OCEANSAT-3 SCATTEROMETER (O3SCAT) LEVEL-2B ATBD

Version 1.1

October 2021

DOCUMENT CONTROL AND DATA SHEET

1.	**Date**	October 2021
2.	**Title**	Retrieval algorithm for ocean surface wind vectors using observations from the scatterometer on-board Oceansat-3 (EOS-06)
3.	**Doc. No.**	SAC/EPSA/OCEANSAT-3/ATBD/OP-01/OCT-2021-V1
4.	**Type of Report**	Technical - Algorithm Theoretical Basis Document (ATBD)
5.	**No. of Pages**	25
6.	**Authors**	Abhisek Chakraborty, Pradeep Kumar Thapliyal & Atul Kumar Varma
7.	**Originating Centre**	Space Applications Centre (ISRO), Ahmedabad
8.	**Abstract**	An algorithm is developed for the generation of ocean surface wind vector products (Level-2B) from the ISRO's third scatterometer mission on-board Oceansat-3 (EOS-06). The algorithm follows its heritage from the same used in Oceansat-2 scatterometer (2009) and Scatsat-1 (2016) with additional enhancements to take care for the improved hardware configurations. The wind vector cell (WVC) wise prioritized vector solutions are retrieved using Normalised Standard Deviation (NSD) method. Subsequently the directional ambiguities are resolved using Directional Stability and Conservation of Scattering (DiSCS) method. The entire algorithm is demonstrated using Scatsat-1 data.
9.	**Keywords**	OCEANSAT-3, EOS-06, scatterometer, sea surface wind vector
10.	**Approving Authority**	Oceansat-3 ATBD Review Committee
11.	**Classification**	Unrestricted
12.	**Circulation**	Open

[PREPARED USING THE COMMON TEMPLATE FOR ALL OPERATIONAL PRODUCTS FROM OCEANSAT-3 (EOS-06)]

1.0 Algorithm Specifications:

Version	Date	Prepared by	Description
1.1	October 2021	Abhisek Chakraborty, Pradeep Kumar Thapliyal, Atul Kumar Varma	Algorithm for generation of Level-2B operational products from Oceansat-3 Scatterometer

2.0 Introduction

2.1 Satellite and Instrument

Indian Space Research Organization (ISRO) is going to launch Oceansat-3 mission in the second quarter of 2021. The mission will comprise of three payloads dedicated for the studies of global oceans. Out of the three payloads, the scatterometer (O3SCAT) will join the series of tandem scatterometer missions of ISRO started from Oceansat-2 in 2009. The O3SCAT will follow the heritage from SCATSAT-1 scatterometer and will be working in Ku-band (13.515 GHz). The instrument will be fitted with a 1.4 m cassegrain antenna with two differently polarized beams that will scan the ocean surface in circular manners at incidence angles 49˚ (HH-polarized) and 57˚ (VV-polarized). The inner and outer swaths will be 1400km and 1800km respectively, with nominal spatial size of a wind vector cell (WVC) as 25 km x 25 km over the swaths. The instrument will cover the global oceans in two days. Apart from the nominal mode, an experimental high resolution mode is also proposed for O3SCAT with spatial resolution of 12.5 km x 12.5 km. Instrument design will follow the same heritage as that of the SCATSAT-1 except the microwave antenna which was parabolic in SCATSAT-1. The data processing chain will follow the same as that of the SCATSAT-1. Level-1B will contain scan-wise backscattered data over the slices and footprints. Level-2A will contain composite backscattered power over the satellite swath. The local equatorial crossing time at descending node will be 12 noon.

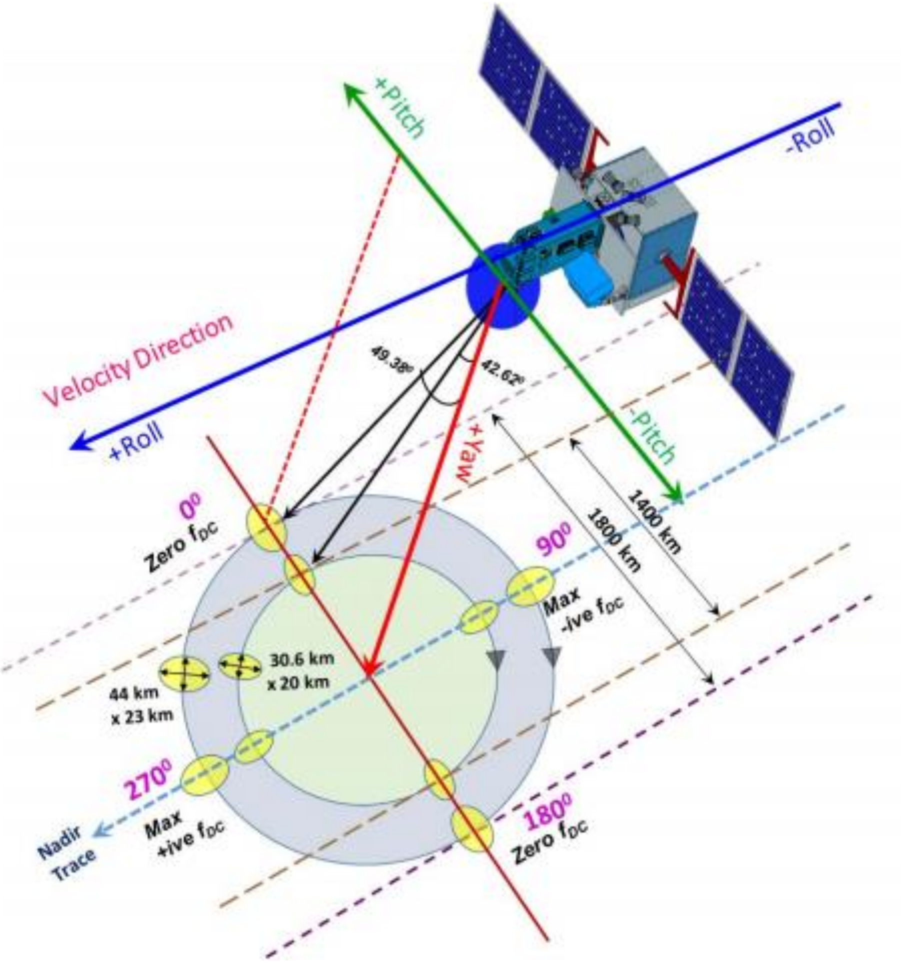

***Figure 1**: Observation/operating geometry of the proposed O3SCAT.*

3.0 Overview & background

3.1 Theoretical background

The ocean surface wind is the main driving force for ocean circulation and for generation of surface waves and currents. It plays an important role in air-sea interaction, upwelling, biogeochemical transport in the ocean and several other processes. The ocean surface wind vector is an essential input parameter for prediction models of ocean circulation and waves, which are used for oceanographic applications and climate related studies (Chakraborty et al., 2014). It is also an indispensable parameter (along with a few others) for the prediction of cyclogenesis, cyclone track prediction, storm surges and coastal inundation. Wind observations over the oceans can also be useful for ocean wave mapping and wave forecasting, offshore activities, ship routing, fisheries etc. Besides, wind vectors, when properly assimilated in an numerical weather prediction model, helps improving weather forecast. Repetitive measurements of surface wind field over global oceans are thus necessary for most of the meteorological and oceanographic studies and applications.

Wind vectors are usually retrieved from microwave scatterometers operating at microwave frequencies in 5-14 GHz range (Ulaby et al., 1981). This part of the spectrum is useful for measurements under all weather conditions except heavy precipitation. However, the wind speeds can also be obtained from space-borne microwave radiometers, synthetic aperture radars and altimeters. Moreover, the microwave polarimetry is being considered very favourable for vector wind measurements especially at high wind conditions.

3.2 Indian Scenario

Indian Space Research Organization (ISRO) has started contributing towards international tandem scatterometer missions by successfully launching Oceansat-2 scatterometer (OSCAT) in 2009. After a major power failure of OSCAT in February 2014, ISRO launched its second scatterometer mission onboard SCATSAT-1 in September 2016. The wind data from SCATSAT-1 are now operational. Both OSCAT and SCATSAT-1 have not only catered the scientific community with good quality wind observations but also provided invaluable information for the prediction of cyclogenesis over the global oceans. The excellent quality of SCATSAT-1 data products has found their way to the operational weather prediction centers worldwide. The O3SCAT will be following the heritage of SCATSAT-1.

3.3 Global scenario

In the international context, there are presently three European operational scatterometers viz. ASCAT-A/B/C onboard two MetOP platforms from which data are being disseminated to the global users. All these instruments are working in C-band (5.35 GHz). The Fan-beam geometry followed by these instruments renders the wind observations from two swaths (of size 550 km) separated by a huge nadir gap of 700 km. So the number of observations from these scatterometers are relatively less in comparison to our Ku-band scatterometers (viz. SCATSAT-1).

4.0 Algorithm description

This section describes the retrieval algorithms for generating Level-2B ocean surface vector wind product as the primary geo-physical parameter from O3SCAT. This retrieval algorithm for O3SCAT will follow the heritage from the same applied on SCATSAT-1 and OSCAT. Retrieval of ocean surface wind vector from space borne microwave scatterometer essentially consists of the following important steps:

1. Development of geophysical model function (GMF), which is the most crucial element for wind vector retrieval. This requires global data of ocean surface wind vector from numerical

weather prediction (NWP) models and other satellites concurrent and collocated with the scatterometer radar backscatter observations over the sufficient period of time covering preferably the whole dynamic range of winds.

2. Development of retrieval algorithms that involves point-wise extraction of prioritized wind vector solutions from radar backscatter data by making use of suitable GMF.

3. Development of techniques for wind directional ambiguity removal over the entire swath divided into three regions namely, nadir, middle (sweet) and outer regions. The ambiguity removal specifically in the outer region requires auxiliary data of wind fields from NWP models in the form of forecast/analysis.

4. Development of procedures for flagging out data under rainy conditions. This requires rainfall information from microwave radiometer or rain-radar on board the same or other satellites.

We shall describe the technical details of all the algorithms mentioned above along with the necessary data in the subsequent sections.

4.1 Input satellite data

The primary input to the Level-2B module will be the Level-2A data from O3SCAT. Level-2A data products generally contains composite (VV/HH/AFT/FORE) footprints of backscattering coefficients (Sigma0) over each and every wind vector cell (WVC) throughout the swath. Along with Sigma0, there will be several other sensor parameters like radar azimuths, incidence angles, brightness temperatures, Kp-values, SNRs and quality flags (land/ocean/ice etc.).

4.2 Auxiliary data

Quality of retrieved wind directions depends on the removal of ambiguous solutions, proper flagging of the rainy events as well as fine tuning of the GMF coefficients. These requires additional information from other sources. Table 1 below specifies the various auxiliary data that will be required for Level-2B product generation from O3SCAT.

Table 1: Data Requirements for Operational Geophysical Data Product Generation

Source	Data	Period (months)	Purpose
Global NWP Models:## NCEP/ ECMWF/ NCMRWF	Global NWP Reanalysis data of Surface Wind Vector	#T0 to T0+6	GMF Fine-tuning & Algorithm testing
	Global Forecast & Reanalysis data of Surface Wind Vector, SST, surface and air temperature and humidity	T0 Onwards	GMF & Algorithm Testing
	***On-operational basis, global forecast of surface wind vector**	**T0 onwards**	**Operational Data Product generation**
Insitu Data: Ships & Buoys	Surface Wind Vector	T0 onwards	Wind Product validation
Satellite Products: Scatterometer, Radiometers, Rain Radar Data	O3SCAT backscatter & ancillary observations, Surface wind vector (from other scatterometers), surface wind speed (from radiometers) and rain rate (from radiometer and radar)	T0 Onwards	Wind Retrieval, GMF Fine-tuning and rain flagging algorithm verification

***Forecast validity to be decided by operational turn-around time.**

#T0 is O3SCAT Launch

Final selection of NWP model will be based availability of infrastructure including establishment of downlink facility at NRSC-IMGEOS.

4.3 The forward model

The exact behavior of radar backscatter varies with scatterometer operating frequency, polarization and the incidence angle. However, the general trend of radar backscatter dependency on wind vector remains same, specifically the directional dependency of radar backscatter. It has been observed over decades using earlier satellite missions and also based on theoretical models that radar backscatter depends upon wind speed with a power law while it depends bi-harmonically on wind direction. This harmonic nature of radar backscatter on wind direction leads to multiple possibility of wind vector yielding the same radar backscatter value and thus causes ambiguity in wind direction determination using a set of radar backscatter measurements. The radar backscatter decreases with incidence angle for given wind vector and polarization. Moreover, radar backscatter in vertical polarization is higher than that of horizontal polarization.

The ocean surface vector winds (OSVW) can be retrieved from space-borne scatterometers by using the return power measured by a scatterometer. For a monostatic scatterometer system, the return power is represented through backscattering coefficient (σ0) expressed in decibel (dB). Winds blowing over the ocean alter the surface roughness. This, in turn, modulates the scatterometer backscattered power and hence the σ0. Thus over the ocean, the wind generated surface roughness is measured by σ0. Therefore retrieval of ocean winds from σ0 is essentially an inverse problem. In order to resolve this, we need to have a forward model. The simulations from the forward model can be compared with the observed data to retrieve the wind information. Physically this forward model is expressed as (Romeiser et al., 1997):

$$\sigma 0 = 8\pi k^4 cos^4\theta \, |\alpha_{pp}|^2 [\varphi(K_B) + \varphi(-K_B)] \quad (1)$$

Where k is the radar wave number, θ is radar incidence angle, α is scattering coefficient dependent on polarization and incidence angle and φ is the directional ocean wave spectra dependent on the wind speed, wind direction and Bragg's wave number (K_B). Now in order to simulate σ0 at each and every WVC using (1), we need to have priori information of φ, which is not practically possible because there are only few wave-rider buoys over the global oceans which give accurate measurements of this parameter. Thus in operational scenario, we can't use the physical forward model for the retrieval of ocean winds from scatterometers. Thus to alleviate this problem, in scatterometer community, it is conventional to develop empirical relationship among σ0 and wind speed, wind direction and other sensor specific parameters. Such an empirical relationship is known as Geophysical Model Function (GMF). This relationship is established empirically using global satellite radar backscatter observations and the corresponding ocean surface wind vector obtained from various sources like global atmospheric circulation models, in-situ data from ships and buoys and other satellites for a desired period of time (Fischer, 1972, Ulaby et al., 1981, Schroeder et al., 1982, Pierson et al., 1989, Long., 1991). The GMF is generally developed post-facto using collocated wind observations mostly from NWP model and the scatterometer observations over a period of several months covering the full dynamic range of wind vector (Wentz et al.,1984, 1999). The GMF is mathematically expressed as (Gohil et al, 2013):

$$\sigma 0 = A0(1 + A1cos\chi + A2cos2\chi + A3cos3\chi + \cdots) \quad (2)$$

Where $A0$, $A1$, $A2$ and $A3$ coefficients are dependent on scatterometer incidence angle and wind speed and χ is the relative azimuth representing the angle between the wind direction and antenna azimuth.

Now in order to estimate the unknown coefficients in (2), scatterometer Level-2A data is collocated with wind speed and direction information coming from a global NWP for sufficient longer period such that the full dynamic ranges of speed and direction are covered within the collocated data. For Ku-band scatterometer system where two differently polarized beams are rotated at fixed incidence angles, two sets of separate coefficients corresponding to VV and HH polarization are estimated. From the collocated data, mean and standard deviation of σ0 for each wind speed and direction bin are calculated. In Figure 2, variation of SCATSAT-1 Level-2A σ0 with relative azimuth for different wind speed bins for ten months of SCATSAT-1/ECMWF collocated data is shown.

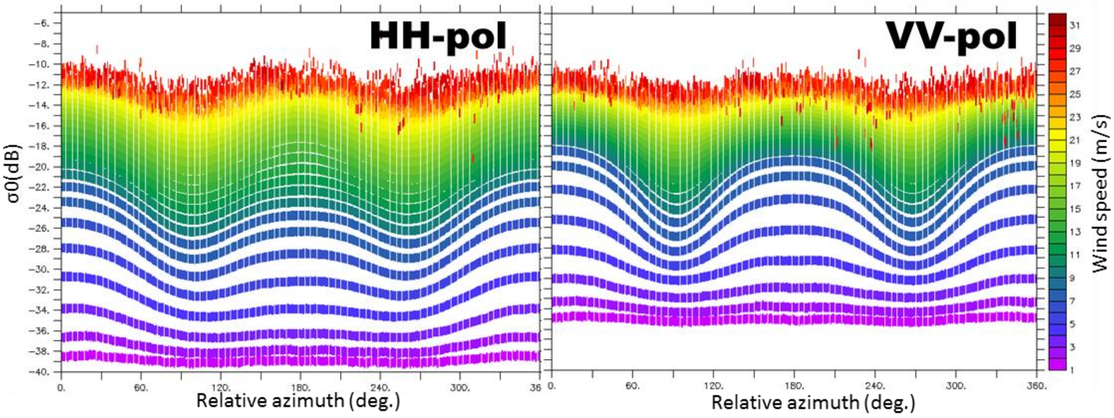

Figure 2: *Collocated SCATSAT-1/ECMWF data for October 2016 – July 2017.*

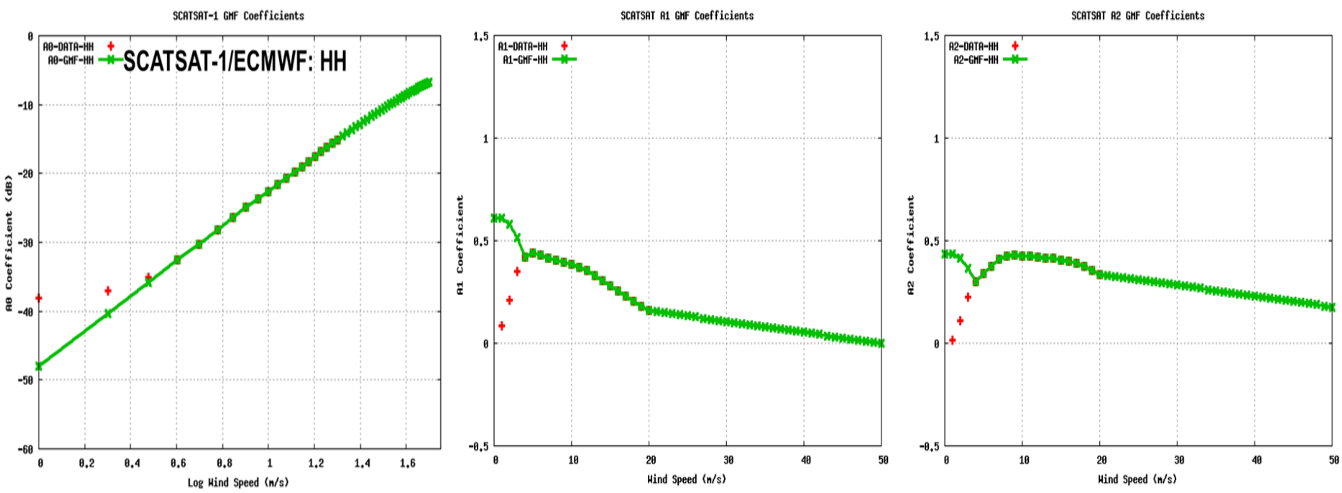

Figure 3: *GMF coefficients (A0, A1, A2) for SCATSAT-1 V1.1.3 data.*

To estimate the GMF coefficients, several processing of the collocated data is performed. For each wind speed bin, the *A0* coefficient is estimated by summing the σ0 over entire range of relative azimuth. Thus *A0* represents the linear (in log scale) relationship between ocean surface wind speed and the backscattering coefficient. Once the *A0* is estimated, the other coefficients can be calculated using liner multiple regression. Since in the collocated data, it is difficult to get higher wind speeds (30 ~ 50 m/s) with all possible direction values, the GMF coefficients thus estimated are interpolated up to 50 m/s wind speed. Also to main the sufficient bi-harmonicity for lower winds (<3 m/s), the coefficients are scaled based on the standard deviation of σ0 in the lower wind speed bins. Finally the GMF coefficients are stored in the form of lookup table to be used during wind retrieval. To demonstrate the coefficients, the plots of first three GMF coefficients for SCATSAT-1 V1.1.3 data are shown in Figure 3.

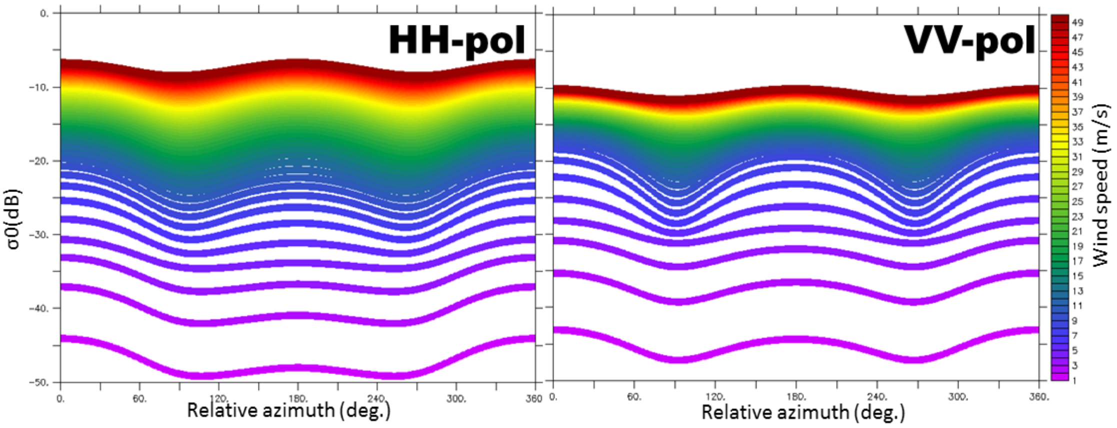

Figure 4: *Final SCATSAT-1 V1.1.3 GMF for HH and VV polarizations*

The functional forms of the SCATSAT-1 V.1.13 GMF for both of inner (HH-pol) and outer (VV-pol) beams are shown in Figure 4. It can be noted that, though we didn't have sufficient collocated points beyond 27 m/s (Figure 2), GMF coefficients are extrapolated up to 50 m/s (Figure 5). Proper bi-harmonicity for lower winds is also maintained.

4.4 GMF Development / Fine-tuning for O3SCAT

The GMF developed for one scatterometer system, in principle, can only be applied to the same system due to inherent characteristics embedded empirically in the derived GMF (Gohil et al, 2013). However, its use with another system is possible provided the parameters of that system are kept unchanged or least deviated, which then can be further fine-tuned. As the sensor specifications of O3SAT are kept same as that of SCATSAT-1 the present version of the SCATSAT-1 GMF (Version 1.1.4) developed for SCATSAT-1, form the baseline and is planned to be used for O3SCAT during its initial phase. However, it is envisaged that fine-tuning of this SCATSAT-1 GMF will be required due to minor change in the incidence angles, orbit timings of O3SCAT during its initial phase.

4.5 Development of algorithm

In this section, we describe the technical details of the algorithm. Our retrieval algorithm is based on three steps. The first step is essentially a preprocessing step which splits the composite footprint data available in Level-2A into four distinct flavors based on the observations made in two beams (outer:VV and inner:HH) and two look (FORE and AFT) configuration at each WVC level. At the same time the NWP forecast data is also interpolated on to the WVCs. In the second step, prioritized wind vector solutions are calculated by computing the Normalized Standard Deviation (NSD) (Gohil et al., 2008). The rain flagging is also performed in the second step. The third step is dedicated for removing the ambiguities in the wind vector solution by using Directional Stability and Conservation of Scattering (DiSCS) algorithm (Gohil et al., 2010). The flow chart for the operational algorithm is shown in Figure 5.

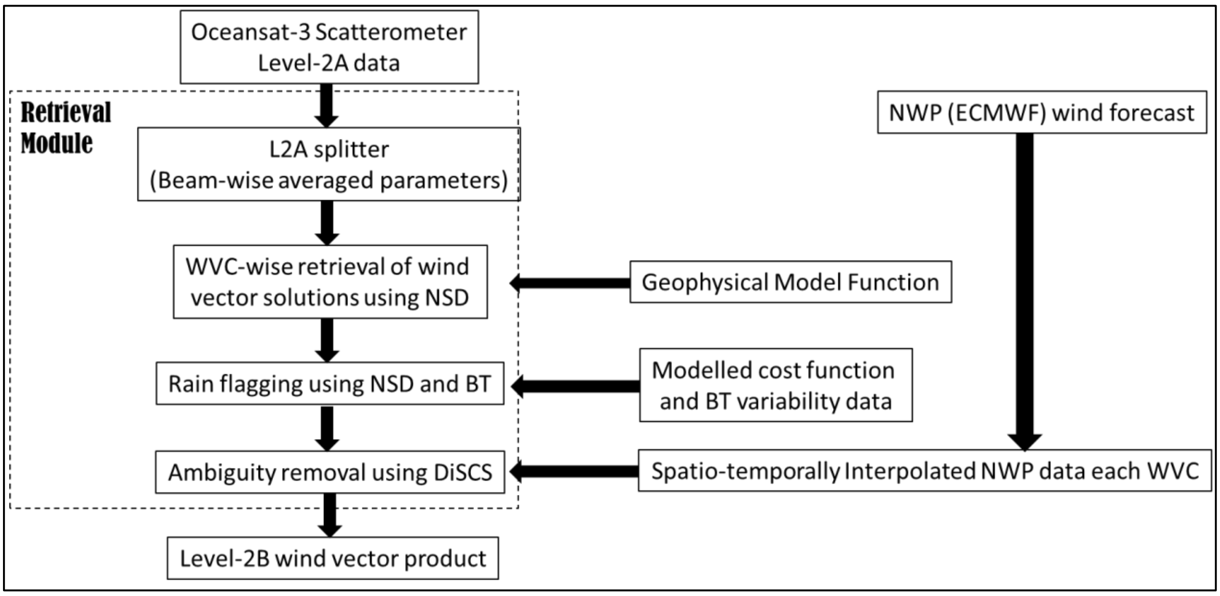

Figure 5: *Proposed flow chart for operational Level-2B product generation from O3SCAT.*

4.5.1 Splitting of Level-2A data

This is pre-processing first step of our operational algorithm for the retrieval of ocean surface vector winds from O3SCAT. The input to this step is Level-2A data containing backscattering coefficient, geolocations, radar parameters (e.g., incidence angle, azimuth angle, SNR, Kp

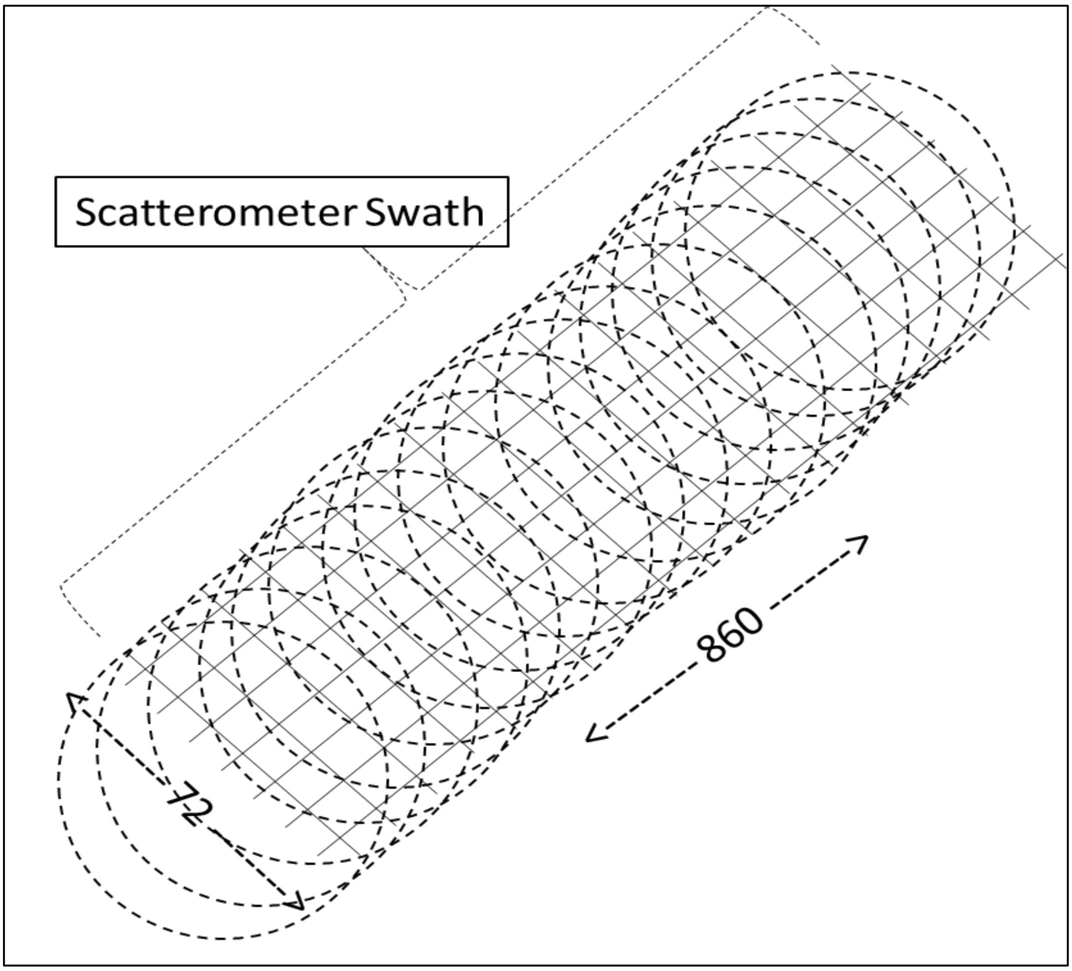

Figure 6: *Schematic representation of circular scanning over the swath. Small squares over the swath represents wind vector cells (WVCs). There are 860 rows along the swath and 72 cells across the swath in SCATSAT-1. The numbers will be doubled in O3SCAT with nominal spatial resolution of 12.5 km.*

etc.). Ku-band scatterometers follow the conical pencil beam configuration. In such a configuration, two differently polarized (VV and HH) beams scan the ocean surface in a circular manner (Figure 1). The area sweeps over the ocean surface defines the swath for the scatterometer (Figure 5). The entire swath is divided into square resolution cell known as wind vector cells (WVCs). The size of WVCs defines the nominal spatial resolution of the scatterometer. For example, the WVC size is 25km x 2km in SCATSAT-1 and the same is going to be 12.5km x 12.5km in the proposed O3SCAT. There are multiple observations (i.e., footprint) available for each WVC. Based on the beam type (inner or outer) and look type (AFT or FORE), the composite footprints over each WVC is splitted into 4 types as VV-AFT/VV-FORE/HH-AFT/HH-FORE and then averaged appropriately. Thus this step produces maximum 4 observations in each WVC for the inner beam and maximum 2 observations in each WVC for the outer beam (only VV observations). Apart from this, based on the centre geolocation of the WVCs, the NWP forecast winds are interpolated in time and space. The NWP forecast directions are used in the step three of our algorithm which performs the ambiguity removal.

4.5.2.1 Extraction of Prioritized Wind Vector Solutions

Assuming the other parameters constant and the dominant dependency of radar backscatter on ocean surface wind vector (speed and direction), extraction of wind speed and direction is carried out by comparing the measured radar backscatter with those simulated using sensor specific GMF for assumed wind speed and direction varied in its entire range valid for the GMF being used. This process yields multiple solutions of wind vector among which one solution corresponds to true wind vector while others are ambiguities. The wind speed values of these vector solutions have small differences while the direction values are quite different. These solutions are prioritized according to the deviation of measured radar backscatter from the simulated values with the vector solution having minimum deviation treated as highest priority solution. Under noise free conditions, the highest priority vector solution always identifies the correct (true) wind vector while under moderately noisy conditions, the highest priority solutions identify the correct wind vectors in about half of the data cases considered. Such performance of the algorithm is heavily dependent on the noise present in radar backscatter data (Chi and Li., 1988). The characteristic of these prioritized solutions is such that the majority of correct wind vector cases can be identified between the first two highest priority solutions. Moreover, in most of the cases the directions of the first two highest priority solutions are mostly opposite to each other. Thus, when wind vectors are retrieved from scatterometer data over the swath, about half of the directions may be found in opposite direction to the overall wind directional flow in the data region. These directional ambiguities are filtered out by using another process known as directional ambiguity removal process.

The dependencies of scatterometer measured backscatter on the wind speed and the wind direction being of non-linear (power-law) and bi-harmonic nature, respectively, yield multiple solutions of wind vector from a set of backscatter measurements while performing retrieval using GMF (Stoffelen et al., 1997, 2006). An algorithm known as the "Normalized Standard Deviation (NSD)" algorithm (Gohil et al, 2006, 2008) has been developed in-house for retrieving prioritized wind vector solutions from the scatterometer data and has been used

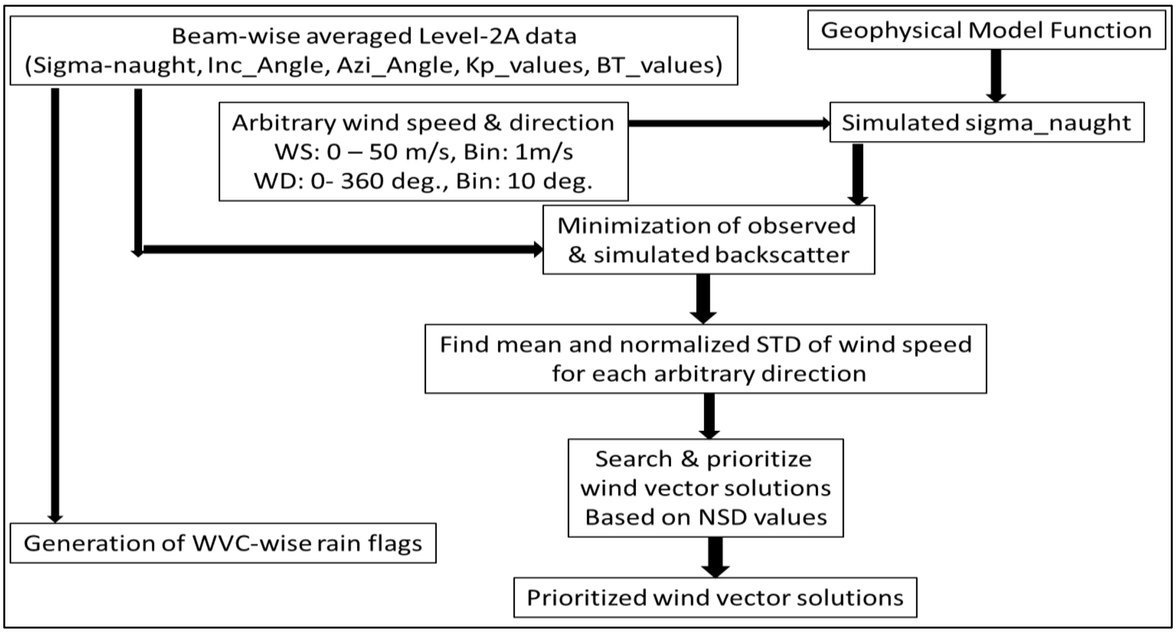

Figure 7: *Block diagram of algorithm for retrieving wind vector solutions.*

operationally for OSCAT and SCATSAT-1and the same is being planned to be used for O3SCAT as well. The input to this step of our proposed retrieval algorithm is the beam-wise averaged Level-2A parameters and interpolated NWP winds at each WVC level. The algorithm makes use of closure form of relationship between the wind speed and the backscatter for an aspect direction to retrieve wind speed from a given single backscatter measurement. From a given set of backscatter data for a given wind vector cell, the mean and the normalized standard deviation of wind speed are obtained for all the aspect directions.

To illustrate this, let us consider a case for a given WVC and for a given beam (either inner-HH or outer-VV) and look (either FORE or AFT). For all aspect direction ranging from 0 to 360 degrees in an interval of 10 degree, we can simulate backscattering coefficient ($\sigma 0$) for all wind speed ranging between 1 to 50 m/s using the specific GMF. Those simulated $\sigma 0$ values are then compared with the observed values for that given WVC , given beam and given look. The wind speed corresponding to the lowest difference between the observed and simulated $\sigma 0$ is taken for the given bin of the aspect direction. This is repeated for all the beams and looks resulting maximum four wind speed values for each bin of aspect direction. From all four values mean and standard deviations are computed. NSD for the given direction bin is then calculated by normalizing the standard deviation by mean values of the wind speeds. The prioritized wind vector solutions are obtained through searching minima of wind speed NSD along the aspect wind direction and ranked according to the NSD values. The prioritization of

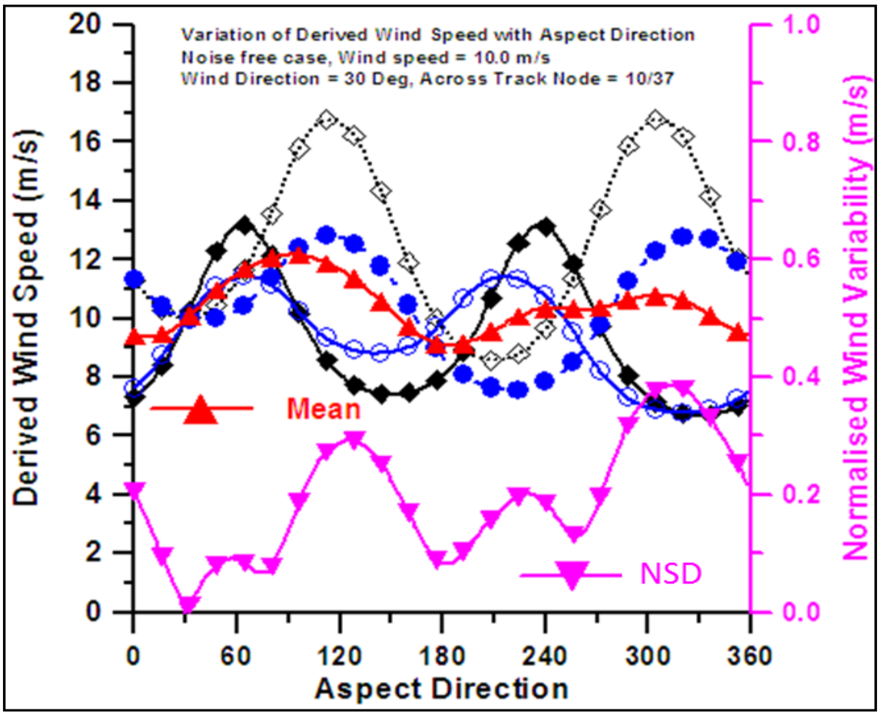

Figure 8: *Illustration of Normalized Standard Deviation (NSD) for the noise-free scenario.*

solutions is based on the fact that for an aspect wind direction to be the true wind direction the derived wind speeds from a set of backscatter measurements should be the same or on the other hand the NSD value should be zero or minimum. Among the multiple wind direction solutions only one direction is true direction while remaining are ambiguities.

The rank-1 direction is always the true direction for noise-free data cases while for the real (noisy) data cases, the true direction is possibly represented by the first two highest ranking solutions which may either be true or in almost opposite direction (an ambiguity). In practice, the real data from a scatterometer is always associated with noises. To consider the effect of noise in our retrieval, we compute the Kp parameter as given below:

$$Kp = \sqrt{(\alpha + \frac{\beta}{\sigma 0_{GMF}} + \frac{\gamma}{(\sigma 0_{GMF})^2})} \quad (3)$$

Where, α,β,γ are three component of Kp available from Level-2A data, $\sigma 0_{GMF}$ represents the σ0 values simulated using the GMF. Thus in noisy real cases, instead of computing the simple mean and NSD of the wind speed, Kp weighted mean wind speed (W_φ) and NSD are computed for each bin (φ) of the aspect direction as given by (4) and (5).

$$W_\phi = \sum_{k=1}^{M} W_k [\frac{1}{1+Kp_k}] \, / \sum_{k=1}^{M} [\frac{1}{1+Kp_k}] \quad (4)$$

$$NSD_{\phi} = (\frac{1}{W_{\phi}})\sqrt{(\frac{1}{M})\sum_{k=1}^{M}(W_k - W_{\phi})^2} \quad (5)$$

Where M represents number total observations (maximum 4) available for each bin. Once the NSD values are calculated for all aspect directions, six prioritized wind vector solutions are chosen corresponding to the first six NSD minima. The chosen vector solutions are ranked by ascending NSD values.

4.5.2.2 Rain flagging

Scatterometer observations are affected by the presence of rainy events. Rain generally has three major effects on the scatterometer measurements. First, the scatterometer signal gets attenuated in the atmosphere during transmission and reception. Secondly, the rain droplets will introduce volume scattering. Finally the rain droplets will perturb the ocean surface influencing the scatterometer backscatter. In reality, combination of these three effects make the situation highly complex and the derived wind vectors are either underestimated or overestimated. In order to flag out the rain contaminated observations, a heuristic approach is proposed. In this approach, two parameters namely scatterometer brightness temperature (BT) in the outer beam (VV-polarized) available from the Level-2A data and standard deviation (SD) of winds are used. These two parameters are chosen because they are found to carry the signatures of rain (Gohil et al., 2015). Here the BT values are calibrated scatterometer noise whereas the SD values are WVC wise NSD values multiplied by the rank-1 wind speed as estimated in the earlier step. Since the rain dependence of the BT values changes with latitudinal belts and day and night time, rain probability of BT values is defined as

$$P_{btrain} = [BT_{VV}(Lat, Time) - BT_{MEAN}(Lat, Time)] / 2BT_{SD}(Lat, Time) \quad (6)$$

Where, BT_{vv} represents the BT in outer beam, “Time” represents day/night time as applicable for the ascending and descending passes, “MEAN” and “SD” represent average and standard deviation of the BT respectively.

The cost function (SD) based rain probability is defined as

$$P_{sdrain} = [SD(ws1, wvc) - SD_{MEAN}(ws1, wvc)]/2SD_{SD}(ws1, wvc) \quad (7)$$

Where, “ws1” and “wvc” represents rank-1 wind speed and wind vector cell.

The rain detection probability is defined as

$$P_{rain} = log_e[\frac{e^{P_{btrain}} + e^{P_{sdrain}}}{2}] \quad (8)$$

Finally a given WVC is marked as rain contaminated if P_{rain} exceeds a threshold values.

4.5.2.3 Directional Ambiguity Removal

The bi-harmonic variability of backscattering coefficient with respect to the full range of relative azimuth angle introduces ambiguity in the wind direction retrieval process. Physically, the backscattered power over each and every footprint is not sufficient to interpret whether the wind is coming towards the footprint and or the wind is going away from the footprint. In order to resolve this kind of ambiguity associated with the prioritized wind directions, we need to have some first guess data. Practically such first guess data is provided in terms of NWP model forecast. It is proposed to perform this directional ambiguity removal process by using the Directional Stability and Conservation of Scattering (DiSCS) algorithm (Gohil et al, 2010). The flowchart for this algorithm is given in Figure 9.

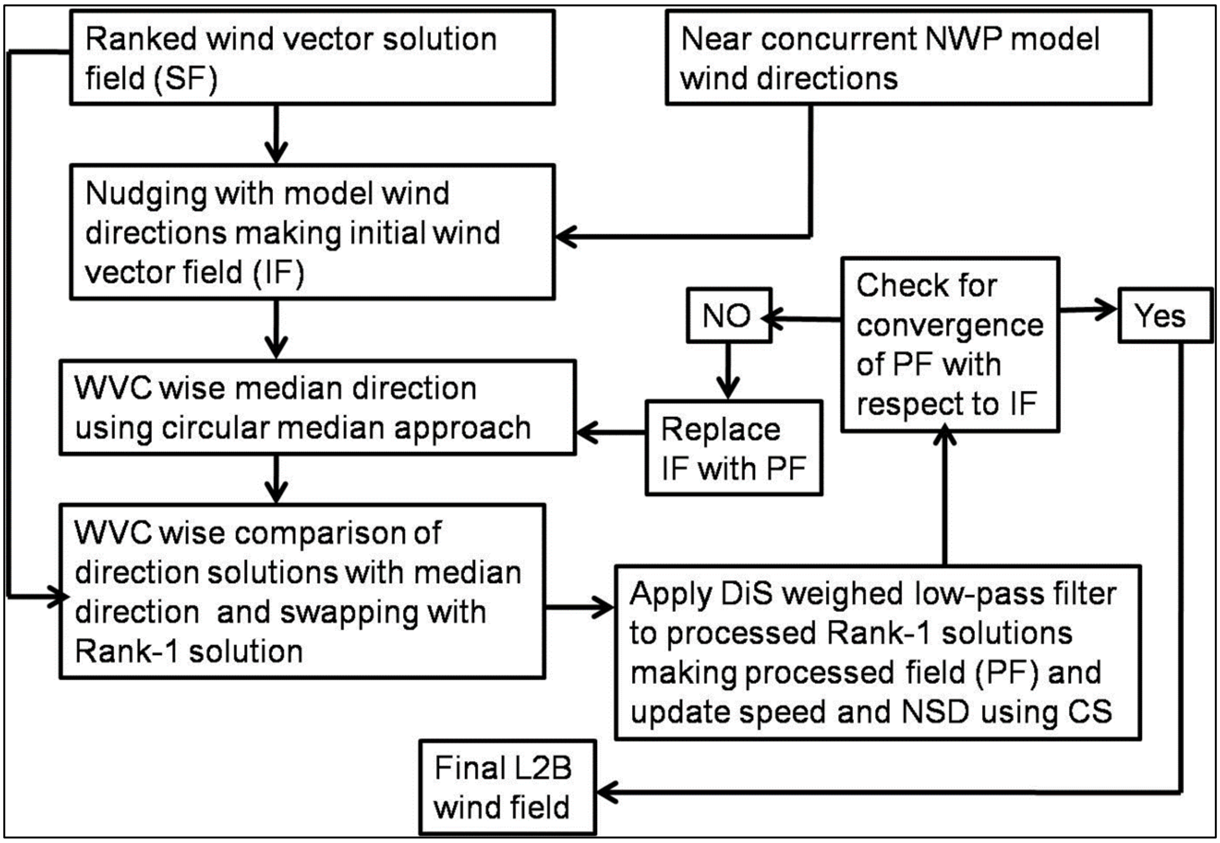

Figure 9: *Flowchart for the directional ambiguity removal using DiSCS algorithm.*

This algorithm procedure takes the rank-wise six prioritized wind vector solutions at each WVC from the earlier step. The multiple wind vector solutions and corresponding NSD values derived for each WVC for the entire orbit will be stored and termed as solutions field (SF). Then an initial field (IF) will be created for the entire orbit choosing a solution whose direction is close to the collocated NWP wind field. Using all the directions (*ni*) falling within a window of 7 x 7 (N=3) neighboring cells around the *jk* th WVC, a circular median direction is computed. Then for that given WVC, all the directions within the SF are compared with the circular median (φ_{jk}^{M}) direction. The entry in SF that is closest to the circular median direction is swapped with the rank-1 solution (including the corresponding wind speed and NSD values). This will be done for all the WVCs. A stability parameter is computed as

$$S_{jk} = cos^2\{[\{\sum_{n=j-N}^{n=j+n}\sum_{i=k-N}^{i=k+N}(\phi_{ni} - \phi_{jk}^{M})^2_{)^2 mod(180)}\}/(2N+1)^2]^{-\frac{1}{2}}/2\} \quad (9)$$

Once the stability parameter is computed, DiS-weighted mean wind direction will be calculated using the wind components (u,v) as shown below:

$$\phi_{jk}^{w} = tan^{-1}[\sum_{n=j-N}^{n=j+n}\sum_{i=k-N}^{i=k+N} v_{ni}S_{ni} / \sum_{n=j-N}^{n=j+n}\sum_{i=k-N}^{i=k+N} u_{ni}S_{ni}] \quad (10)$$

This DiS-weighted mean wind direction will be different from what was obtained through NSD. Thus the backscattering coefficient corresponding to φ_{jk}^{w} will be different from what was observed by the scatterometer. Hence in order to conserve the scattering, wind speed will be recomputed employing NSD for the DiS-weighted mean direction and observed backscattered data. Then for all the WVCs, the swapped rank-1 vector solutions in SF will be replaced by the corresponding DiS-weighted mean wind directions and the recomputed wind speeds along with the updated NSD values making it as processed field (PF). At this stage, DiS-weighted mean wind direction and the direction in the IF for the same WVC will be compared and if the this deviation for the entire orbit is more than 0.1% (i.e., convergence not achieved), IF will be replaced by the PF and next iteration will be performed, Maximum 30 iterations will be attempted otherwise quality flag will be raised. Once convergence is achieved the PF and the corresponding wind speed and NSD will become final L2B wind product.

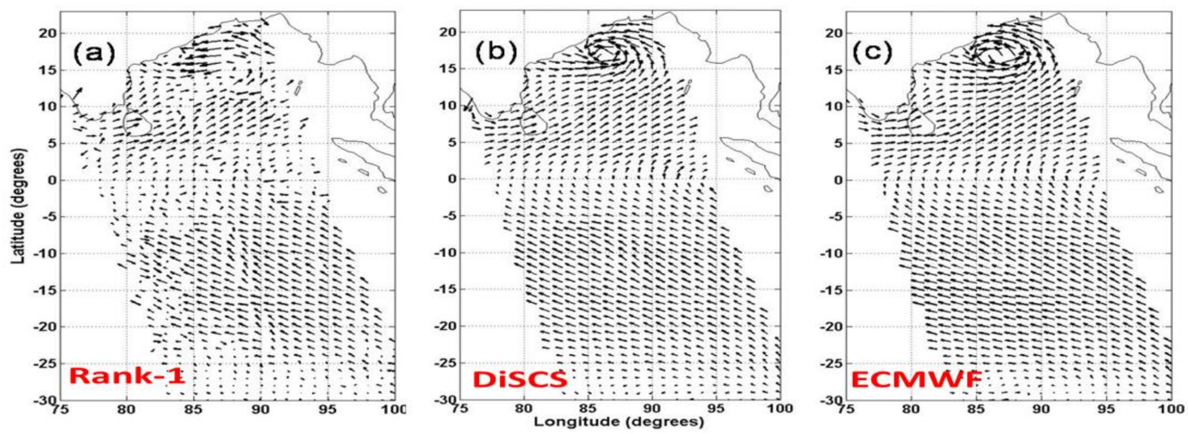

Figure 10: *Illustration of Rank-1 wind direction, wind direction through DiSCS and corresponding ECMWF wind direction for a given orbit.*

4.5.2.4 Atmospheric Corrections

The Ku-band radar backscatter is affected by heavy clouds and precipitation in terms of attenuating the transmitted and received powers of scatterometer. Thus, if such information is available in a suitable manner, the radar backscatter can be corrected for atmospheric attenuation improving the wind vector retrieval. Simulations have been earlier performed to study the impact of atmospheric corrections to ADEOS-1 NSCAT Ku-band scatterometer simulated data for wind vector retrieval under cloudy conditions. The atmospheric correction is carried out scaling (multiplying) the backscattering coefficient by a factor as given below:

$$Q = 1/(0.9892 - 0.00412 * wv)^{2sec\theta} \quad (11)$$

Where, "wv" is monthly water vapor climatology in gm/cm^2 and θ is the scatterometer incidence angle.

4.5.2.5 Quality flags

To maintain the quality of the retrieved wind vector products, we propose to use Level-2A flags to control the quality of our input. The following Level-2A quality flags are used:

- Sea/Land flag
- Good/Poor Sigma0
- Valid/Invalid Sigma0
- Good/Poor BT
- Valid/Invalid BT
- Land-sea boundary
- +ve/-ve Sigma0
- Ice flags

Once the final wind vectors are retrieved, we propose to provide the following quality flags in the Level-2B product:

- Rain/No-rain
- Ambiguity filter
- Vector quality
- Surface (Sea/Coast/Land)
- Atmospheric correction
- Orbit mean Sigma0
- Orbit mean wind speed

- Net –ve sigma0

All the scatterometer flags will be provided in 16-bit un-signed integer values.

4.6 Error/uncertainty analysis of algorithm

The retrieval algorithm mentioned in the previous sub-sections follows the heritage of OSCAT and SCATSAT-1. The nominal mode of O3SCAT will follow identical configuration of SCATSAT-1 only the WCV spatial size will change from 25km (in SCATSAT-1) to 12.5 km (in O3SCAT). O3SCAT will be fitted with a 1.4 m diameter antenna in comparison to the 1m diameter antenna in SCATSAT-1. This will lead to smaller footprints and improved SNR. The wind speed and direction errors in SCATSAT-1 is less than 1.8 m/s and less than 20° respectively for the wind speed range 3-30 m/s. Similar accuracy can be expected from O3SCAT wind products. Only because of the improved SNR, the noise standard deviation (Kp)

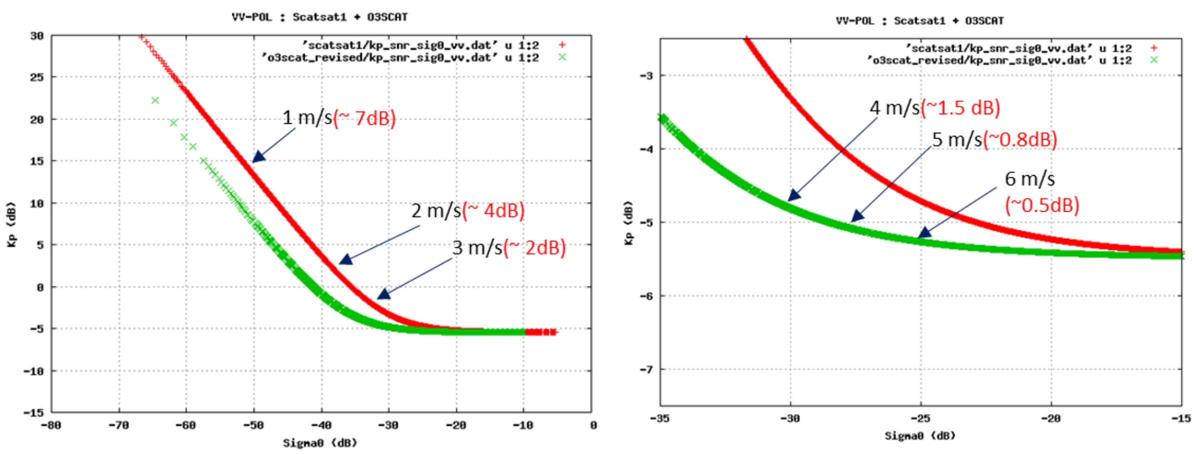

Figure 11: *Kp vs Sigma0 in VV-pol mode plotted using lab-data for both SCATSAT-1 and O3SCAT.*

of Sigma0 will also improve. It can be noted from Figure 11, that from the lab-based data of both SCATSAT-1 and O3SCAT, the low (< 6m/s) wind estimation will be better in O3SCAT, assuming the actual O3SCAT observations should follow the quality as revealed in the lab-based data.

5.0 Assessment/validation

Assessment of the retrieved geophysical products in Level-2B is proposed to be carried out with respect to wind observing systems like global moored buoys, analyzed winds from NWP models as well as contemporary satellites that will provide winds (e.g., ASCAT, WindSAT etc.).

5.1 Data requirement

Specifically we shall require calibrated moored buoy data from NDBC (Atlantic and Pacific), TAO (Central Pacific), PIRATA (Atlantic), RAMA (Indian Ocean) buoys. Mostly surface observations from all these buoy will be sufficient. NWP analyses from ECMWF, NCEP and NCMRWF will be used for swath-wise validations. Other data from wind measuring sensors like ASCAT-A/B, WindSAT will also be used depending upon their spatio-temporal collocations. In Figure 12, we show the location of the moored buoys from which we can use observations to validate our O3SCAT wind products.

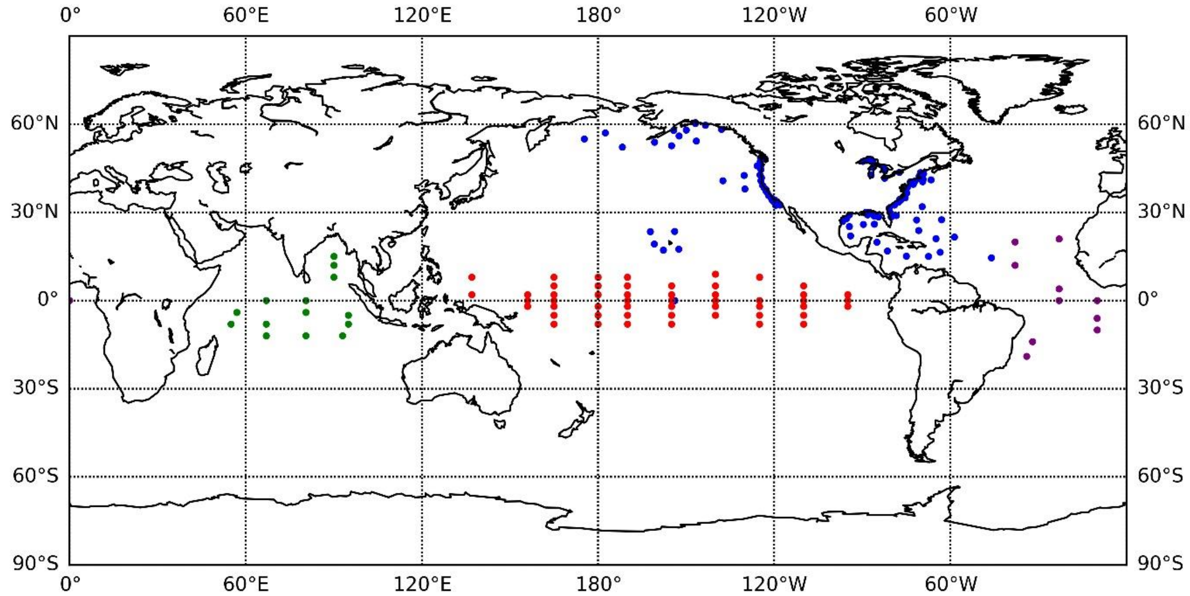

Figure 12*: Locations of moored buoys used for this study. The NDBC, TAO, PIRATA and RAMA buoys are represented in blue, red, purple and green colors respectively.*

5.2 Special campaign (if required)

Observations from moored buoys represents point measurements without any spatial variability. So ship-cruise based campaigns can be arranged to collect ground truths for validating O3SCAT derived winds.

5.3 Methodology

In general, scatterometer derived winds are validated by collocating with other wind measurements within spatio-temporal windows of 0.25˚ and ± 30 minutes. Also since scatterometer GMF is tuned for estimating equivalent winds at 10 m heights, wind data from other sources needs to be converted first to represent 10 m equivalent winds using surface observations prior to collocations. Once the collocations procedure is over, several statistics of the collocated pairs are computed to estimate the accuracy of the retrieved wind products (Chakraborty and Varma, 2018).

5.4 Assessment (using proxy or actual data)

In the following figure, quality assessment of SCATSAT-1 Level-2B wind products is shown.

Here SCATSAT-1 winds are compared with buoy/ ASCAT/ NWP winds for the period from April – December 2018.

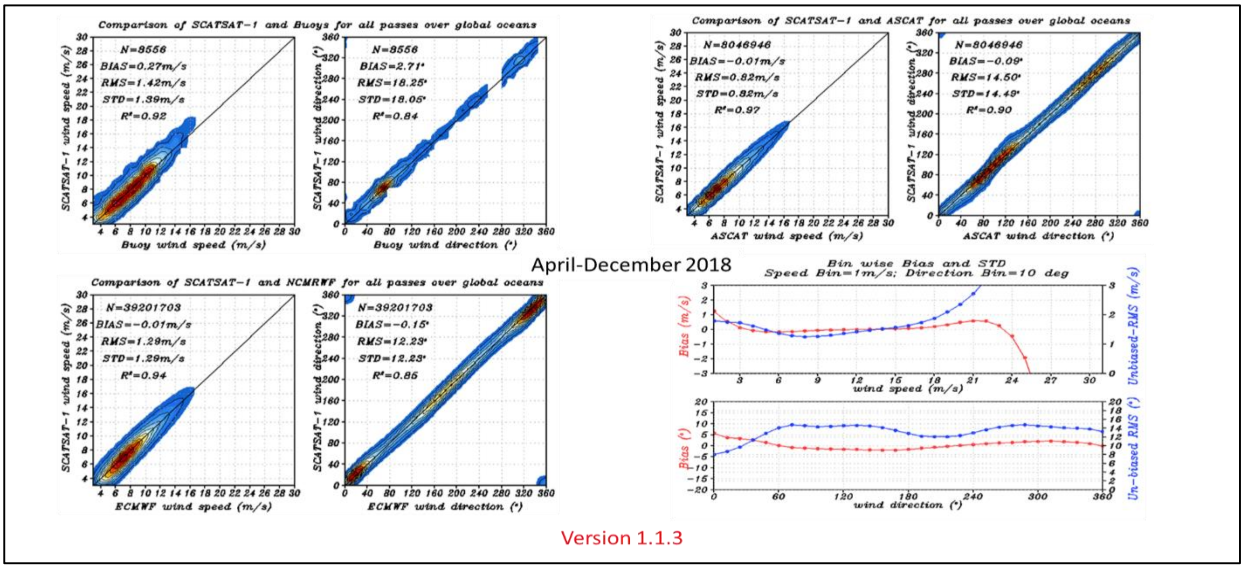

***Figure 13**: Assessment of Level-2B wind products from SCATSAT-1*

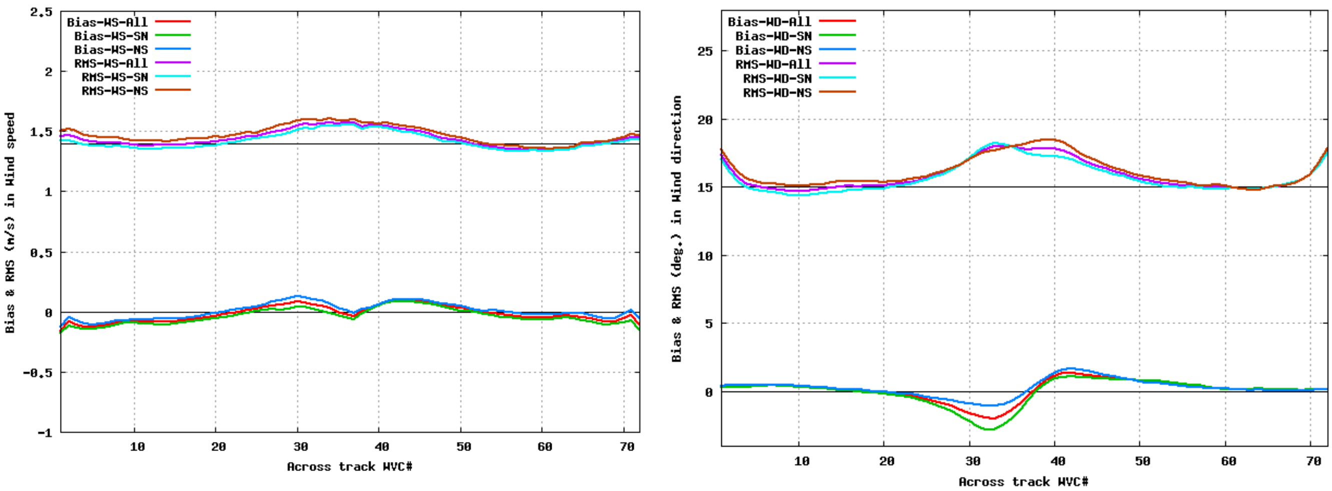

***Figure 14**: Across-track variation of bias and RMS of SCATSAT-1 wind speed (left panel) and wind direction (right panel)*

In Figure 14, we show the across track (throughout the 72 WVCs) variation of bias and RMS of wind speed and direction. It can be noted that, the accuracy of the products near nadir region and over the outer swaths is limited by the number of observations per WVC. Also in these two regions, the azimuthal diversity is mostly less (AFT and FORE observations will be around 180˚ apart). Rest of the WVCs (over "sweet swath zones") will have more accurate wind products (Chakraborty and Varma 2018).

5.5 Future scope

The algorithm described above has been successfully utilized for generating operational Level-2B products from OSCAT as well as SCATSAT-1. The quality of the products retrieved using the algorithm is satisfactory and is at par with international missions. There are few aspects which can be addressed in future to achieve *climate quality* in the products. One such aspect is to minimize the rain contamination in the retrieved products. Though the operational algorithm discussed above generates flags for the rainy events, it has been found that the higher RMS values in both wind speeds and directions are still associated with regions dominated by rains. This implies that our rain flagging can be improved further. In Oceansat-3, along with O3SCAT there will be SSTM which will measure brightness temperatures at TIR-1 (10.5 μm). From this sensor, surface rains can be estimated and those estimated rain values can further be used in our algorithm to flag out the rainy events. Apart from this, it has been identified that Ku-band backscatter from the scatterometer depends on SST and hence the wind retrieval accuracy. An attempt will be made in future to eliminate the SST-induced bias from the retrieved winds.

6.0 References

Chakraborty, A., R. Sharma, R. Kumar, and S. Basu, (2014), "An OGCM assessment of blended OSCAT winds", Journal of Geophysical Research , 119, pp.173 – 186.

Chakraborty, A. K. Varma, and R. Kumar (2018), "On the assessment of ocean surface vector winds from Scatsat-1", SAC/EPSA/AOSG/GRD/SR/46/2018.

Chi, C. and F.K. Li, (1988), "Comparative study of several wind estimation algorithms for spaceborne scatterometers", IEEE Tran. Geosci. Remote Sens., 26, pp. 115-12.

Draper, D.W. and D.G. Long, (2004a), "Simultaneous wind and rain retrieval using SeaWinds data", IEEE Trans. Geosci. Remote Sens., vol 42, No.. 7, pp 1411-1423.

Draper, D.W. and D.G. Long, (2004b), "Evaluating the effect of rain on SeaWinds scatterometer measurements", J. Geophy. Res., Vol. 109, C02005, doi: 10.1029/20021C001741, pp. 1-12.

Fischer, R.E., (1972), "Standard deviation of scatterometer measurements from space", IEEE Trans. Geosci. Electronics, Vol. GE-10, No. 2, pp. 106-113.

Gohil, B.S., A. Sarkar, A.K. Varma and V.K. Agarwal, (2006), "Wind vector retrieval algorithm for Oceansat-2 scatterometer", Proc. SPIE, vol. 6410, doi: 0.1117/12.693563.

Gohil, B. S, Abhijit Sarkar and V. K. Agarwal, (2008) "A new algorithm for wind-vector retrieval from scatterometers", IEEE GRSL, Vol. 5, No. 3, July 2008.

Gohil, B. S, Priti Sharma, Rajesh Sikhakolli and Abhijit Sarkar (2010)," Directional Stability and Conservation of Scattering (DiSCS) based directional-ambiguity removal algorithm for improving wind-fields from scatterometer: A QuikSCAT example", IEEE GRSL, Vol. 7, No. 3, July 2010.

Gohil, B. S, Rajesh Sikhakolli and Rishi Kumar Gangwar (2013), "Development of Geophysical Model Functions for Oceansat-2 Scatterometer", IEEE GRSL, Vol. 10, No.2. pp 377-380.

Gohil, B. S, Rajesh Sikhakolli, R.K. Gangwar and A.S. Kiran Kumar (2015), "Oceanic rain-flagging using radar backscatter and noise measurements from Oceansat-2 Scatterometer", IEEE TGRS, Vol 54, No 4, April 2016.

Huddleston, J.N. and B.W. Stiles, (2000), "Multidimensional histogram rain-flagging technique for SeaWinds on QuikSCAT", Proc. IGARSS2000, vol. 3, pp. 1232-1234

Long, D.G, and J.M. Mendel, (1991), "Identifiability in wind estimation from wind scatterometer measurements", IEEE Trans. Geosci. Remote Sensing, vol 29, No. 2, pp 268-276.

Schroeder, L., D.H. Boggs, G. Dome, I.M. Halberstam, W.L. Jones, W.J. Pierson, and F.J. Wentz, (1982), "The Relationship Between the Wind Vector and the Normalized Radar Cross Section Used to Derive Seasat-A Satellite Scatterometer Winds," J. Geophys. Res., Vol. 87, No. C5, pp. 3318-3336

Stiles, B.W. and S.H. Yueh, (2002), "Impact of rain on spaceborne Ku-band wind scatterometer data", IEEE Trans. Geosci. Remote Sensing, vol. 40, pp. 1973-1983.

Stoffelen, A. and D. Anderson, (1997), "Scatterometer data interpretation: measurement space and inversion", J. Atmos. and Ocean Technol., vol. 14(6), pp. 1298-1313

Stoffelen, A. and M. Portabella, (2006), "On Bayesian scatterometer wind inversion", IEEE Trans. Geosci. Remote. Sensing, Vol. 44, No. 6, pp. 1523-1533

Pierson, W.J., (1989), "Probabilities and statistics for backscatter estimates obtained by a scatterometer", J. Geophy. Res., vol. 94, C7, pp. 9743-9759.

== End of the document ==