1 = \begin{cases} 0 & \text{for } t < \beta_3 - 2\beta_4 \\ t - (\beta_3 + 0.5\beta_4) & \text{for } t > \beta_3 - 2\beta_4 \end{cases} \quad (3.12)$$

$$Q_2 = \begin{cases} 0 & \text{for } t < \beta_7 - 2\beta_8 \\ t - (\beta_7 + 0.5\beta_8) & \text{for } t > \beta_7 - 2\beta_8 \end{cases}$$

Both BETA5 (Equation 3.7) and BETA9 (Equation 3.11) have been used to generate coastal products. Reasons for specifically using BETA5 and BETA9 retarckers is because SARAL/AltiKa has very low mispointing angle which gives an exponential form to trailing edge of the waveform. So the linear trailing edge is not an appropriate choice for retracking. The method used for fitting model to the waveform is an iterative non-linear fitting approach, which is the least squares method with appropriate weighing scheme (Deng, 2003).

Geophysical parameters derived from the BETA retrackers are provided in the coastal product as per the following naming convention:

For 5 parameter BETA retracker

SSHA :: **ssha_beta5_40hz**

SSH :: **ssh_beta5_40hz**

SWH :: **swh_beta5_40hz**

WIND SPEED :: **wind_speed_beta5_40hz**

Similarly, for 9 parameter BETA retracker

SSHA :: **ssha_beta9_40hz**

SSH :: **ssh_beta9_40hz**

SWH :: **swh_beta9_40hz**

WIND SPEED :: **wind_speed_beta9_40hz**

3.2.2 Brown with Asymmetric Gaussian Peak model (BAGP)

This model adds the asymmetric Gaussian peak with the ocean type waveform in order to model the waveforms in the coastal region. Halimi et al. (2013) gave a Brown + peak model and implemented it by using MLE and Nelder-Mead unconstrained optimization method. The functional form of the model is given as:

$$W(t) = W_b(t) + P_k(t) \tag{3.11}$$

Where $W_b(t)$ is same as eq. 3.1 and the peak component $P_k(t)$ is given as

$$P_k(t) = A_k \, exp\left[\frac{-1}{2\sigma_k^2}\,(t - T_k)^2\right]\left\{\gamma\left[\frac{(t-T_k)}{\sqrt{2}}\right]\right\} \tag{3.12}$$

A_k, T_k, σ_k, and γ are amplitude, position, width and asymmetry coefficient of the peak respectively.

Two type of fitting methods for this algorithm, following Halimi et al. (2013), are provided. One fitting is done by the least square method while the other is using Nelder Mead (Nelder et al, 1965) method of fitting. The latter will be referred to as BAGP (nm).

The geophysical parameters are provided as variables in the product as:

SSHA :: **ssha_bagp_40hz/ ssha_bagp_nm_40hz**

SSH :: **ssh_bagp_40hz/ ssh_bagp_nm_40hz**

SWH :: **swh_bagp_40hz/ swh_bagp_nm_40hz**

WIND SPEED :: **wind_speed_bagp_40hz/ wind_speed_bagp_nm_40hz**

3.3 Other related parameters

These are some other parameters (not exactly geophysical products) related to retrackers that are important for inclusion in the product. They are described in the following sub-sections.

3.3.1 Backscatter Coefficient

Backscatter coefficient (Sigma(0)) is an important parameter for wind speed computation. This variable is computed from each of the retrackers and are named as follows:

sigma_zero_mle4_40hz for MLE4 retracker

sigma_zero _beta5_40hz for 5 parameter BETA retracker

sigma_zero _beta9_40hz for 9 parameter BETA retracker

sigma_zero _bagp_40hz for BAGP retracker

sigma_zero _bagp_nm_40hz for BAGP (nm) retracker

3.3.2 Quality flags for retrackers.

The retracking quality flags are provided in the coastal product in the following manner:

flag_mle4_40hz for MLE4 retracker

flag_beta5_40hz for 5 parameter BETA retracker

flag_beta9_40hz for 9 parameter BETA retracker

flag_bagp_40hz for BAGP retracker

flag_bagp_nm_40hz for BAGP (nm) retracker

This is a simple flag. Its value is zero if retracking has been performed.

Note: Users must note that sometimes the retracking is successful but the fitted waveforms still do not fit the original waveforms. Therefore, an additional fitting quality parameter, mean quadratic error (MQE) is also provided. This parameter gives an idea about the errors in fitting from various algorithms.

MQE is mean squared difference between the observed waveforms and the fitted model. Waveform and model waveform power are normalized by the maximum power in waveforms.

$$MQE = \frac{1}{N}\sum_{i=1:N}(waveform(i) - model(i))^2 \quad (3.13)$$

N=128 for SARAL

Lesser the MQE better the retracking result. MQE also depends on the noise content in waveforms and therefore relative MQE and the flags have to be checked before using the geophysical parameter.

mqe_mle4_40hz for MLE4 retracker

mqe_beta5_40hz for 5 parameter BETA retracker

mqe_beta9_40hz for 9 parameter BETA retracker

mqe_bagp_40hz for BAGP retracker

mqe_bagp_nm_40hz for BAGP (nm) retracker

Note: It is suggested that the both retracking flags as well as MQE should be checked before using the geophysical parameters from any retracker. Users can set a threshold for MQE for using the data.

There is no rain flag in the SARAL data but an additional **trailing_edge_variation_flag_40hz** parameter is provided in the IGDR product. This flag accounts for the rain as well as presence of dense cloud as SARAL/AltiKa is more sensitive to water vapor than Ku-C dual frequency altimeters. Same flag has been provided in the product.

4. Shape Classification of altimetric waveforms

Different type of shapes of waveforms other than the standard deep ocean type (Brown type) waveforms are usually encountered in the coastal areas. The algorithms discussed in the Section 3.2 were based on modeling the shapes of the coastal waveforms, so it becomes necessary to classify the waveform based on predefined shape. In coastal product a linear discriminant analysis (LDA) based technique was used to classify the waveforms on the basis of their shapes.

As shown in the Figure 7 there are different types of shape in which waveforms are classified. Explanation of these classes is given as follows:

Class 1: Brown type waveforms; which are characteristic for deep ocean and follows Brown model.

Class 2: Peak echoes; which are received due to high reflectance either due to still water presence or due to high reflection from land.

Class 3: Very noisy type echoes; having a lot of noise and no shape feature is identified.

Class 4: Peak at the end of echoes; found near land.

Class 5: Brown + peaky echoes; these type along with class7 are received when both ocean and land exist in the footprint of altimeter. It is a mixed type of signal.

Class 6: Linear; found near land or due to on-board tracker errors

Class 7: Brown + peak on the trailing edge; described in class 5.

Class 8: Peaky + Noise echoes; formed due to high reflectance from land in the footprint of altimeter.

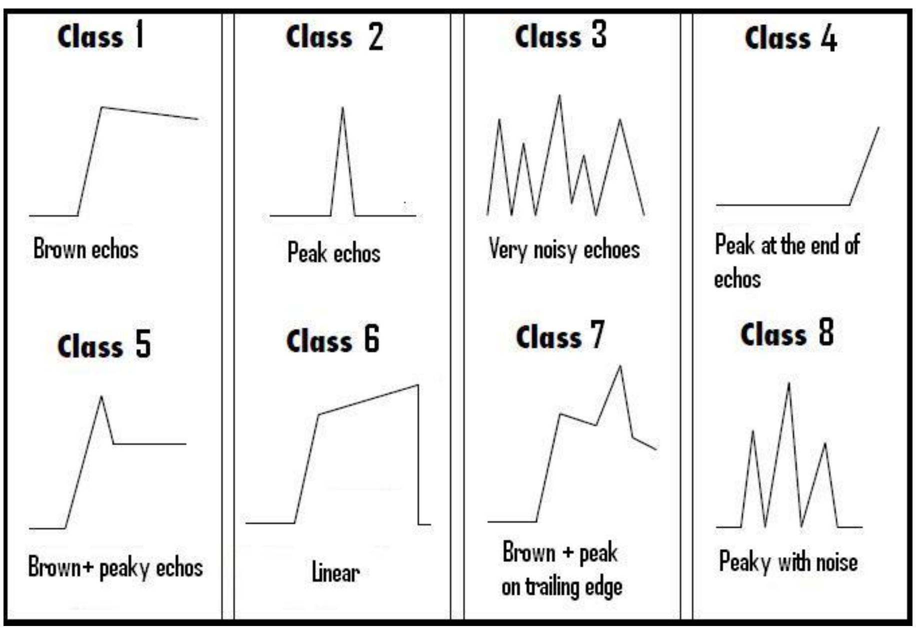

Figure 7. Different classes of waveforms

Classification involves three steps:

1) Feature selection
2) Dimensionality reduction by LDA
3) Class assignment by Bayesian classifier

More details are provided in the Chaudhary et al. (2015).

The waveform class is provided as **waveform_class** variable in the product. In addition, original waveforms from the S-IGDR product as **waveforms** are also provided.

Note: It is suggested to users should not use the very noisy (Class 3), peak with noise (Class 8), Peak at the end (Class 4) and Linear (Class 6) because they have very high noise or tracker failures

5. Geophysical Corrections

There are various geophysical corrections which need to be applied to the range measurements to account for the signal delay. All these corrections are provided in the S-IGDR product as 1 Hz. The same values have been interpolated at 40-Hz using cubic spline interpolation. No specific processing of the corrections in this version of coastal product has been done. However, for the sake of brevity, standard corrections provided in S-IGDR version for 1-Hz are listed below:

1) Dry Tropospheric correction

This correction is due to the presence of the dry air medium between the satellite and the oceans which affects the velocity of propagation of the radio pulse. Its value is approx. -2.3 m and it varies very less. European Center for Medium Range Weather Forecasting (ECMWF) numerical weather prediction models are used to compute the surface pressure (Chelton et.al ,2001) and then inverse barometer corrections. These values are provided in S-IGDR product. In the present coastal product, the variable **dry_tropo_model_interp_40hz** represents the 40-Hz interpolated dry tropospheric corrections.

2) Wet Tropospheric correction

This correction is due to the presence of water vapor and the liquid water. It is highly variable in the atmosphere and many times the correction reaches up to 40 cm. It is corrected in the open ocean by the use of onboard MWR at different frequencies. In the coastal areas, however, the radiometer itself is contaminated thus providing inaccurate corrections. Therefore, since the present product is within 50 km, wet tropospheric corrections calculated from the ECMWF model is used. These corrections are once again interpolated to 40-Hz. It is provided as **wet-tropo_model_interp_40hz** in the product.

3) Tidal corrections

There are three types of contributions to the tidal effect:

a) Geocentric Ocean tide

This correction is taken from the original S-IDGR data, interpolated at 40-Hz and is provided as **geoc_ocean_tide_sol1_interp_40hz.** It is calculated from GOT 4.8 Ocean Tide Model Ray (1999)

b) Solid Earth tide

This correction is taken from the original S-IDGR data, interpolated at 40-Hz and is provided as **solid_earth_tide_interp_40hz.** More details about this correction is provided in SARAL/AltiKa Product Handbook (December, 2013).

c) Pole tide

This correction is taken from the original S-IDGR data, interpolated at 40-Hz and is provided as **pole_tide_interp_40hz.** It is calculated in IGDR as described in Wahr (1985). Users can refer SARAL/AltiKa Products Handbook (December, 2013) for details about these corrections.

4) Sea state Bias corrections

This correction arises due to asymmetry of the reflecting properties of various scattering elements contributing for the average return. Troughs on the reflecting surface reflect better than the crests which creates the bias of the measured heights towards the troughs. Also the instrument measures the median rather than the mean scattering surface which creates an additional error. The distribution of the reflecting elements on the surface is skewed rather than symmetrical. This error is due to sea state and hence known as sea state bias. This is computed by empirical algorithms as described in Labroure (2004). This correction is provided as **sea_state_bias_interp_40hz.**

5) Ionospheric Corrections

This correction arises due to slowing down of group velocity of radar pulse by the presence of free electrons in the ionosphere. Ionospheric correction in Ka band altimeter is one order less than Ku band altimeters. Dual frequency ionospheric correction is not possible in SARAL/AltiKa due to the absence of additional altimeter frequency. Therefore, external data are used to compute ionospheric correction. Total Electron Content computed from GPS based observations and ionosphere model (JPL GIM model) are used to account for this correction.

6) Inverse Barometer Corrections

This correction corresponds to the change in sea level due to variations in atmospheric pressure variations. Higher the pressure lower is the sea level. It is computed from the surface pressure values as provided by numerical prediction model (NWP) and dry tropospheric correction. In the present version of the coastal product, it is provided as **inv_barr_interp_40hz**. This correction given for 1-Hz data in S-IGDR has been once again interpolated to 40-Hz data.

7) High frequency fluctuation Corrections

This correction is ocean's response to the wind and pressure and has energy at periods shorter than 20 days. It is considered as the departure from the inverse barometers effect to pressure and additionally wind effects. This correction is calculated by using specific models (SARAL/AltiKa Products Handbook, 2013). These corrections are interpolated at 40-Hz and provided as **hf_fluctuations_interp_40hz**. More details about this correction are in Stammer et al. (1999) and Tierney et al. (2000).

6. Mean Sea Surface, Geoid and Bathymetry

In order to compute the SSHA, MSS is required. SARAL/AltiKa S-IGDR product provides MSS from MSS_CNES_CLS11 model which is computed from 16 years of satellite altimetry data. 1-Hz MSS data has been interpolated to 40-Hz.

There are two different geoid provided in the product. One is **geoid_interp_40hz** which is interpolated at 40-Hz from the EGM96 geopotential model (Lemoine et al., (1998)) provided in the S-IGDR data.

Another one is **geoid_sac**, which is a high resolution geoid in the Indian Ocean (Sreejith et al., 2013).

Bathymetry is provided in the product from Sindhu et al. (2007) which is made using Smith and Sandwell, 2 minute bathymetry, ETOPO2v2, specifically corrected for the Indian Ocean region.

7. Other parameters

Some other parameters are also provided as listed below:

1) Geolocation: The geolocation is provided as **longitude_40hz, latitude_40hz**

2) Time: Time of the observation is provided as seconds since 2000-01-01 00:00:00.0. It is provided as **time_40hz**

3) Distance from the coast: This parameter is calculated from high resolution coastline created at Space Applications Centre (SAC). It is provided as **distance_from_coast_40hz**

4) Land Flag: This flag is calculated from high resolution coastline created at SAC. It is provided as **land_flag_40hz.**

Note: It is suggested that users check the retracking quality flags, mqe threshold, distance from the coast, waveform class, trailing edge variation flag and valid parameter range for filtering out bad data values.

Appendix A: List of Acronyms

BAGP: Brown with Asymmetric Gaussian Peak
BAGP-NM: Brown with Asymmetric Gaussian Peak – Nelder Mead
CNES: Centre National d'Etudes Spatiales
ECMWF: European Center for Medium range Weather Forecasting
FFT: Fast Fourier Transform
GDR: Geophysical Data Record
I-GDR: Interim Geophysical Data Record
ISRO: Indian Space Research Organisation
MSS: Mean Sea Surface
MWR: Microwave Radiometer
MLE: Maximum Likelihood Estimator
MQE: Mean Quadratic Error
NetCDF: Network Common Data Format
NWP: Numerical Weather Prediction
POD: Precision Orbit Determination
RMS: Root Mean Square
SLA: Sea Level Anomaly
SAC: Space Applications Centre
S-IGDR: Sensor Interim Geophysical Data Record
SSHA: Sea Surface Height Anomaly
SSH: Sea Surface Height
SWH: Significant Wave height
SARAL: Satellite with ARgos and AltiKa
TEC: Total Electron Content

Appendix B: References

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Appendix C: AltiKa 40-Hz Coastal Product Header Information

```
netcdf SRL_031_0610_20160218122829_20160218122947_INDIANCOAST_SIGDR_VER1.1
{
dimensions:
	time = 36 ;
	meas_ind = 40 ;
	wvf_ind = 128 ;
variables:
	double time(time) ;
		time:longname = "time  (sec. since 2000-01-01)" ;
		time:standard_name = "time" ;
		time:calender = "gregorian" ;
		time:tai_utc_difference = -35. ;
		time:leap_second = "0000-00-00 00:00:00" ;
		time:units = "seconds since 2000-01-01 00:00:00.0" ;
		time:comment = "[tai_utc_difference] is the difference between TAI and UTC
reference time (seconds) for the first measurement of the data set. [leap_second] is the UTC time
at which a leap second occurs in the data set, if any. After this UTC time, the [tai_utc_difference]
is increased by 1 second" ;
	byte meas_ind(meas_ind) ;
		meas_ind:long_name = "elementary measurement index" ;
		meas_ind:units = "count" ;
	byte wvf_ind(wvf_ind) ;
		wvf_ind:long_name = "Waveform index" ;
		wvf_ind:units = "count" ;
	int latitude_40hz(time, meas_ind) ;
		latitude_40hz:_FillValue = 2147483647 ;
		latitude_40hz:longname = "latitude" ;
		latitude_40hz:units = "degrees_north" ;
		latitude_40hz:scale_factor = 1.e-06 ;
		latitude_40hz:comment = "Positive latitude is North latitude, negative latitude is
South latitude" ;
	int longitude_40hz(time, meas_ind) ;
		longitude_40hz:_FillValue = 2147483647 ;
		longitude_40hz:longname = "latitude" ;
		longitude_40hz:units = "degrees_east" ;
		longitude_40hz:scale_factor = 1.e-06 ;
		longitude_40hz:comment = "East longitude relative to Greenwich meridian" ;
	double time_40hz(time, meas_ind) ;
		time_40hz:_FillValue = 1.84467440737096e+19 ;
		time_40hz:longname = "time 40-Hz (sec. since 2000-01-01)" ;
		time_40hz:standard_name = "time" ;
		time_40hz:calender = "gregorian" ;
		time_40hz:tai_utc_difference = -35. ;
		time_40hz:leap_second = "0000-00-00 00:00:00" ;
		time_40hz:units = "seconds since 2000-01-01 00:00:00.0" ;
```

time_40hz:comment = "[tai_utc_difference] is the difference between TAI and UTC reference time (seconds) for the first measurement of the data set. [leap_second] is the UTC time at which a leap second occurs in the data set, if any. After this UTC time, the [tai_utc_difference] is increased by 1 second" ;
short waveforms(time, meas_ind, wvf_ind) ;
waveforms:_FillValue = 32767s ;
waveforms:longname = "Waveform samples" ;
waveforms:units = "count" ;
waveforms:comment = "Waveforms are not corrected for the Low Pass Filter effects" ;
byte trailing_edge_variation_flag_40hz(time, meas_ind) ;
trailing_edge_variation_flag_40hz:_FillValue = 127b ;
trailing_edge_variation_flag_40hz:longname = "40-Hz trailing edge variation flag" ;
trailing_edge_variation_flag_40hz:flag_values = "0b, 1b" ;
trailing_edge_variation_flag_40hz:flag_meanings = "non_short_scale_variation short_scale_variation" ;
trailing_edge_variation_flag_40hz:coordinates = "longitude_40hz latitude_40hz" ;
int distance_from_coast_40hz(time, meas_ind) ;
distance_from_coast_40hz:_FillValue = -999000000 ;
distance_from_coast_40hz:longname = "distance from the coast" ;
distance_from_coast_40hz:units = "Km" ;
distance_from_coast_40hz:scale_factor = 1.e-06 ;
distance_from_coast_40hz:coordinates = "longitude_40hz latitude_40hz" ;
byte land_flag_40hz(time, meas_ind) ;
land_flag_40hz:_FillValue = 127b ;
land_flag_40hz:longname = "40-Hz land flag" ;
land_flag_40hz:units = "0b 1b" ;
land_flag_40hz:flag_meanings = "no_land land" ;
land_flag_40hz:coordinates = "longitude_40hz latitude_40hz" ;
short waveform_class(time, meas_ind) ;
waveform_class:_FillValue = 32767s ;
waveform_class:longname = "waveform_class of" ;
waveform_class:units = "1-8" ;
waveform_class:flag_values = "99" ;
waveform_class:flag_meanings = "99=flag" ;
waveform_class:coordinates = "longitude_40hz latitude_40hz" ;
waveform_class:reference = "Chaudhary A., Basu S., Kumar R, Mahesh, C. and Sharma R. 2015. Shape classification of AltiKa 40-Hz waveforms using Linear Discriminant Analysis and Bayes Decision Rule in the Gujarat Coastal region Marine Geodesy" ;
waveform_class:class_meaning = "1=Brown 2=Peak 3=Very_noisy 4=Peak_at_the_end 5=Brown+peak 6=Linear 7=Brown+peak_on_the_trailing_edge 8=Peaky+Noise" ;
int ssh_mle4_40hz(time, meas_ind) ;
ssh_mle4_40hz:_FillValue = -999000000 ;

```
		ssh_mle4_40hz:longname = "40-Hz ssh from MLE4 algorithm" ;
		ssh_mle4_40hz:quality_flag = "flag_mle4_40hz" ;
		ssh_mle4_40hz:units = "m" ;
		ssh_mle4_40hz:scale_factor = 1.e-06 ;
		ssh_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssh_beta5_40hz(time, meas_ind) ;
		ssh_beta5_40hz:_FillValue = -999000000 ;
		ssh_beta5_40hz:longname = "40-Hz ssh from BETA5 algorithm" ;
		ssh_beta5_40hz:units = "m" ;
		ssh_beta5_40hz:quality_flag = "flag_beta5_40hz" ;
		ssh_beta5_40hz:scale_factor = 1.e-06 ;
		ssh_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssh_beta9_40hz(time, meas_ind) ;
		ssh_beta9_40hz:_FillValue = -999000000 ;
		ssh_beta9_40hz:longname = "40-Hz ssh from BETA9 algorithm" ;
		ssh_beta9_40hz:units = "m" ;
		ssh_beta9_40hz:quality_flag = "flag_beta9_40hz" ;
		ssh_beta9_40hz:scale_factor = 1.e-06 ;
		ssh_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssh_bagp_40hz(time, meas_ind) ;
		ssh_bagp_40hz:_FillValue = -999000000 ;
		ssh_bagp_40hz:longname = "40-Hz ssh from BAGP algorithm" ;
		ssh_bagp_40hz:units = "m" ;
		ssh_bagp_40hz:quality_flag = "flag_bagp_40hz" ;
		ssh_bagp_40hz:scale_factor = 1.e-06 ;
		ssh_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssh_bagp_nm_40hz(time, meas_ind) ;
		ssh_bagp_nm_40hz:_FillValue = -999000000 ;
		ssh_bagp_nm_40hz:longname = "40-Hz ssh from BAGP using nelder mead
algorithm" ;
		ssh_bagp_nm_40hz:units = "m" ;
		ssh_bagp_nm_40hz:quality_flag = "flag_bagp_nm_40hz" ;
		ssh_bagp_nm_40hz:scale_factor = 1.e-06 ;
		ssh_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssha_mle4_40hz(time, meas_ind) ;
		ssha_mle4_40hz:_FillValue = -999000000 ;
		ssha_mle4_40hz:longname = "40-Hz ssha from MLE4 algorithm" ;
		ssha_mle4_40hz:units = "m" ;
		ssha_mle4_40hz:quality_flag = "flag_mle4_40hz" ;
		ssha_mle4_40hz:scale_factor = 1.e-06 ;
		ssha_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int ssha_beta5_40hz(time, meas_ind) ;
		ssha_beta5_40hz:_FillValue = -999000000 ;
		ssha_beta5_40hz:longname = "40-Hz ssha from BETA5 algorithm" ;
		ssha_beta5_40hz:units = "m" ;
		ssha_beta5_40hz:quality_flag = "flag_beta5_40hz" ;
```

```
                ssha_beta5_40hz:scale_factor = 1.e-06 ;
                ssha_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int ssha_beta9_40hz(time, meas_ind) ;
                ssha_beta9_40hz:_FillValue = -999000000 ;
                ssha_beta9_40hz:longname = "40-Hz ssha from BETA9 algorithm" ;
                ssha_beta9_40hz:units = "m" ;
                ssha_beta9_40hz:quality_flag = "flag_beta9_40hz" ;
                ssha_beta9_40hz:scale_factor = 1.e-06 ;
                ssha_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int ssha_bagp_40hz(time, meas_ind) ;
                ssha_bagp_40hz:_FillValue = -999000000 ;
                ssha_bagp_40hz:longname = "40-Hz ssha from BAGP algorithm" ;
                ssha_bagp_40hz:units = "m" ;
                ssha_bagp_40hz:quality_flag = "flag_bagp_40hz" ;
                ssha_bagp_40hz:scale_factor = 1.e-06 ;
                ssha_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int ssha_bagp_nm_40hz(time, meas_ind) ;
                ssha_bagp_nm_40hz:_FillValue = -999000000 ;
                ssha_bagp_nm_40hz:longname = "40-Hz ssha from BAGP using nelder mead
algorithm" ;
                ssha_bagp_nm_40hz:units = "m" ;
                ssha_bagp_nm_40hz:quality_flag = "flag_bagp_nm_40hz" ;
                ssha_bagp_nm_40hz:scale_factor = 1.e-06 ;
                ssha_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        short sigma_zero_mle4_40hz(time, meas_ind) ;
                sigma_zero_mle4_40hz:_FillValue = 32767s ;
                sigma_zero_mle4_40hz:longname = "40-Hz corrected backscatter coefficient" ;
                sigma_zero_mle4_40hz:standard_name =
"surface_backwards_scattering_coefficient_of_radar_wave" ;
                sigma_zero_mle4_40hz:units = "dB" ;
                sigma_zero_mle4_40hz:quality_flag = "flag_mle4_40hz" ;
                sigma_zero_mle4_40hz:scale_factor = 0.01 ;
                sigma_zero_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int sigma_zero_beta5_40hz(time, meas_ind) ;
                sigma_zero_beta5_40hz:_FillValue = -999000000 ;
                sigma_zero_beta5_40hz:longname = "40-Hz sigma0 from BETA5 algorithm" ;
                sigma_zero_beta5_40hz:units = "dB" ;
                sigma_zero_beta5_40hz:quality_flag = "flag_beta5_40hz" ;
                sigma_zero_beta5_40hz:scale_factor = 1.e-06 ;
                sigma_zero_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int sigma_zero_beta9_40hz(time, meas_ind) ;
                sigma_zero_beta9_40hz:_FillValue = -999000000 ;
                sigma_zero_beta9_40hz:longname = "40-Hz sigma0 from BETA9 algorithm" ;
                sigma_zero_beta9_40hz:units = "dB" ;
                sigma_zero_beta9_40hz:quality_flag = "flag_beta9_40hz" ;
                sigma_zero_beta9_40hz:scale_factor = 1.e-06 ;
```

```
		sigma_zero_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int sigma_zero_bagp_40hz(time, meas_ind) ;
		sigma_zero_bagp_40hz:_FillValue = -999000000 ;
		sigma_zero_bagp_40hz:longname = "40-Hz sigma0 from BAGP algorithm" ;
		sigma_zero_bagp_40hz:units = "dB" ;
		sigma_zero_bagp_40hz:quality_flag = "flag_bagp_40hz" ;
		sigma_zero_bagp_40hz:scale_factor = 1.e-06 ;
		sigma_zero_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int sigma_zero_bagp_nm_40hz(time, meas_ind) ;
		sigma_zero_bagp_nm_40hz:_FillValue = -999000000 ;
		sigma_zero_bagp_nm_40hz:longname = "40-Hz sigma0 from BAGP using
Nelder Mead algorithm" ;
		sigma_zero_bagp_nm_40hz:units = "dB" ;
		sigma_zero_bagp_nm_40hz:quality_flag = "flag_bagp_nm_40hz" ;
		sigma_zero_bagp_nm_40hz:scale_factor = 1.e-06 ;
		sigma_zero_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	short swh_mle4_40hz(time, meas_ind) ;
		swh_mle4_40hz:_FillValue = 32767s ;
		swh_mle4_40hz:longname = "40-Hz corrected significant waveheight" ;
		swh_mle4_40hz:standard_name = "sea_surface_wave_significant_height" ;
		swh_mle4_40hz:units = "m" ;
		swh_mle4_40hz:quality_flag = "flag_mle4_40hz" ;
		swh_mle4_40hz:scale_factor = 0.001 ;
		swh_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int swh_beta5_40hz(time, meas_ind) ;
		swh_beta5_40hz:_FillValue = -999000000 ;
		swh_beta5_40hz:longname = "Significant Wave Height from BETA5 algorithm" ;
		swh_beta5_40hz:units = "m" ;
		swh_beta5_40hz:quality_flag = "flag_beta5_40hz" ;
		swh_beta5_40hz:scale_factor = 1.e-06 ;
		swh_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int swh_beta9_40hz(time, meas_ind) ;
		swh_beta9_40hz:_FillValue = -999000000 ;
		swh_beta9_40hz:longname = "Significant Wave Height from BETA9 algorithm" ;
		swh_beta9_40hz:units = "m" ;
		swh_beta9_40hz:quality_flag = "flag_beta9_40hz" ;
		swh_beta9_40hz:scale_factor = 1.e-06 ;
		swh_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int swh_bagp_40hz(time, meas_ind) ;
		swh_bagp_40hz:_FillValue = -999000000 ;
		swh_bagp_40hz:longname = "Significant Wave Height from BAGP algorithm" ;
		swh_bagp_40hz:units = "m" ;
		swh_bagp_40hz:quality_flag = "flag_bagp_40hz" ;
		swh_bagp_40hz:scale_factor = 1.e-06 ;
		swh_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
	int swh_bagp_nm_40hz(time, meas_ind) ;
```

```
                swh_bagp_nm_40hz:_FillValue = -999000000 ;
                swh_bagp_nm_40hz:longname = "Significant Wave Height from BAGP using
Nelder Mead algorithm" ;
                swh_bagp_nm_40hz:units = "m" ;
                swh_bagp_nm_40hz:quality_flag = "flag_bagp_nm_40hz" ;
                swh_bagp_nm_40hz:scale_factor = 1.e-06 ;
                swh_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        byte flag_mle4_40hz(time, meas_ind) ;
                flag_mle4_40hz:_FillValue = 127b ;
                flag_mle4_40hz:longname = "40-Hz flag MLE4" ;
                flag_mle4_40hz:units = "0b 1b" ;
                flag_mle4_40hz:flag_meanings = "use dont_use" ;
                flag_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        byte flag_beta5_40hz(time, meas_ind) ;
                flag_beta5_40hz:_FillValue = 127b ;
                flag_beta5_40hz:longname = "40-Hz flag BETA5" ;
                flag_beta5_40hz:units = "0b 1b" ;
                flag_beta5_40hz:flag_meanings = "use dont_use" ;
                flag_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        byte flag_beta9_40hz(time, meas_ind) ;
                flag_beta9_40hz:_FillValue = 127b ;
                flag_beta9_40hz:longname = "40-Hz flag BETA9" ;
                flag_beta9_40hz:units = "0b 1b" ;
                flag_beta9_40hz:flag_meanings = "use dont_use" ;
                flag_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        byte flag_bagp_40hz(time, meas_ind) ;
                flag_bagp_40hz:_FillValue = 127b ;
                flag_bagp_40hz:longname = "40-Hz flag BAGP" ;
                flag_bagp_40hz:units = "0b 1b" ;
                flag_bagp_40hz:flag_meanings = "use dont_use" ;
                flag_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        byte flag_bagp_nm_40hz(time, meas_ind) ;
                flag_bagp_nm_40hz:_FillValue = 127b ;
                flag_bagp_nm_40hz:longname = "40-Hz flag BAGP (nelder mead)" ;
                flag_bagp_nm_40hz:units = "0b 1b" ;
                flag_bagp_nm_40hz:flag_meanings = "use dont_use" ;
                flag_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
        int mqe_mle4_40hz(time, meas_ind) ;
                mqe_mle4_40hz:_FillValue = -99900000 ;
                mqe_mle4_40hz:longname = "40-Hz mqe MLE4" ;
                mqe_mle4_40hz:units = "count" ;
                mqe_mle4_40hz:scale_factor = 1.e-05 ;
                mqe_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                mqe_mle4_40hz:commment = "Mean Quadratic Error between the waveforms
samples and the corresponding model samples built from the  mle4 (Ocean) retracking outputs" ;
        int mqe_beta5_40hz(time, meas_ind) ;
```

```
                mqe_beta5_40hz:_FillValue = -99900000 ;
                mqe_beta5_40hz:longname = "40-Hz mqe BETA5" ;
                mqe_beta5_40hz:units = "count" ;
                mqe_beta5_40hz:scale_factor = 1.e-05 ;
                mqe_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                mqe_beta5_40hz:commment = "Mean Quadratic Error between the waveforms
samples and the corresponding model samples built from the  BETA5 retracking outputs" ;
        int mqe_beta9_40hz(time, meas_ind) ;
                mqe_beta9_40hz:_FillValue = -99900000 ;
                mqe_beta9_40hz:longname = "40-Hz mqe BETA9" ;
                mqe_beta9_40hz:units = "count" ;
                mqe_beta9_40hz:scale_factor = 1.e-05 ;
                mqe_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                mqe_beta9_40hz:commment = "Mean Quadratic Error between the waveforms
samples and the corresponding model samples built from the  BETA9 retracking outputs" ;
        int mqe_bagp_40hz(time, meas_ind) ;
                mqe_bagp_40hz:_FillValue = -99900000 ;
                mqe_bagp_40hz:longname = "40-Hz mqe BAGP" ;
                mqe_bagp_40hz:units = "count" ;
                mqe_bagp_40hz:scale_factor = 1.e-05 ;
                mqe_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                mqe_bagp_40hz:commment = "Mean Quadratic Error between the waveforms
samples and the corresponding model samples built from the  BAGP retracking outputs" ;
        int mqe_bagp_nm_40hz(time, meas_ind) ;
                mqe_bagp_nm_40hz:_FillValue = -99900000 ;
                mqe_bagp_nm_40hz:longname = "40-Hz mqe BAGP (nelder mead)" ;
                mqe_bagp_nm_40hz:units = "count" ;
                mqe_bagp_nm_40hz:scale_factor = 1.e-05 ;
                mqe_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                mqe_bagp_nm_40hz:commment = "Mean Quadratic Error between the
waveforms samples and the corresponding model samples built from the  BAGP(nm) retracking
outputs" ;
        int wind_speed_mle4_40hz(time, meas_ind) ;
                wind_speed_mle4_40hz:_FillValue = -999000000 ;
                wind_speed_mle4_40hz:longname = "40-Hz wind speed MLE4" ;
                wind_speed_mle4_40hz:units = "m/s" ;
                wind_speed_mle4_40hz:scale_factor = 1.e-06 ;
                wind_speed_mle4_40hz:quality_flag = "flag_mle4_40hz" ;
                wind_speed_mle4_40hz:coordinates = "longitude_40hz latitude_40hz" ;
                wind_speed_mle4_40hz:reference = "Lillibridge J., Scharroo R., Abdalla S. and
Vandemark D. 2014. One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry.
Journal of Atmos. & Oce. Tech.,31: 630-638" ;
        int wind_speed_beta5_40hz(time, meas_ind) ;
                wind_speed_beta5_40hz:_FillValue = -999000000 ;
                wind_speed_beta5_40hz:longname = "40-Hz wind speed BETA5" ;
                wind_speed_beta5_40hz:units = "m/s" ;
```

wind_speed_beta5_40hz:scale_factor = 1.e-06 ;
wind_speed_beta5_40hz:quality_flag = "flag_beta5_40hz" ;
wind_speed_beta5_40hz:coordinates = "longitude_40hz latitude_40hz" ;
wind_speed_beta5_40hz:reference = "Lillibridge J., Scharroo R., Abdalla S. and Vandemark D. 2014. One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry. Journal of Atmos. & Oce. Tech.,31: 630-638" ;
int wind_speed_beta9_40hz(time, meas_ind) ;
wind_speed_beta9_40hz:_FillValue = -999000000 ;
wind_speed_beta9_40hz:longname = "40-Hz wind speed BETA9" ;
wind_speed_beta9_40hz:units = "m/s" ;
wind_speed_beta9_40hz:scale_factor = 1.e-06 ;
wind_speed_beta9_40hz:quality_flag = "flag_beta9_40hz" ;
wind_speed_beta9_40hz:coordinates = "longitude_40hz latitude_40hz" ;
wind_speed_beta9_40hz:reference = "Lillibridge J., Scharroo R., Abdalla S. and Vandemark D. 2014. One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry. Journal of Atmos. & Oce. Tech.,31: 630-638" ;
int wind_speed_bagp_40hz(time, meas_ind) ;
wind_speed_bagp_40hz:_FillValue = -999000000 ;
wind_speed_bagp_40hz:longname = "40-Hz wind speed BAGP" ;
wind_speed_bagp_40hz:units = "m/s" ;
wind_speed_bagp_40hz:scale_factor = 1.e-06 ;
wind_speed_bagp_40hz:quality_flag = "flag_bagp_40hz" ;
wind_speed_bagp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
wind_speed_bagp_40hz:reference = "Lillibridge J., Scharroo R., Abdalla S. and Vandemark D. 2014. One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry. Journal of Atmos. & Oce. Tech.,31: 630-638" ;
int wind_speed_bagp_nm_40hz(time, meas_ind) ;
wind_speed_bagp_nm_40hz:_FillValue = -999000000 ;
wind_speed_bagp_nm_40hz:longname = "40-Hz wind speed BAGP (nelder mead)" ;
wind_speed_bagp_nm_40hz:units = "m/s" ;
wind_speed_bagp_nm_40hz:scale_factor = 1.e-06 ;
wind_speed_bagp_nm_40hz:quality_flag = "flag_bagp_nm_40hz" ;
wind_speed_bagp_nm_40hz:coordinates = "longitude_40hz latitude_40hz" ;
wind_speed_bagp_nm_40hz:reference = "Lillibridge J., Scharroo R., Abdalla S. and Vandemark D. 2014. One- and Two-Dimensional Wind Speed Models for Ka-Band Altimetry. Journal of Atmos. & Oce. Tech.,31: 630-638" ;
int dry_tropo_model_interp_40hz(time, meas_ind) ;
dry_tropo_model_interp_40hz:_FillValue = -999000000 ;
dry_tropo_model_interp_40hz:longname = "interpolated model dry tropospheric correction 40-Hz" ;
dry_tropo_model_interp_40hz:units = "m" ;
dry_tropo_model_interp_40hz:scale_factor = 1.e-06 ;
dry_tropo_model_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
dry_tropo_model_interp_40hz:comment = "interpolated value of model dry tropospheric correction at 40-Hz from SARAL SIGDR at 40-Hz used in ssh calculation" ;

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	int wet_tropo_model_interp_40hz(time, meas_ind) ;
		wet_tropo_model_interp_40hz:_FillValue = -999000000 ;
		wet_tropo_model_interp_40hz:longname = "interpolated  model wet tropospheric 
correction 40-Hz" ;
		wet_tropo_model_interp_40hz:units = "m" ;
		wet_tropo_model_interp_40hz:scale_factor = 1.e-06 ;
		wet_tropo_model_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		wet_tropo_model_interp_40hz:comment = "interpolated value of model wet 
tropospheric correction at 40-Hz from SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int geoc_ocean_tide_sol1_interp_40hz(time, meas_ind) ;
		geoc_ocean_tide_sol1_interp_40hz:_FillValue = -999000000 ;
		geoc_ocean_tide_sol1_interp_40hz:longname = "interpolated  geocentric ocean 
tide 40-Hz\000\000\000interpola" ;
		geoc_ocean_tide_sol1_interp_40hz:units = "m" ;
		geoc_ocean_tide_sol1_interp_40hz:scale_factor = 1.e-06 ;
		geoc_ocean_tide_sol1_interp_40hz:coordinates = "longitude_40hz latitude_40hz" 
;
		geoc_ocean_tide_sol1_interp_40hz:comment = "interpolated value of geocentric 
ocean tide at 40-Hz from SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int solid_earth_tide_interp_40hz(time, meas_ind) ;
		solid_earth_tide_interp_40hz:_FillValue = -999000000 ;
		solid_earth_tide_interp_40hz:longname = "interpolated  solid earth tide 40-Hz" ;
		solid_earth_tide_interp_40hz:units = "m" ;
		solid_earth_tide_interp_40hz:scale_factor = 1.e-06 ;
		solid_earth_tide_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		solid_earth_tide_interp_40hz:comment = "interpolated value of solid earth tide at 
40-Hz from SARAL SIGDR at 40-Hz used in ssh calculatio" ;
	int pole_tide_interp_40hz(time, meas_ind) ;
		pole_tide_interp_40hz:_FillValue = -999000000 ;
		pole_tide_interp_40hz:longname = "interpolated  pole tide 40-Hz" ;
		pole_tide_interp_40hz:units = "m" ;
		pole_tide_interp_40hz:scale_factor = 1.e-06 ;
		pole_tide_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		pole_tide_interp_40hz:comment = "interpolated value of pole tide at 40-Hz from 
SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int ssb_interp_40hz(time, meas_ind) ;
		ssb_interp_40hz:_FillValue = -999000000 ;
		ssb_interp_40hz:longname = "interpolated  sea state bias 40-Hz" ;
		ssb_interp_40hz:units = "m" ;
		ssb_interp_40hz:scale_factor = 1.e-06 ;
		ssb_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		ssb_interp_40hz:comment = "interpolated value of sea state bias at 40-Hz from 
SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int inv_barr_interp_40hz(time, meas_ind) ;
		inv_barr_interp_40hz:_FillValue = -999000000 ;
```

```
		inv_barr_interp_40hz:longname = "interpolated  inverted barometer height
correction 40-Hz" ;
		inv_barr_interp_40hz:units = "m" ;
		inv_barr_interp_40hz:scale_factor = 1.e-06 ;
		inv_barr_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		inv_barr_interp_40hz:comment = "interpolated value of inverted barometer height
correction at 40-Hz from SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int hf_fluctuations_interp_40hz(time, meas_ind) ;
		hf_fluctuations_interp_40hz:_FillValue = -999000000 ;
		hf_fluctuations_interp_40hz:longname = "interpolated  high frequency
fluctuations of the sea surface topography 40-Hz" ;
		hf_fluctuations_interp_40hz:units = "m" ;
		hf_fluctuations_interp_40hz:scale_factor = 1.e-06 ;
		hf_fluctuations_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		hf_fluctuations_interp_40hz:comment = "interpolated value of high frequency
fluctuations of the sea surface topography at 40-Hz from SARAL SIGDR at 40-Hz used in ssh
calculation" ;
	int mss_interp_40hz(time, meas_ind) ;
		mss_interp_40hz:_FillValue = -999000000 ;
		mss_interp_40hz:longname = "interpolated  mean sea surface height above
reference ellipsoid 40-Hz" ;
		mss_interp_40hz:units = "m" ;
		mss_interp_40hz:scale_factor = 1.e-06 ;
		mss_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		mss_interp_40hz:comment = "interpolated value of sea state bias at 40-Hz from
SARAL SIGDR at 40-Hz used in ssh calculation" ;
	int geoid_interp_40hz(time, meas_ind) ;
		geoid_interp_40hz:_FillValue = -999000000 ;
		geoid_interp_40hz:longname = "interpolated geoid height above reference
ellipsoid 40-Hz" ;
		geoid_interp_40hz:units = "m" ;
		geoid_interp_40hz:scale_factor = 1.e-06 ;
		geoid_interp_40hz:coordinates = "longitude_40hz latitude_40hz" ;
		geoid_interp_40hz:comment = "interpolated value of geoid height above
reference ellipsoid at 40-Hz from SARAL SIGDR at 40-Hz" ;
	double bathymetry(time, meas_ind) ;
		bathymetry:_FillValue = 1.84467440737096e+19 ;
		bathymetry:longname = "bathymetry" ;
		bathymetry:standard_name = "bathymetry" ;
		bathymetry:units = "m" ;
		bathymetry:coordinates = "longitude_40hz latitude_40hz" ;
		bathymetry:reference = "Sindhu, B., I. Suresh, A. S. Unnikrishnan, N. V. Bhatkar,
S.Neetu and G. S. Michael 2007. Improved bathymetric data sets for the shallow water regions in
the Indian Ocean. J. Earth Syst. Sci.,116,61274" ;
	double geoid_sac(time, meas_ind) ;
		geoid_sac:longname = "geoid_sac" ;
```

```
                geoid_sac:standard_name = "geoid from Space Applications Centre (SAC)" ;
                geoid_sac:units = "m" ;
                geoid_sac:coordinates = "longitude_40hz latitude_40hz" ;
                geoid_sac:reference = "Sreejith, K.M., Rajesh, S., Majumdar, T.J., Srinivasa Rao G., Radhakrishna,  M.,  Krishna, K.S., Rajawat A.S., 2013. High-resolution residual geoid and gravity anomaly data of the northern Indian Ocean - an input to geological understanding. J. Asian Earth Sci. 62, 616626" ;

// global attributes:
                :Conventions = "CF-1.6" ;
                :version = "1.1" ;
                :Institution = "Space Applications Centre,ISRO" ;
                :source = "radar altimeter" ;
                :mission_name = "SARAL" ;
                :altimeter_sensor_name = "ALTIKA" ;
                :cycle_number = "031" ;
                :pass_number = "0610" ;
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                :last_meas_time = "20160218122947 (yyyymmddHHMMSS)" ;
                :creator_email = "aditya.osd@sac.isro.gov.in" ;
                :publisher_name = "MOSDAC" ;
                :publisher_site = "www.mosdac.gov.in" ;
                :license = "Information delivered in this product is public and may be used and redistributed freely. Any publication using this product should acknowledge data creator organization. Neither the data creator, nor the data publisher, nor any of their employees or contractors, makes any warranty, express or implied, including warranties of merchantability and fitness for a particular purpose, or assumes any legal liability for the accuracy, completeness, or usefulness, of this information." ;
                :title = "SARAL/AltiKa Coastal Product (Indian region)" ;
                :geospatial_lat_min = "05N" ;
                :geospatial_lat_max = "24N" ;
                :geospatial_lon_min = "68E" ;
                :geospatial_lon_max = "90E" ;
}
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