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RapidScat Level 2B NetCDF

Guide Document

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Jet Propulsion Laboratory
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1. Abstract:

This ocean surface wind vector dataset is provided as a service to the oceanographic and meteorological research communities on behalf of the NASA/JPL RapidScat Science Data Systems (SDS) Team in collaboration with the NASA International Ocean Vector Winds Science Team (IOVWST). This document is intended to provided technical user support for the RapidScat Level 2B (L2B) datasets (spanning multiple release versions) which provide nominal 12.5 km (pixel spacing) swath bins of ocean surface wind vector retrievals with approximately 90% global coverage between approximately 56° S and 56° N latitude within 48 hours. This is the second release of the User's Guide, and primarily describes the latest version of the Level 2B climate-quality datasets (version 2), with specific information detailing the calibration and algorithm improvements in these datasets compared to their earlier predecessor datasets featuring standard quality. Since the ISS-RapidScat Mission officially ended with the completion of Phase-F in September 2018, the only planned continuation for improvements of RapidScat data products will take place through Principal Investigator led projects, namely through funding provided by NASA's MEaSUREs 2018 program. The latest processing version is consistently calibrated with the QuikSCAT Version 4.0 L2B dataset (https://doi.org/10.5067/QSX12-L2B40). This RapidScat L2B dataset incorporates most of the QuikSCAT Version 4 algorithm updates, and product development. RapidScat has been calibrated using non-spinning QuikSCAT data so that the two data records are consistent. The Version 4 QuikSCAT algorithm updates, product development, and calibration/validation information are described in further detail in the QuikSCAT Level 2B Version 4 User Guide. The newer updates in Version 4 will be published in the near future, and listed in the Citation and Documentation tabs of the following dataset information pages:

- https://doi.org/10.5067/QSX12-L2B40
- https://doi.org/10.5067/RSX12-L2C20

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2. Acknowledgements:

NOTE: Please refer all questions concerning this dataset to PO.DAAC User Services: podaac@podaac.jpl.nasa.gov.

The research described within this document was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The following people have contributed to the procurement and validation of the described datasets and user guide documentation:

Principal Investigator:
Dr. Ernesto Rodriguez[1]

Co-Investigators:
Bryan Stiles[1], Frank Wentz[2], Lucrezia Ricciardulli[2], Thomas Werne[1], Alexander Fore[1], Philip Callahan[1], Scott Dunbar[1], Brent Williams[1], Alexandra Chau[1], and Sermsak Jaruwatanadilok[1]

User Guide Authors:
David Moroni[1]
Bryan Stiles[1]
Alex Fore[1]
Alexander Wineteer[1]

[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Remote Sensing Systems

3. Mission Description:

The International Space Station (ISS) RapidScat (hereafter, ISS-RapidScat) mission is a time-series continuation mission to fill the gap created by the loss of data from the NASA QuikSCAT mission, which due to a mechanical failure officially stopped providing a continuous data record of ocean vector winds beyond 22 November 2009. ISS-RapidScat was launched from Cape Canaveral, Florida on a Space-X Dragon on 15 September 2014. On 19 August 2016 (orbital revolution number 10827), ISS-RapidScat completed its last operational data retrieval which coincided with an irrecoverable power loss to the ISS Columbus module that provided power to the scatterometer. After many attempts to recover power to the ISS Columbus module, it was decided by December 2018 to officially decommission ISS-RapidScat, which resulted in the beginning of Phase-F (i.e., decommissioning) that was ultimately completed on 30 September 2018. Nonetheless, ISS-RapidScat was heralded by many key stakeholders of ocean surface wind vector data within the U.S. and internationally as a success, particularly given the historical uniqueness of being the first operational Earth observing mission funded by NASA to be mounted to the ISS platform, which presented its own engineering and scientific challenges that have been presented and discussed at past science team meetings and publications.

The legacy of the RapidScat instrument is from recycled spare parts of the SeaWinds instrument, which was previously flown on QuikSCAT and ADEOS-II. RapidScat is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans, both night and day. Scatterometer wind data, combined with measurements from various scientific disciplines, will help to understand mechanisms of global climatic change and weather. These measurements will help to determine atmospheric forcing, ocean response and air-sea interaction mechanisms on various spatial and temporal scales. Wind stress is the single largest source of momentum to the upper ocean, driving oceanic motions on scales ranging from surface waves to basin-wide current systems. Winds over the ocean modulate air-sea fluxes of heat, moisture, gases and particulates, regulating the crucial coupling between atmosphere and ocean that establishes and maintains global and regional climate. Measurements of surface wind velocity can be assimilated into regional and global numerical weather and wave prediction models, improving our ability to predict future weather.

ISS flies at an altitude approximately half that of QuikSCAT, which allows RapidScat to retrieve wind vectors in an asynchronous orbit with respect to the sun. This daytime/nighttime asynchronicity enables RapidScat to retrieve winds at the same location at variable times of the day which can provide two distinct advantages over a sun-synchronous platform: 1) more precise temporal co-location between multiple remote sensing spacecraft and 2) observation of diurnal processes.

As the only remote sensing system able to provide accurate, frequent, high-resolution measurements of ocean surface wind speed and direction under both clear sky and cloudy conditions, day and night, scatterometers have played an increasingly important role in oceanographic, meteorological and climatic studies over the past several decades.

Scatterometers use an indirect technique to measure wind velocity over the ocean, since the atmospheric motions themselves do not substantially affect the radiation emitted and received by the radar. These instruments transmit microwave pulses and receive backscattered power from the ocean surface. Changes in wind velocity cause changes in ocean surface roughness, modifying the radar cross-section of the ocean and the magnitude of the backscattered power. Scatterometers measure this backscattered power, allowing estimation of the normalized radar cross-section (σ_o) of the sea surface. Backscatter cross section varies with both wind speed and direction when measured at moderate incidence angles. Multiple, collocated, nearly simultaneous σ_o measurements acquired from several directions can thus be used to solve simultaneously for wind speed and direction.

The first spaceborne scatterometer flew as part of the Skylab missions in 1973 and 1974, demonstrating that spaceborne scatterometers were indeed feasible. The Seasat-A Satellite Scatterometer (SASS) operated from June to October 1978 and proved that accurate wind velocity measurements could be made from space. The SASS cross section measurements have been used to significantly refine the empirical model relating backscatter to wind velocity, and the SASS data have been applied to a variety of oceanographic and meteorological studies. As a much improved extension of the European Space Agency's Earth Remote Sensing (ERS) scatterometer data record (ERS-1/2), the Advanced Scatterometer (ASCAT) provided by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) flown on MetOp-A/B/C has extended the previous single-swath scatterometer into a dual-swath instrument operating at C-band and providing an extended global time series of ocean surface wind vectors from March 2007 through present. NSCAT was launched on ADEOS-1 (Midori) in August 1996 and returned nearly 10 months of dual-swath, 25-km resolution Ku-band backscatter and wind data until the demise of the spacecraft in June 1997. QuikSCAT was launched by NASA on 20 June 1999 and provided calibrated ocean surface vector winds until 22 November 2009 when it ceased nominal operations due to a failure of its antenna spin mechanism. Despite this limitation of a fixed-beam antenna, QuikSCAT continued to produce calibrated backscatter data, albeit on a narrow 25-km wide swath, that proved useful for ongoing calibration of other scatterometers including RapidScat and SCATSAT. The SeaWinds on Midori-II (a.k.a. ADEOS-2) mission, which employed a clone of the QuikSCAT instrument, producing science-quality data from 10 April 2003 until 24 October 2003, thus allowing for a tandem (QuikSCAT/ADEOS-2) mission with 4 overlapping (nominal) local time-of-day Ku-band measurements during its lifetime. A similar Ku-band scatterometer (OSCAT) onboard OceanSat-2 was flown by the Indian Space Research Organization from 23 September 2009 to 20 February 2014. A wind vector data product consistent with QuikSCAT and RapidScat was produced for OSCAT by JPL and is archived by PO.DAAC; see: https://doi.org/10.5067/OSCT2-L2BV2. On 26 September 2016, ISRO launched SCATSAT-1 to serve as a continuity mission for OceanSat-2. SCATSAT-1 is expected to remain operational through 2019.

3.1 Mission Requirements

The temporal scales of important motions in the atmosphere and the ocean range from seconds to decades, and spatial scales range from meters to tens of thousands of kilometers.

Given the wide range of geophysical studies requiring surface wind velocity data, construction of a unified, consistent, achievable set of requirements for a satellite instrument is difficult. Following the successful flight of the Seasat Scatterometer (SASS) in 1978, NASA established the interdisciplinary Satellite Surface Stress Working Group to define the scientific requirements for the next spaceborne NASA scatterometer system. As understanding of both science issues and scatterometer capabilities grew during the 1980's, the Working Group report evolved into specific mission requirements. In short, the system must measure winds between 3 and 30 m/s with an accuracy better than (the greater of) 2 m/s or 10% in speed and 20° in direction with a spatial resolution of 50 km; virtually the entire ocean surface must be covered at least once every two days; geophysically useful products must be produced within days after data are acquired; and the instrument must be designed to acquire data for at least three years in order to allow investigation of annual and inter-annual variability. A summary of the ISS-RapidScat technical requirements is given in Table 1.

Quantity	Requirement	Applicable Range
Wind speed	2 m/s (rms)	3-20 m/s
	10%	20-30 m/s
Wind direction	20° (rms) selected ambiguity	3-30 m/s
Spatial resolution	25 km	σ_o cells
	25 km	Wind vector cells
Location accuracy	25 km (rms)	Absolute
	10 km (rms)	Relative
Coverage	90% daily coverage between 56 degrees N and S latitude	Global
Mission duration	24 months	24-36 Months

Table 1: ISS-RapidScat Technical Mission Requirements

3.2 Satellite Description

As the NASA ISS-RapidScat instrument was mounted on the International Space Station (ISS), Table 2 outlines the nominal orbit parameters for ISS.

Orbital Period (range)	91 to 93 minutes (16 orbits/day)

Altitude above Equator (range)	370-460 km
Inclination	51.65º

Table 2: ISS Nominal Orbit Parameters

3.3 SNR Anomaly Description

After about one year of operation, the instrument suffered a decrease in the observed signal-to-noise ratio (SNR). Subsequently, it oscillated between different states, which were stable over a period of months. Table 3 documents the number of states and their duration. The root cause of this degradation was not established, but production of science data at 25 km resolution was still possible for each state.

	Start Date	End Date	Number of Orbits
High-SNR	2014/10/3	2015/08/15	4341
Low-SNR 1	2015/8/19	2015/09/18	386
High-SNR (2)	2015/09/18	2015/10/06	252
Low-SNR 2	2015/10/07	2016/02/07	1664
Low-SNR 3	2016/02/11	2016/03/29	666
Low-SNR 4	2016/04/01	2016/08/19	1944

Table 3: *SNR Anomaly timeline and number of GOOD or MARGINAL orbits of data in each. Orbits classified as BAD are not included in the number of orbits column. High SNR 2 was a two-week period where the instrument returned to the original SNR state after the first period of Low-SNR; they are only book-kept separately here to illustrate the time-line more clearly.*

3.4 Anomaly effects on science data

The primary effect is an increase in the noise floor of the system by approximately 10 dB. Due to the accurate estimates of signal + noise and noise of the system, we are still able to recover the signal below the noise floor. The quality of wind retrievals below 5/6 m/s is somewhat worse for low-SNR than for high-SNR, however, above that point the wind performance of low-SNR is nearly as good as high-SNR. Of the most significant effects of low-SNR is the inability to use the noise-only observation as a rain detector as was done for QuikSCAT, and High-SNR RapidScat. For high-SNR data we use the noise-only observation as a radiometer (a rather noisy radiometer), in which the signal for rain is much higher than that for ocean. Due to the increase in the noise floor, we effectively have a radiometer with 10 times larger noise-equivalent delta brightness temperature, T_B, and it is impossible to tell the difference between ocean and rain T_Bs without a large amount of averaging to beat down the increased noise in low-SNR data.

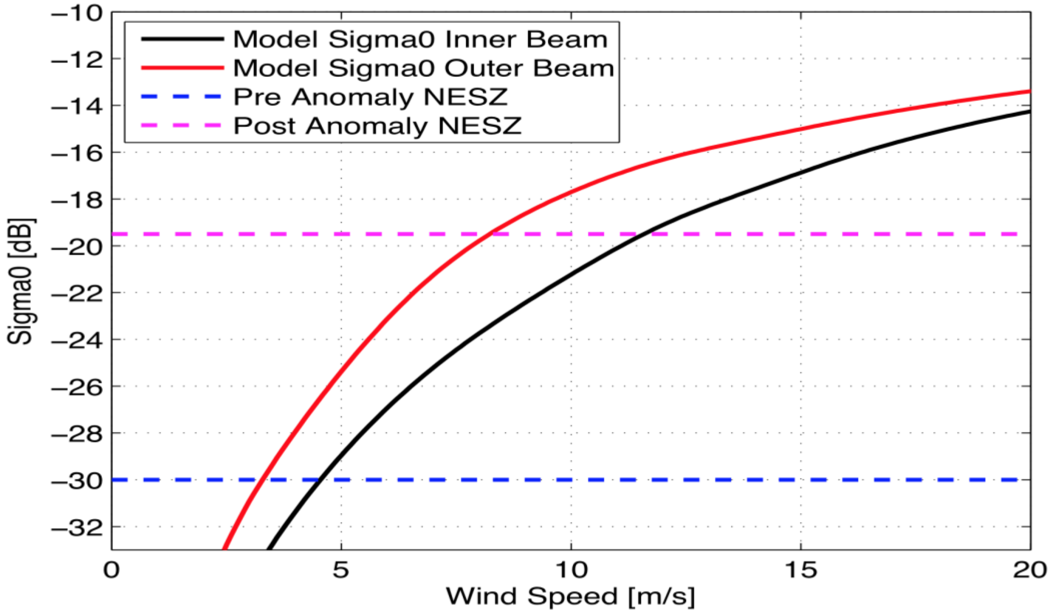

Figure 1: *Plotted here is the NRCS versus wind speed relationship for inner and outer beams as well as the typical noise-equivalent NRCS (NESZ). For high-SNR mode, the NESZ was roughly 3 m/s or so while for low-SNR it is near the signal for 7-10 m/s. Due to the system design, all SeaWinds scatterometers have highly accurate measurements of noise and signal + noise in the RapidScat scatterometer thus we are able to measure signals well below the noise floor of the system.*

In Figure 1, the NRCS (normalized radar cross-section) is plotted as a function of wind speed in black (inner) and red (outer) lines, the pre-anomaly Noise-equivalent NRCS (NESZ) as blue dashed line, and the post anomaly NESZ as a magenta dashed line. Note that after the SNR anomaly, the NESZ is near 7-10 m/s, which means that a large portion of the Ocean has NRCS that is below the noise floor of the system. However, due to the system design of SeaWinds, the noise and signal + noise measurements are very accurate, enabling us to estimate NRCS well below the noise floor. This is not how one typically wants to operate a radar, however, this is exactly how radiometers are able to measure ~100 K signals on top of a system with a system noise temperature of order 1000 K.

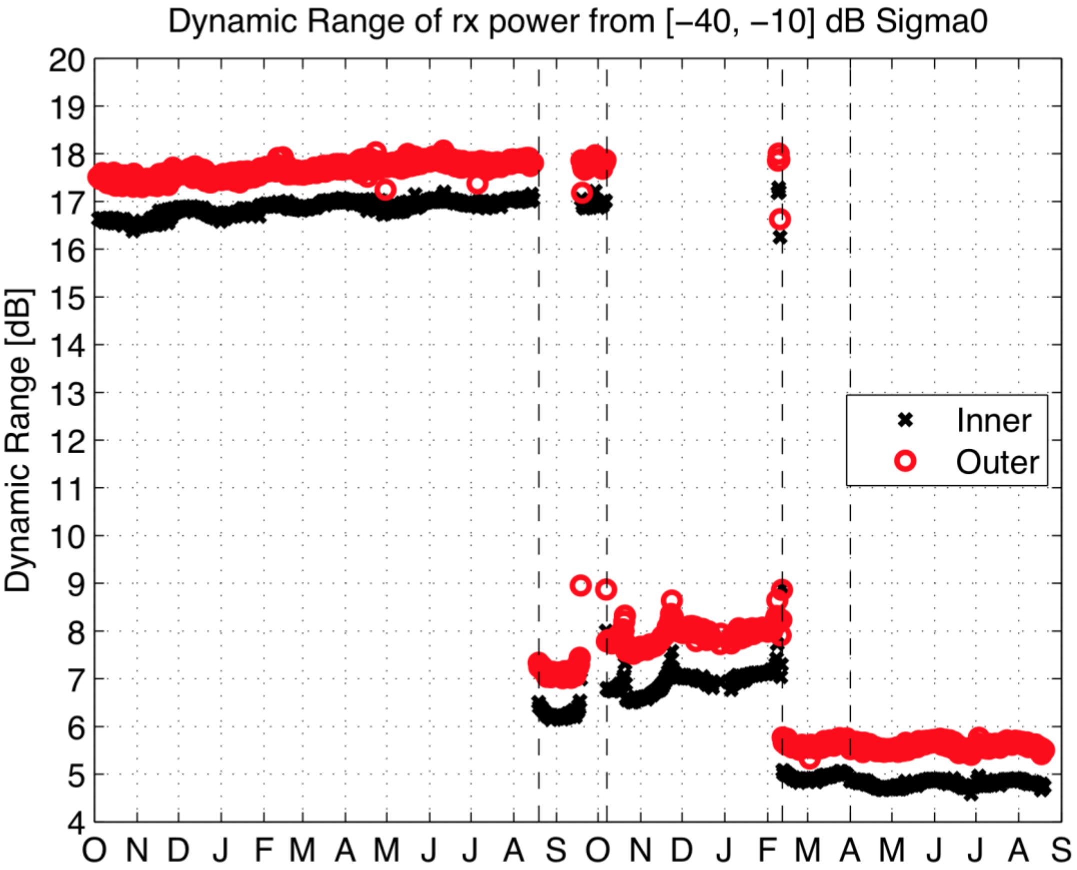

Figure 2: *Plotted here is the dynamic range of the received power, for the interval of -40 to -10 dB of NRCS. The dashed lines are the start of each SNR anomaly (Low-SNR1, 2, 3, and 4). Received power is before noise subtraction, while NRCS is after noise subtraction. This is a measure of how far -10 dB NRCS is above the noise floor (-40 dB is well into the noise floor for High-SNR data). We see that all of the Low-SNR modes have at least 10 dB higher noise floor than High-SNR mode.*

In Figure 2, the dynamic range of the received power is plotted, corresponding to NRCS observations from -40 dB to -10 dB. This gives us a measurement of how far -10 dB NRCS is above the noise floor. Changes in this plot correspond directly to changes in the noise floor of the system. We see that all low-SNR modes have a noise floor that is at least 10 dB larger than the nominal high-SNR mode. The dashed lines represent the start of each low-SNR mode. We note that low-SNR 3 and 4 had higher noise floor than low-SNR 1 and 2, indicating continued degradation of the instrument.

In Figure 3, the wind speed bias is plotted on the left, as a function of the averaged of WindSat and RapidScat wind speeds, for each SNR state. On the right we plot the same for the wind speed root-mean-square (RMS) difference. We note a clear degradation in the low wind speed performance of the Low-SNR states as compared to the High-SNR states. In addition we find that low-SNR 3 and 4 are somewhat worse than low-SNR 1 and 2, in agreement with Figure 2. However, RapidScat still meets the QuikSCAT science requirement of 2 m/s RMS for the majority of wind speeds.

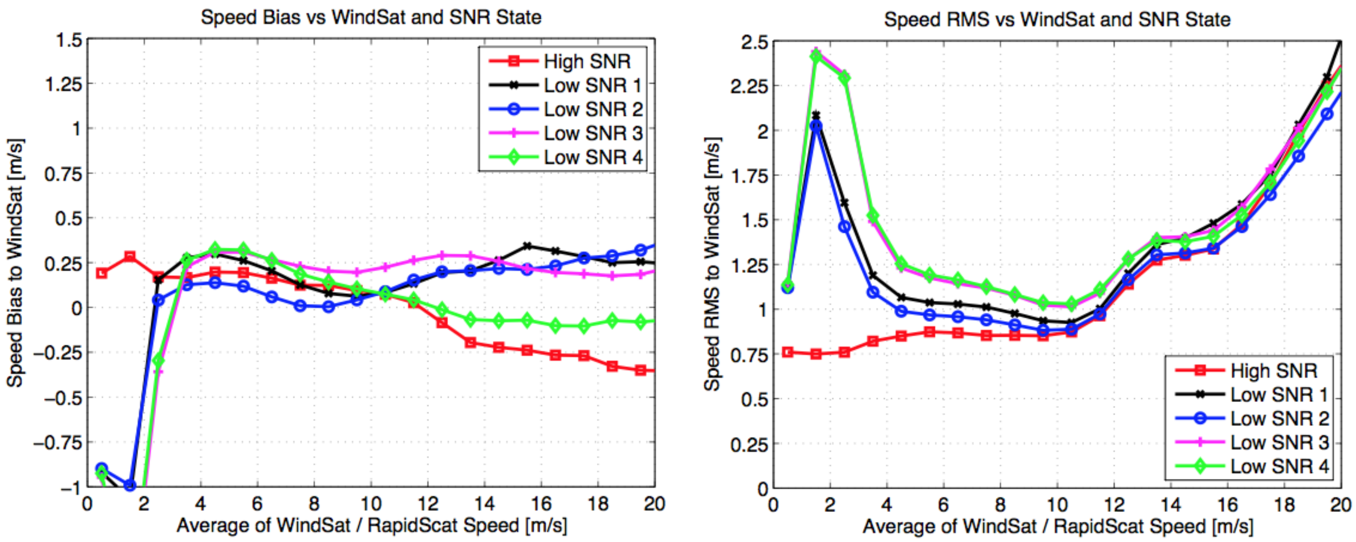

Figure 3: *(left) RapidScat wind speed bias to ECMWF, plotted as a function of the average RapidScat and ECMWF wind speed, versus SNR state; (right) same for wind speed root-mean-square difference. Note that for wind speeds below 4-5 m/s the performance of Low-SNR is significantly worse.*

4. Sensor Overview:

The RapidScat instrument is an active microwave radar designed to measure electromagnetic backscatter from wind-roughened ocean surface. RapidScat uses a rotating dish antenna with two spot beams that conically sweep producing a circular pattern on the Earth's surface. The antenna radiates microwave pulses at a frequency of 13.4 GHz (Ku-band) across broad regions on Earth's surface. The instrument collects data over ocean, land, and ice in a continuous, 1000-kilometer-wide swath centered on the nadir subtrack, making approximately 1.1 million ocean surface wind measurements and covering 90% of Earth's ocean surface (nominally between 56° N and 56° S latitude) every 2 days. Due to occasional variations in the orbit of ISS, RapidScat measurements have been rarely observed more poleward in to the 60° to 61° degree North and South latitude bands. A pencil-beam scatterometer has several key advantages over a fan-beam scatterometer: it has a higher signal-to-noise ratio, is smaller in size, and provides superior coverage.

4.1 Principles of Operation

Spaceborne scatterometers transmit microwave pulses to the ocean surface and measure the backscattered power received at the instrument. Since atmospheric motions themselves do not substantially affect the radiation emitted and received by the radar, scatterometers use an indirect technique to measure wind velocity over the ocean. Wind stress over the ocean generates ripples and small waves, which roughen the sea surface. These waves modify the σ_o of the ocean surface and hence the magnitude of backscattered power. In order to extract wind velocity from these measurements, one must understand the relationship between σ_o and near-surface winds (i.e., the GMF).

The RapidScat scatterometer design, which is also shared by QuikSCAT and SeaWinds on Midori-II (a.k.a. ADEOS-2), is a significant departure from the fan-beam scatterometers flown on previous missions (Seasat SASS and NSCAT) and the current ASCAT. RapidScat employs a single 1-meter parabolic antenna dish with twin-offset feeds for vertical and horizontal polarization. The antenna spins at a rate of 18 rpm, scanning two pencil-beam footprint paths at nominal incidence angles of 49° (H-pol, inner beam) and 56° (V-pol, outer beam). The transmitted radar pulse is modulated, or “chirped”, and the received pulse (after Doppler compensation) is passed through an FFT stage to provide sub-footprint range resolution. The range resolution may be commanded between 2 km and 10 km, with the nominal value set at about 6 km. The nominal pulse repetition frequency is 166.37 Hz. Each telemetry frame contains data for 100 pulses. Signal and noise measurements are returned in the telemetry for each of the 12 sub-footprint “slices.” Ground processing locates the pulse “egg” and “slice” centroids on the Earth’s surface. The σ_o value is then computed for both the “egg” and the best 8 of the 12 “slices” (based on location within the antenna gain pattern).

RapidScat generates an internal calibration pulse and associated load pulse every scan of the antenna. In ground processing, the load pulses are averaged over a 20-minute window, and the calibration pulses over a 10-pulse (approximately 18-second) window, to provide current instrument gain calibration needed to convert telemetry data numbers into power measurements for the σ_o calculation.

5. Processing Methodology:

Instrument power measurements are calibrated and converted to normalized radar cross section (σ_o) to produce the time-ordered Level 1B (L1B) product. The σ_o measurements are then grouped into an along-track, cross-track grid of “wind vector cells” (WVC) for wind retrieval, which is known hereafter as Level 2A (L2A). A WVC typically contains several measurements looking both forward and backward from both the inner and outer beams. Slice measurements are grouped into both 25 km and 12.5 km WVC resolution. The tradeoff is between resolution and noise. Data products indicate the resolution. The data described here are L2B 12.5 km WVC resolution netCDF data files. The L1B and L2A data products remain in their native HDF-4 format.

Wind retrieval processing is performed in three steps. First, a point-wise maximum likelihood estimate of wind speed and wind direction is computed resulting in multiple ambiguous solutions (typically two to four). Next, a median filter is used to select the best ambiguity. Third, Directional Interval Retrieval (DIR) (Stiles et al. 2002) processing is performed, which uses the directional spread of the objective function and allows the retrieved wind direction to vary within a region of high likelihood about the selected ambiguity. Finally, wind speed measurements are corrected empirically for rain contamination and for biases as a function of cross track distance due to variable instrument geometry. The correction due to rain contamination are made using neural network techniques described in (Stiles and Dunbar, 2010, and Stiles et al, 2014). These corrections can be several meters/second for especially rainy conditions. The size of the correction is recorded in the data set and can be used as a quality estimate as larger corrections imply larger residual errors. The cross track bias correction is small (a few tenths of a m/s except in rainy conditions) and is used to remove systematic biases that could effect climatological studies. The value of this correction is also reported in the data files.

The RapidScat Climate Version 2 L2B (https://doi.org/10.5067/RSX12-L2C20, hereafter RSCAT Climate V2) dataset, representing the second iteration of the climate-quality RapidScat L2B datasets, has two important improvements over the previous version (https://doi.org/10.5067/RSX12-L2C11). First, an SST-dependent GMF developed by Lucrezia Ricciardulli of Remote Sensing Systems is used in wind retrieval in order to fix persistent speed biases in Ku-band data over cold ocean. Second, flagging is simplified and extra flags are provided. All the previously existing flags are still there and still mean the same thing. A new single bit 'wind_retrieval_likely_corrupted_flag' specifies the approximately 3% of the data which is known to have suboptimal performance due to rain, ice, or a few other rare anomalous cases. Another bit 'wind_retrieval_possibly_corrupted_flag' specifies the approximately 15% of the data near rain, near ice, or near the coast, that is thought to be high quality but may not match up well with numerical wind models due to either remaining rain/ice/land contamination or variability in the winds near ice, rain, and coasts that are not reflected in the NWPs. In addition to these two new bits, copious quality information is provided in the data to allow users to tailor flags to meet their own needs.

More details of the Version 3 processing methodology are found in Fore et al. (2013). The details regarding the processing lifecycle from telemetry to L2B may be found in the "QuikSCAT Science Data Product User's Manual" (Version 4.0, 2018).

RapidScat Version 2.0 (climate quality) data is processed similarly to QuikSCAT Version 4, while RapidScat Version 1.0 (climate quality) shares more commonality with QuikSCAT Version 3.1. All L2B datasets (including RapidScat pre-climate versions 1.1, 1.2, and 1.3; i.e., standard quality) have an additional improvement to the neural network wind speed correction in rain that allows for more accurate corrected speeds in storms and other areas of high wind (>20 m/s). To achieve this performance a hybrid technique incorporates the two speed corrections described in [Stiles and Dunbar, 2010 and Stiles et al, 2014] whenever rain contamination is detected. Both the corrected speeds and the DIRTH speeds without rain correction are included in the data product.

6. Calibration and Validation

The calibration of RapidScat was more challenging than a typical scatterometer due to the various SNR anomalies that occurred during the mission lifetime as well as the attitude environment of the International Space Station. Due to the unpredictable attitude and errors in recovery of the exact attitude, slice composite processing did not prove as reliable for RapidScat as it is for other scatterometers with more stable platforms. Thus we decided to release a footprint based data product as the final version of the RapidScat Ocean Vector Wind product. In addition, each SNR period (High SNR, and Low-SNR 1-4) had to be calibrated separately.

6.1 Cross-calibration with QuikSCAT

Under the direction of NASA's Senior Review Process, JPL operated the QuikSCAT instrument in its reduced capability (non-spinning) mode since 2010 to maintain the nearly 20-year calibration standard for Ku-band scatterometers. In Figure 4 we plot the QuikSCAT $\boldsymbol{\gamma}_0 := \boldsymbol{\sigma}_0/\cos(\boldsymbol{\Theta}_{inc})$, where $\boldsymbol{\Theta}_{inc}$ is the incidence angle and $\boldsymbol{\sigma}_0$ is the normalized radar cross-section (NRCS) over the entire non-spinning period, from 2010 until present. There is a small decreasing trend in the backscatter over the Amazon, which we estimate as no larger than 0.03 dB/year. We see that QuikSCAT has been extremely stable and can form a basis for the intercalibration of Ku-band scatterometers.

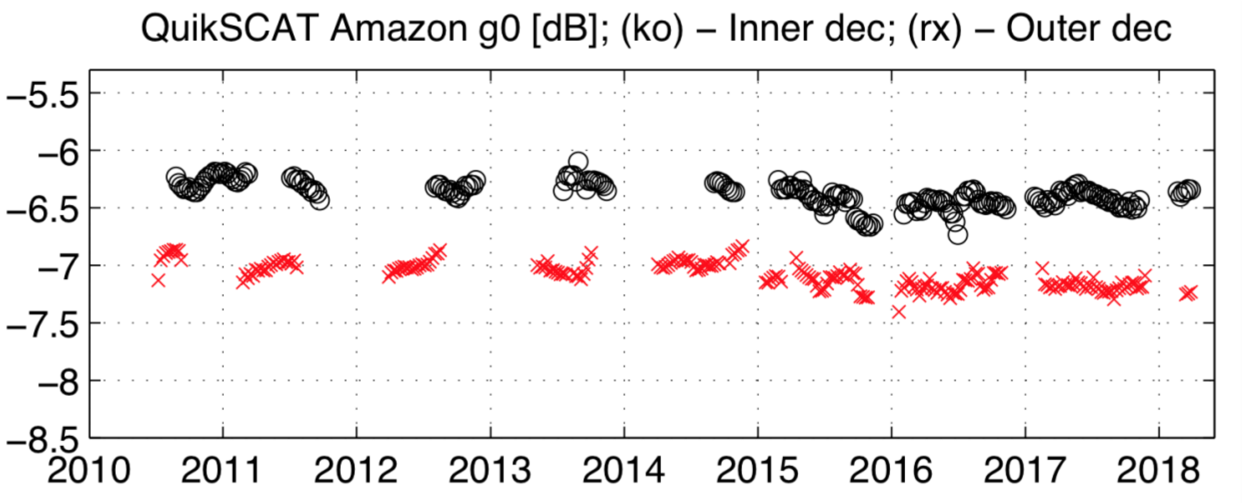

Figure 4: QuikSCAT γ_0 over the Amazon rain forest, plotted as a function of time. Only descending data is used, as there is less seasonal variation at the descending node time of QuikSCAT than at the ascending node time. We see possible evidence of about a long term drift in QuikSCAT that is not larger than 0.03 dB/year.

JPL adjusted the attitude of the QuikSCAT spacecraft to attain the same local incidence angles as for RapidScat, however, we could only match one beam at a time due to the QuikSCAT configuration. Every two weeks we switch operation of QuikSCAT between the modes corresponding to the inner/outer beam polarization and incidence angles of

RapidScat. We operated QuikSCAT in this mode from April, 2014, until August, 2016, with the exception of eclipse season, which spans from mid-November to the end of January.

To cross-calibrate RapidScat to QuikSCAT, we used two main methods: an ocean-based analysis; and an Amazon rainforest based analysis. Using the ocean as a reference surface along with an ancillary wind model, we apply the techniques developed in (Jaruwatanadilok et al. 2014) to determine the calibration of RapidScat relative to QuikSCAT. For the Amazon analysis, we compute the γ_0 for QuikSCAT and for RapidScat. We correct for the differing local times of day for each instrument using a climatology of Amazon γ_0 developed using only RapidScat high-SNR. For both methods, we determine one calibration offset from each two week period of QuikSCAT, and accumulate data as we alternate the operation of QuikSCAT between the two RapidScat modes.

In Table 4 we show the various calibration adjustments derived using both the Amazon and Ocean-based calibration analyses. In addition, we show the difference between the two calibrations and the adjustment that was used in the final version 2.0 RapidScat, which was the average of the two estimates from each method. Note that the numbers in this table are relative to the version 1.0 climate data product's calibration.

In Figure 5 we plot the Amazon $\boldsymbol{\gamma}_0$ for QuikSCAT as black squares, and for RapidScat as red markers for each SNR period. On the left is HH and the right is VV. This analysis was used to generate the Amazon numbers in Table 4.1.

	Ocean	*Amazon*	*Difference*	*Used in Processing*
High SNR HH	0.017	0.024	0.007	0.000
High SNR VV	-0.064	0.152	0.216	0.000
Low-SNR 1 HH	-0.028	-0.056	-0.028	-0.042
Low-SNR 1 VV	0.068	0.263	0.195	0.166
Low-SNR 2 HH	0.253	0.066	-0.187	0.159
Low-SNR 2 VV	0.284	0.172	-0.112	0.228
Low-SNR 3 HH	0.038	0.045	0.007	0.042
Low-SNR 3 VV	0.333	0.253	-0.80	0.293
Low-SNR 4 HH	0.015	0.055	0.040	0.035
Low-SNR 4 VV	0.269	0.227	-0.042	0.248

Table 4: Table of calibration adjustments determined using Amazon cross-comparison to QuikSCAT, Ocean cross-comparison to QuikSCAT, the difference between the two, and the adjustments used in the climate v2.0 data processing. Note that these adjustments are relative to the previous calibration in the version 1 data products.

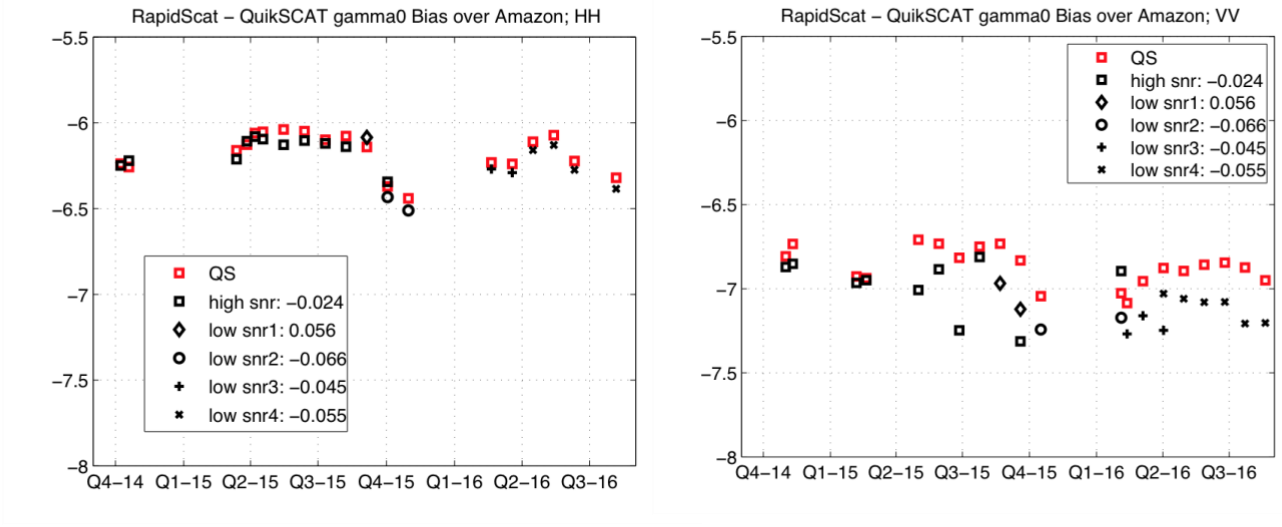

Figure 5: (left) RapidScat and QuikSCAT Amazon γ_0 for inner beam and all SNR periods. In the legend are the RapidScat biases as compared to QuikSCAT for each SNR period; (right) same for outer beam.

6.2 RapidScat Performance

In this section, we discuss the accuracy of the ocean surface wind vectors obtained from the RapidScat instrument. For the most part, the accuracy of RapidScat winds was consistent with that of QuikSCAT, its predecessor. The exceptions to this rule were due to a hardware anomaly that led to decreased SNR for the latter half of the RapidScat mission. The first RapidScat ocean surface wind data was obtained on Oct 3, 2014. RapidScat operated nominally until Aug 14, 2015 at which point a hardware anomaly led to a reduction of signal to noise ratio (SNR) by a factor of 10. With the exception of brief periods of restored high-SNR data after that time, the remainder of the mission was in the anomalous low-SNR mode until the instrument ceased operating on Aug 19, 2016. The absolute calibration of RapidScat was maintained for both High- and Low-SNR mode data by comparison to the non-spinning QuikSCAT backscatter values. The primary effect of the low-SNR anomaly on wind performance was to reduce direction accuracy of winds below 6 m/s.

The final version (2.0) of the RapidScat ocean wind vector product (as well as all previous processing versions) is archived and publicly available at NASA's PO.DAAC. The data has been corrected for rain contamination using methods described in (Stiles et al. 2014) and (Stiles and Dunbar 2010). Wind retrievals also make use of external sea surface temperature (SST) information. Comparisons between coincident RapidScat and ASCAT measurements led us to conclude that Ku-band backscatter has a slight variation due to SST (Wang et al. 2016). We now include SST in the Ku-band geophysical model function (GMF) in order to insure consistency among RapidScat (Ku-band) wind vectors and ASCAT (C-band) wind vectors that are less sensitive to SST and microwave radiometer wind speeds that are already corrected for SST effects (Ricciardulli et al., 2018). Figures

9-12 show the improvement in RapidScat performance that resulted from incorporating SST into the GMF. The RapidScat data are posted on a 12.5-km resolution grid. Two quality bits are set for data that are likely contaminated by rain, land, sea-ice, or other rare issues, or possibly so contaminated. Figure 6 shows the wind direction and speed accuracy (root mean squared and biases) with respect to the European Center for Medium-range Weather Forecasting (ECMWF) now-cast numerical wind product. Metrics are plotted as a function of cross track position in the observed 900-km wide swath. Three different curves are plotted for 1) all RapidSCAT High SNR mode data, 2) the 97% of the data for which contamination was deemed to be not likely, and 3) the 87% of the data for which contamination was deemed not possible. (Highly unlikely would have perhaps been a better term as actual impossibility is a difficult standard to meet.) Figure 7 depicts the same metrics for the Low-SNR data set. The precise definitions of the "likely" and "possibly" corrupted bits are listed below. They differ slightly for low and High-SNR mode. The Low-SNR rain flag has more spurious false detections because no accurate RapidScat brightness temperature measurement is available. It was therefore not feasible to exclude a Low-SNR mode wind vector cell as possibly corrupted when a single cell within its 50-km was flagged as rainy.

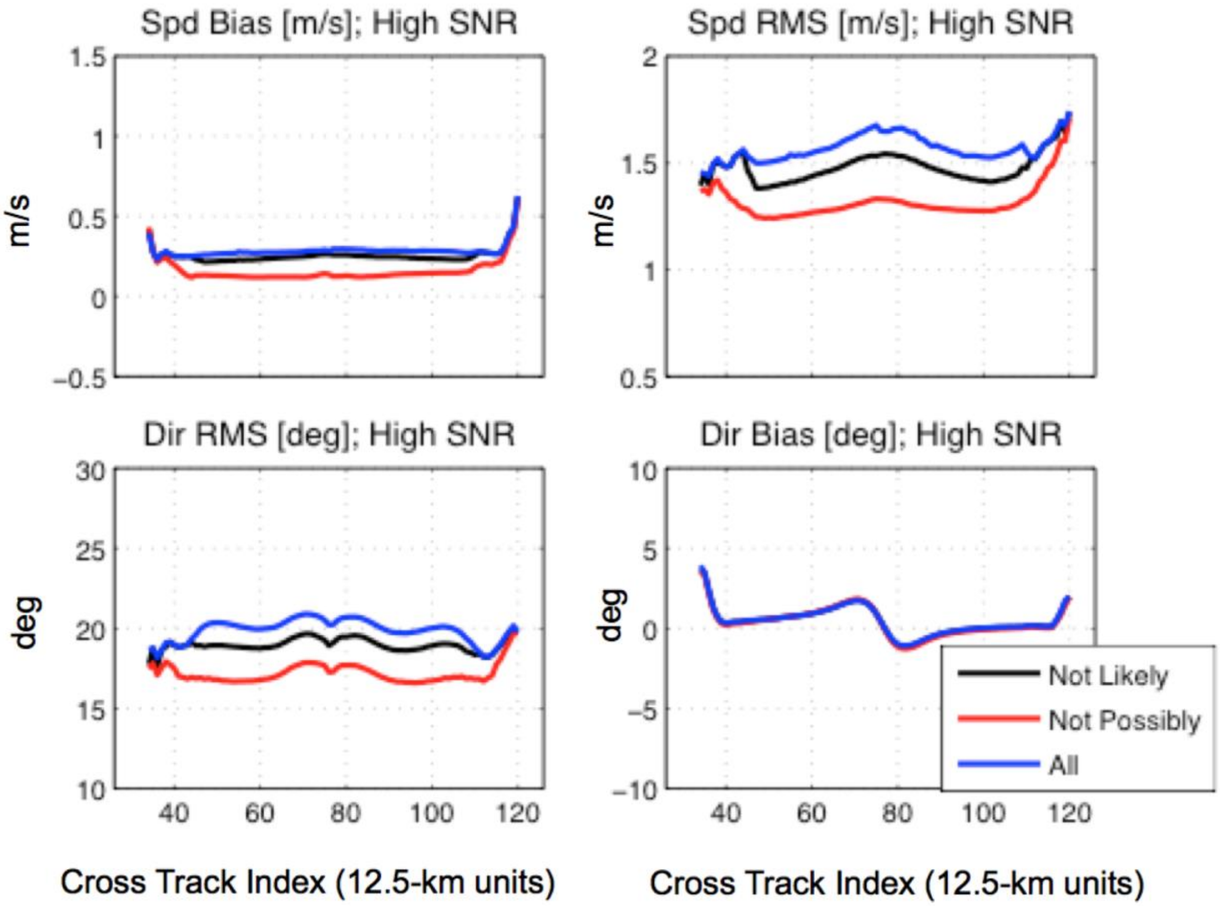

Figure 6: RapidScat High-SNR Mode Wind Performance with respect to ECMWF.

“Likely Corrupted” means at least one of the following is true:

- Autonomous Rain Flag (IMUDH) indicates rain contamination.
- Speed corrected by more than 2 m/s.
- Sea ice found in Wind Vector Cell.
- Scatterometer rain flag unavailable and external microwave radiometer indicates rain within 90 minutes.
- Wind was not retrieved or had invalid value.
- “Possibly corrupted” means at least one of these is true.
- Likely Corrupted Bit set.
- Rain flag set for at least one cell within 50-km (High-SNR), Rain flag set for at least 3 of the 49 cells within 50-km (Low-SNR).
- Sea-ice flag set within 50-km.
- Speed was corrected for rain by more than 0.1 m/s.

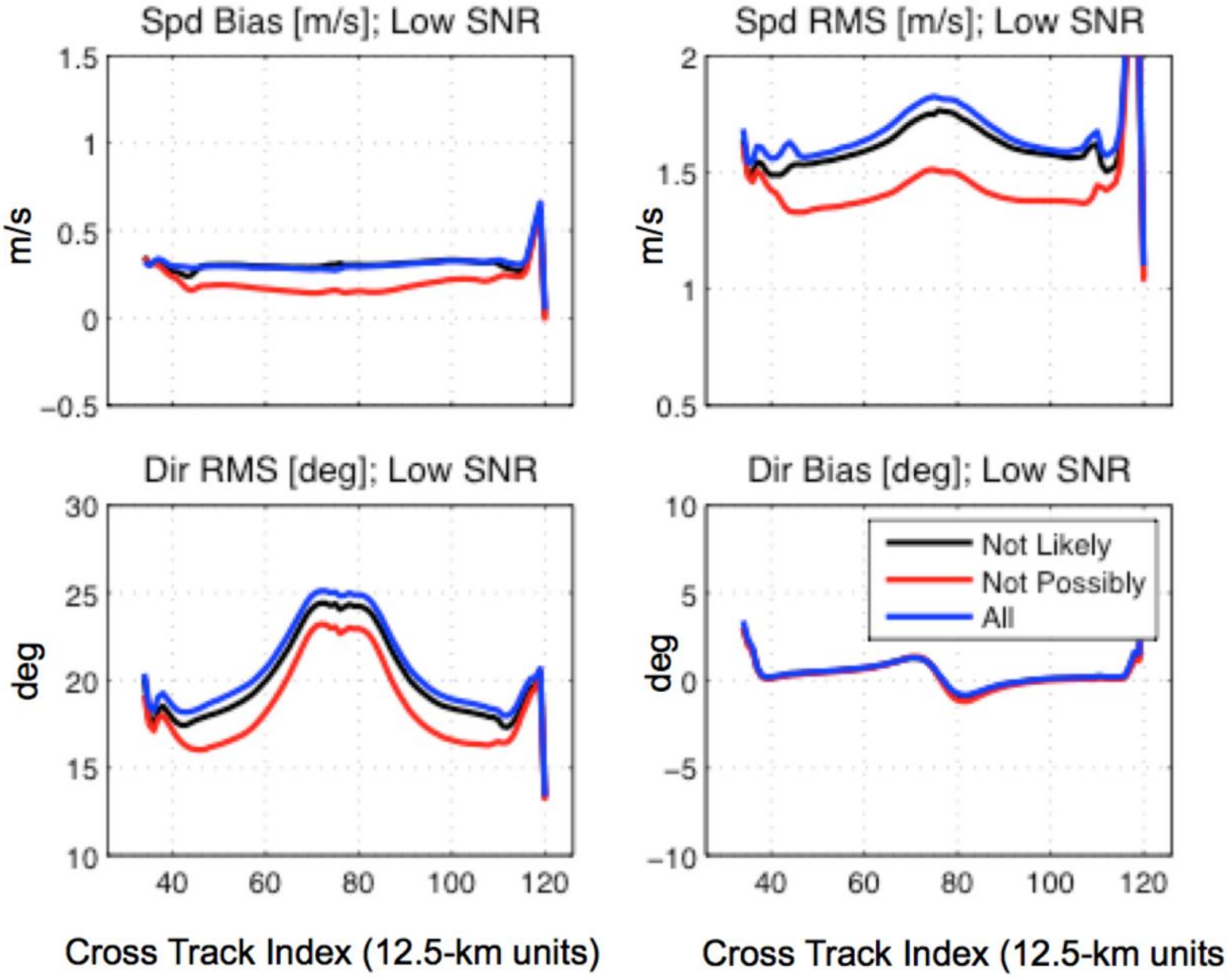

Figure 7: RapidScat Low-SNR Mode Wind Performance with respect to ECMWF.

RapidScat data is 0.2 to 0.3 m/s higher than ECMWF overall. This bias is intentional and reflects the fact that RapidScat was calibrated to agree with speeds from buoys, microwave radiometers, and other scatterometers rather than ECMWF. We show metrics vs. ECMWF here because unlike other comparisons we always have a ECMWF wind vector wherever a RapidScat wind vector is available. The strictest quality controlled data set (possible bit not set) has the smallest bias compared to ECMWF. This reflects the fact that ECMWF and RapidScat differ most in regions in and near rain. The RMS speed difference is well below the 2 m/s QuikSCAT wind speed accuracy requirement. Once again, the smaller difference for stricter quality control indicates that regions in and near rain have the largest differences. These differences can occur due to residual rain contamination after the speed correction algorithms are applied, it can reflect increased wind variability in such regions, and it can also reflect that ECMWF wind fields themselves are poorer near storms. Directional biases are small (less than 5 degrees). Directional RMS differences are below the 20 degree QuikSCAT wind direction requirement for both the lenient and strict quality controlled data sets. The difference gets slightly larger than 20 degrees in the middle of swath when no quality control is applied at all. It is worth noting that the QuikSCAT requirements excluded rain contaminated data.

The low-SNR mode RapidScat performance as shown in Figure 7 is the same as the High-SNR mode performance with two exceptions. First, the directional RMS in the middle of the swath goes up to 25 degrees RMS, five degrees worse than the High-SNR directional RMS. This is due almost entirely to poorer directional accuracy for wind speeds less than 6 m/s. Secondly there is a large spike in speed RMS at the right edge of swath. The spike is due to poor sampling. Wind vectors are almost never retrieved at these cross track locations. They were only seen for the rare instances when the International Space Station had the most extreme spacecraft attitudes for which wind retrieval was still possible. For this reason a single large disagreement between ECMWF and RapidScat due to storm or front misplacement in ECMWF or ambiguity removal error or undetected rain contamination in RapidScat can dominate the error values at these cross track locations.

Figure 3 and 8 shows how wind speed (3) and wind directional (8) accuracy varies with wind speed for Low- and High-SNR. These figures include multiple plots for each different interval in which Low-SNR mode occurred. These intervals were separated by High-SNR intervals that lasted at most weeks but most commonly a day or so. (See Figure 4.2 of the calibration Section).

Figures 9 and 10, show RMS direction difference from ECMWF for winds from 9-14 m/s as a function of cross track direction and latitude. Solid lines are from the final version (2.0) of the data product. Dashed lines are from an earlier data product in which SST was not used in wind retrieval. For the both the high and Low-SNR mode data, in the Southern Ocean (Blue lines, Latitudes -60 to -40 degrees) Version 2 directional accuracy is significantly better in the center of the swath. The cold water is the Southern Ocean is the place where the new GMF with SST differs most from the old. Furthermore due to poorer azimuth diversity the center of the swath is where GMF errors (or any other errors) have the most pronounced effect of directional accuracy. For Low-SNR Mode, Version 2 also shows substantial improvements at the higher northern latitudes. Because only wind speeds greater than 9 m/s are shown, the worst directional performance for Version 2 is approximately 15 degrees for both Low-SNR and High-SNR modes. The Low-SNR performance degradation noticeable in Figure 7 comes from winds below 6 m/s and thus does not impact the metrics shown in Figure 9-12.

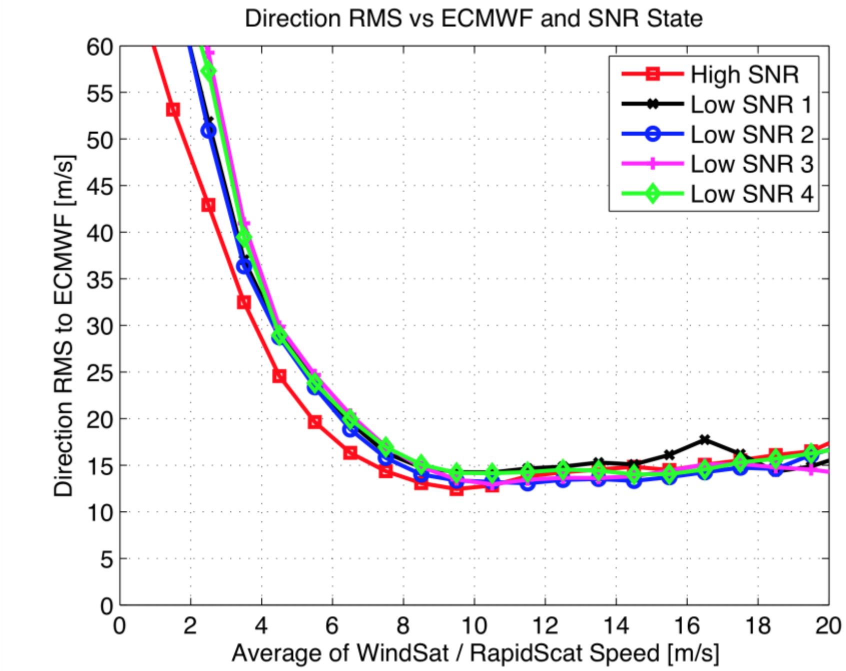

Figure 8: RapidScat Directional Performance for Low and High-SNR mode vs. wind speed.

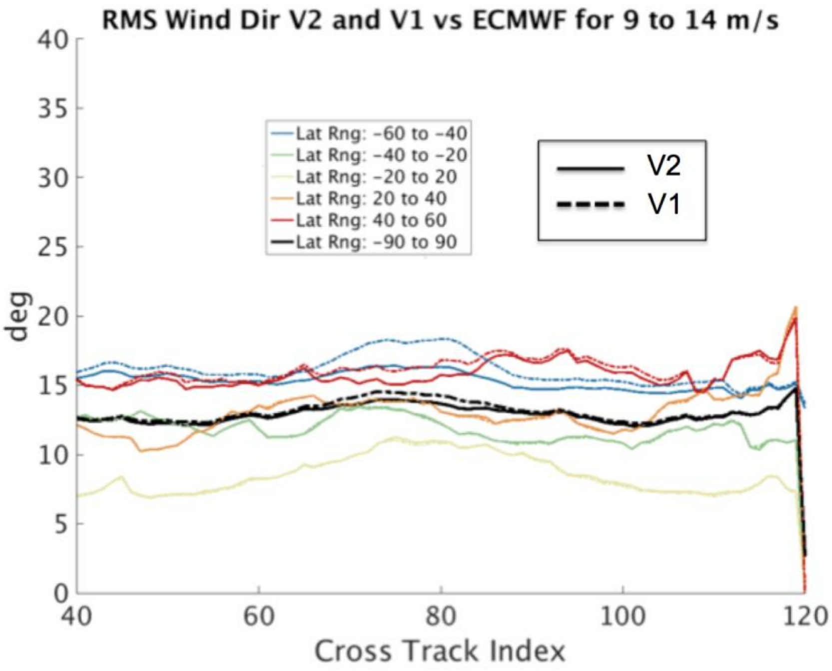

Figure 9: Comparison of Wind Direction performance between latest RapidScat product (Version 2, SST in GMF, solid lines) and previous version (Version 1, no SST in GMF, dashed lines). This figure depicts High-SNR mode data with ECMWF wind speeds between 9 and 14 m/s only. Colors indicate latitude.

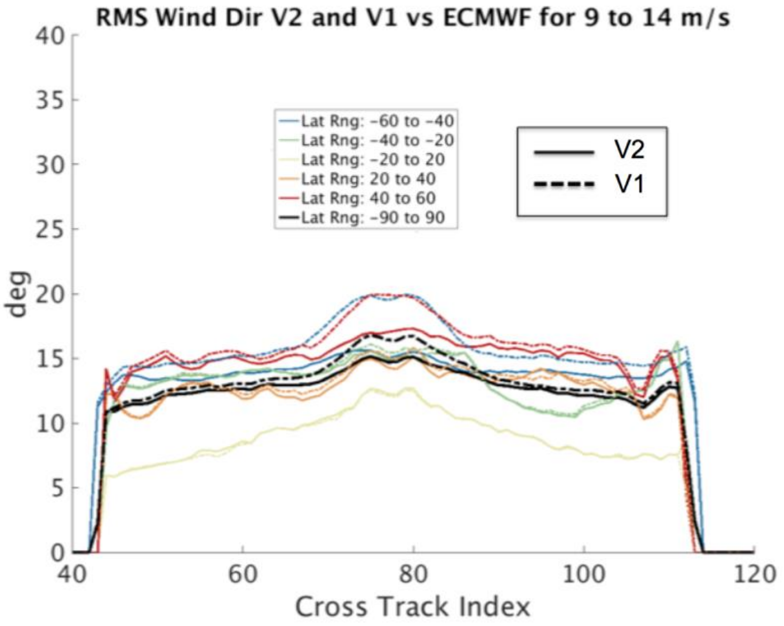

Figure 10: Comparison of Wind Direction performance between latest RapidScat product (Version 2, SST in GMF, solid lines) and previous version (Version 1, no SST in GMF, dashed lines). This figure depicts Low-SNR mode data with ECMWF wind speed between 9 and 14 m/s only. Colors indicate latitude.

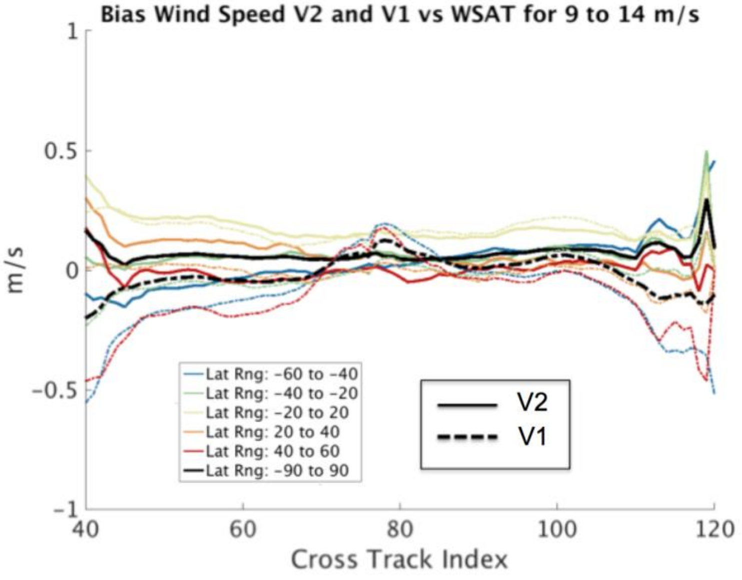

Figure 11: Speed bias between RapidScat and the WindSAT Ocean Wind microwave polarimetric radiometer. Dashed lines are for an older version of the RapidScat data in which SST effects on backscatter were ignored. Solid lines are for the latest version (2.0) in which SST is in the GMF. Colors indicate latitude. Only the High-SNR mode data with ECMWF wind speeds between 9 and 14 m/s is shown in this figure.

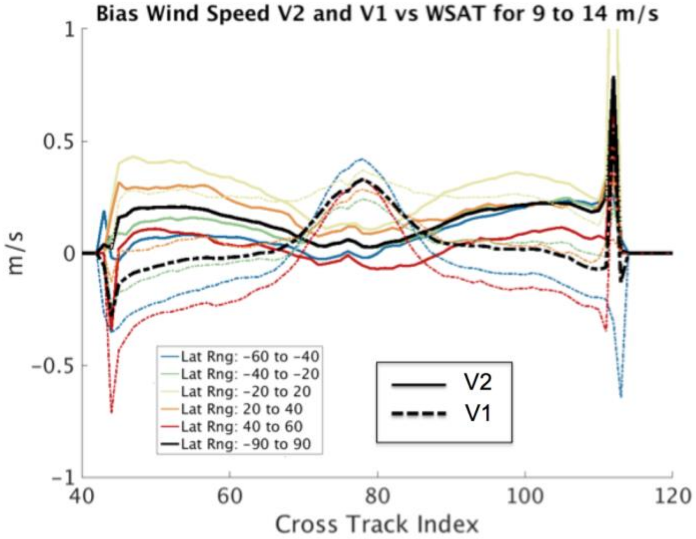

Figure 12: Speed bias between RapidScat and the WindSAT Ocean Wind microwave polarimetric radiometer. Dashed lines are for an older version of the RapidScat data in which SST effects on backscatter were ignored. Solid lines are for the latest version (2.0) in which SST is in the GMF. Colors indicate latitude. Only the Low-SNR mode data is shown in this figure.

The introduction of SST into the geophysical model function flattens out the biases between RapidScat as a function of cross track location. The original processing had a variation of 0.8 m/s peak-to-peak for the high southern and northern latitudes for Low-SNR mode and a variation of 0.6 m/s for those same latitude bands for High-SNR mode. Version 2 processing reduces that variation to 0.2 m/s peak-to-peak.

Unlike QuikSCAT in its operational mission from 1999-2009, RapidScat did not continuously monitor winds. There were interruptions in coverage due to maneuvers performed by its platform, the International Space Station. Table 5 lists the percentages of the time RapidScat acquired data during its mission and breaks down the reasons for the losses in coverage by category. “GOOD” data was recovered in full, processed to winds, and archived. “MARGINAL” data was processed to winds and archived but had significant gaps in the wind field due to spacecraft attitude variation. All other categories are unreported “BAD” data. RapidScat acquired and processed complete wind vector swaths roughly 80% of the time. RapidScat data was not downlinked at all (typically because the instrument was turned off) another 10% of the time. The last ten percent is dominated by suboptimal spacecraft attitude conditions. More than half of this final ten percent of was processed to wind fields with substantial gaps where winds could not be retrieved. In addition to the science data stream, RapidScat also produced 2-hour and 3-hour delay data streams with additional gaps of 20% and 5% respectively in coverage. The near-time data was provided to numerous meteorological agencies all around the world.

Quality	**Category**	**Number of Orbits**	**Percent of Orbits**
GOOD	GOOD	8419	78.9
MARGINAL	Marginal s/c attitude, gaps in data.	856	8.6
BAD	No valid data reached ground	1031	9.7
BAD	Bad s/c attitude	193	1.8
BAD	Orbits used for calibration, and a few other miscellaneous cases.	168	1.6

Table 5: RapidScat data coverage table.

We conclude our discussion of RapidScat performance with the following summarizing points.

- RapidScat operated for 22 months obtaining complete coverage of ocean surface wind vector fields from 57 S to 57 N every 2 days.
- During that time, although it was not in continuous operations due to International Space Station requirements, it acquired 80% of all the data that it would have acquired had it been in continuous operations.
- For the first tenth months of the mission, RapidScat operated nominally and achieved wind vector quality consistent with its QuikSCAT predecessor: Wind direction accuracy better than 20 degrees and wind speed accuracy better than 1.5 m/s.
- For the last year, due to an instrument anomaly, RapidScat SNR was degraded. The only significant degradation in performance was poorer wind direction accuracy for winds less than 6 m/s.

- RapidScat data was used to generate a new Ku-band GMF [4] that includes SST effects on backscatter. RapidScat wind accuracy was improved using the new GMF and it can be applied to future Ku-band missions.

7. Dataset Description:

This data set is being distributed in netCDF version 4 classic (i.e., compatible with netCDF Version 3) format, adhering to CF v1.6 and ISO-8601 conventions. Each file is unique to a particular calendar day of a year and consists of one complete orbital revolution (assuming no data gaps).

7.1 File Naming Convention

The file naming convention is rs_l2b_vN.N_RRRRR_YYYYMMDDhhmm.nc, where:

rs = RapidScat, which is the instrument/platform source of the dataset

l2b = the processing level of the dataset

vN.N = the dataset version identifier of the data file, containing up to 2 numerical digits reserved by ‘N.N’

RRRRR = the 5-digit starting orbital revolution number

YYYY = the 4-digit calendar year of the file creation time

MM = the 2-digit calendar month of year of file creation (e.g., 09 = September)

DD = the 2-digit calendar day of month of file creation

hh = the 2-digit hour of the file creation time

mm = the 2-digit minute of the file creation time

.nc = the file extension indicating the usage of netCDF data formatting

The date and time represented by the file name is with respect to GMT (UTC). To retrieve the actual start and stop times of data observations for each file, as well as the equatorial crossing times, one must refer to the netCDF global attributes.

7.2 Variable Types

Name	Along Track Cells	Cross Track Cells	Data Type	Missing Value	Description

time	3248	N/A	double	N/A	Defines the mean reference time of all WVC measurements along a given WVC row referenced by the number of seconds since 00Z on 1 January 1999.
lat	3248	152	float	N/A	The latitude value at WVC.
lon	3248	152	float	N/A	The longitude value at WVC.
retrieved_wind_speed	3248	152	float	-9999.f	Equivalent neutral wind speed at reference height of 10 m. Corrected using neural network when rain is detected.
retrieved_wind_direction	3248	152	float	-9999.f	Equivalent neutral wind direction at reference height of 10 m.
rain_impact	3248	152	float	-9999.f	Impact of rain upon wind vector retrieval.
flags	3248	152	short	32767s	WVC bit-wise quality flags.
eflags	3248	152	short	32767s	Extended WVC bit-wise quality flags
nudge_wind_speed	3248	152	float	-9999.f	NCEP Model wind speed.
nudge_wind_direction	3248	152	float	-9999.f	NCEP Model wind direction.

retrieved_wind_speed_uncorrected	3248	152	float	-9999.f	Wind speed without rain correction.
cross_track_wind_speed_bias	3248	152	float	-9999.f	Relative wind speed bias with respect to the “sweet spot”. Zeroed out for now. Currently no cross-track speed correction is applied
atmospheric_speed_bias	3248	152	float	-9999.f	Atmospheric wind speed bias. Speed bias removed by rain correction algorithm.
num_ambiguities	3248	152	byte	0b	Number of ambiguous wind directions found in point-wise wind retrieval prior to spatial filtering.
ambiguity_speed	3248	152	4 floats	0	3248 by 152 by 4 array of speeds for each ambiguity in the point-wise wind retrieval step.
ambiguity_direction	3248	152	4 floats	0	3248 by 152 by 4 array of directions for each ambiguity in the point-wise wind retrieval step.
ambiguity_obj	3248	152	4 floats	0	3248 by 152 by 4 array of objective function values for each ambiguity in the point-wise

					wind retrieval step.
number_in_fore	3248	152	short	0	Number of valid measurements from the fore look of the inner HH beam found in a wind vector cell
number_in_aft	3248	152	short	0	Number of valid measurements from the aft look of the inner HH beam found in a wind vector cell
number_out_fore	3248	152	short	0	Number of valid measurements from the fore look of the outer VV beam found in a wind vector cell
number_out_aft	3248	152	short	0	Number of valid measurements from the aft look of the outer VV beam found in a wind vector cell
gmf_sst	3248	152	float	-9999	SST value in degrees C from NCAR Optimum Interpolation Version 2 product used to retrieve wind vector. This is not a RapidScat measurement.
distance_from_coast	3248	152	float	-9999	Distance of wind vector from coast in km. If this value is negative the wvc is over land and no wind vector was retrieved.

Table 6. Dataset Variable Description

7.3 Global Attributes

Attribute Names	Examples
title	Rapidscat Level 2B Ocean Wind Vectors in 12.5km Slice Composites
source	Rapidscat Scatterometer
comment	Rapidscat Level 1B Data Processed to Winds Using QuikSCAT v3 Algorithms
rev_status	GOOD / High SNR
history	2015-106T16:22:49+0000 rscatsa /u/patience-r0/rscatsa/rscat-ops-sds-v0/bin/l2b_to_netcdf --l2bhdf /u/patience-r0/rscatsa/rscat-ops-sds-v0/L2B/12/data/RS_S2B01546.20151000403.CP12 --l1bhdf /u/patience-r0/rscatsa/rscat-ops-sds-v0/L1B/data/RS_S1B01546.20151000359 --nc l2b.nc --l2b l2b_flagged_S3.dat --l2b_ambig l2b.dat\0122015-106T16:22:50+0000 rscatsa /u/patience-r0/rscatsa/rscat-ops-sds-v0/bin/rs_update_nc.py --nc l2b.nc --rdf RS01546.rdf\012
Conventions	CF-1.6
data_format_type	NetCDF Classic
processing_level	L2B
date_created	2015-106T16:22:49
LongName	Rapidscat Level 2B Ocean Wind Vectors in 12.5km Slice Composites
ShortName	RSCAT_LEVEL_2B_OWV_COMP_12_V1
GranulePointer	rs_l2b_v1.1_01546_201504160922.nc
l2b_algorithm_descriptor	Uses NSCAT 2014 GMF developed by Remote Sensing Systems.\012Applies median filter technique for ambiguity removal.\012Ambiguity removal median filter is based on wind vectors over a 7 by 7\012wind vector cell window. Applies no median filter weights. Enhances\012the direction of the selected ambiguity based on the range of\012directions which exceed a specified probability threshold.\012Applies multi-pass median filter technique to reduce the effects of\012rain flagged cells on ambiguity selection.\012Applies Neural Network Rain Correction Version 2 which is applicable to\012high winds.
cross_track_resolution	12.5
along_track_resolution	12.5
zero_index	76
version_id	1.1
NetCDF_version_id	4.3.2 of Jan 14 2015 09:50:47 $
references	null
InstrumentShortName	RapidScat

producer_agency	NASA
institution	JPL
PlatformType	spacecraft
PlatformLongName	International Space Station
PlatformShortName	ISS
project	RapidScat
QAPercentOutOfBoundsData	0
QAPercentMissingData	52
sis_id	686-644-3/2006-09-26
OrbitParametersPointer	RS_SEPHG_01546_20150010032.20150011032
OperationMode	Wind Observation
StartOrbitNumber	1545
StopOrbitNumber	1546
EquatorCrossingLongitude	82.6026001
EquatorCrossingTime	01:00:58.530
EquatorCrossingDate	2015-001
rev_orbit_period	5560.19678
orbit_inclination	51.6595001
rev_orbit_semimajor_axis	6792780.00
rev_orbit_eccentricity	0.000686605810
rev_number	1546
RangeBeginningDate	2015-001
RangeEndingDate	2015-001
RangeBeginningTime	00:37:46.748
RangeEndingTime	02:10:26.945
ephemeris_type	GPS
sigma0_granularity	slice composites
median_filter_method	Wind vector median
sigma0_attenuation_method	Attenuation Map
nudging_method	NWP Weather Map probability threshold nudging.
ParameterName	wind_speed_selection
InputPointer	RS_S2A01546.20151000402.CP12
ancillary_data_descriptors	QS_PC2B0006.CP12\012QS_MC2B0001\012SNWP1201500100\012RS_MODL_NSCAT_2014_EXTENDED\012GLOB0003\012QS_CN2B1130.CP12\012QS_MRCL1130.CP12\012QS_EMOF0001.CP12\012QS_OBTB0001\012LMAP1111\012NCEP_SEAICE_2015001\012RS_MODL_NSCAT_2014-V3proc-extended.dat\012QS_KPRP0002_SimFormat.dat\012kpm_fixed.dat\012ATTN0001\012SNWP1201500100\012liqnet1_June_22_2010.net\012spdnet1_June_22_2010.net\012spdnet2_June_22_2010.net\012rainflagnet_June_22_2010.ne

	t\012rs-ann-hist-match.mat\012rs-ann-stage1.mat\012rs-ann-stage2.mat

Table 7. Dataset Global Attributes Description

7.4 Grid Description

The data is binned in a swath grid pattern at 12.5 km pixel resolution. There are 152 WVCs in the across-track direction and 3248 WVC rows in the along-track direction. The very first WVC row is defined by the beginning of the ascending node with respect to the nadir position of the spacecraft. Full orbital coverage of the earth's circumference requires 3248 rows at 12.5 km pixel resolution (i.e., a single data file with no measurement gaps).

RapidScat's swath footprint extends approximately 500 km on either side of the satellite nadir track, providing a full swath width of 1000 km. However, to maintain consistency with the QuikSCAT L2B data record, the effective swath width represented be the total number of wvc rows extends to 1900km. Thus, each wvc row contains 152 wvc pixels in the cross-track direction. Approximately the first and last 30 wvc pixels are null. As an artifact of the orbital inclination and instrument swath width, consecutive orbits will usually start to overlap poleward of ~47° latitude.

7.5 Related Products

All related data products are referenced here with accessible web links:

a) RapidScat:
http://podaac.jpl.nasa.gov/datasetlist?ids=Collections&values=RAPIDSCAT

b) QuikSCAT:
http://podaac.jpl.nasa.gov/datasetlist?ids=Platform&values=QUIKSCAT

c) SeaWinds on ADEOS-II:
http://podaac.jpl.nasa.gov/datasetlist?ids=Platform&values=ADEOS-II

d) Oceansat-2:
http://podaac.jpl.nasa.gov/datasetlist?ids=Platform&values=Oceansat-2

7.6 Data Quality Flags

The policy adopted within the processing algorithms and software design is to flag values that are out of range or to indicate a non-nominal condition. Except where otherwise noted, a "1" or "set" bit indicates an error or abnormal condition, and a "0" or "cleared" bit indicates a normal condition. Some informational flags may have a number of set bits under normal conditions. Quality flag bits are set at the beginning of processing and are cleared when tests are performed and passed. If abnormal conditions terminate processing early, some bits may remain set. Since the processor may curtail subsequent operations for the wind vector cell that failed the test, those bit flags that normally would be tested in subsequent code also retain their initialized value. Thus, the order in which bit flags are processed determines whether their values are meaningful.

The Wind Vector Cell Preparation algorithm operates on a row of WVC values, passed from the Grouping algorithm, one WVC at a time. This algorithm checks each WVC to determine the data counts (total and by beam), quality flags, and surface flags to determine if there is sufficient data of sufficient quality to perform wind retrieval. It then computes the centroid of the σ_o locations to give a WVC location (latitude/ longitude; the binning grid is essentially "thrown away" at this point), and passes the "good" data to the Wind Retrieval algorithm. Upon return from wind retrieval, the ambiguous wind vector data is placed in the Level 2B output buffer.

The impact-based autonomous IMUDH rain flag algorithm developed for SeaWinds on ADEOS-II using rain impact derived from AMSR is now used for rain-flagging the QuikSCAT and RapidScat wind vector cells in the Level 2B product. A more description of the IMUDH development from SeaWinds and AMSR is provided here: ftp://podaac.jpl.nasa.gov/allData/quikscat/L2B/v2/docs/MUDH_Description_V3.pdf.ds

The transfer of the IMUDH algorithm from SeaWinds to QuikSCAT and finally to RapidScat was expected to involve a transformation and subsequent validation based on expected differences between the IMUDH parameters for the two instruments. This transformation step turned out to be unnecessary; the statistics of the IMUDH parameters for SeaWinds, QuikSCAT, and RapidScat are nearly identical. It was found that the SeaWinds IMUDH algorithm table and spatial filter parameters could be transferred directly, and identically, to QuikSCAT and RapidScat.

The primary improvement of IMUDH over MUDH is in the reduction of the overflagging of high wind speeds and the removal of swath artifacts including overflagging in the outer swath. The overall flagging rate for RapidScat is reduced from 5-6% to 1.92%, nearly identical to that of SeaWinds. This flagging rate was selected by examining various wind quality metrics for flagged and unflagged data with a variety of chosen flagging rates. The dataset containing the externally co-located radiometer rain rate data is available here: https://doi.org/10.5067/RSR12-L2C10.

Quality of wind retrieval is based on the number and the quality of the σ_o measurements within the cell. If the Wind Retrieval Flag (bit 9) is set, then all of wind measurement parameters for the associated wind vector cell contain null values. The significance of each of the bit flags for the "flags" variable is described in Table 6. A Matlab reader for the bit flags is included in the software (*/sw/netcdf/MATLAB/*) directory above the data path.

Variable Name	Bit Number (0=LSB)	Bit Name	Meaning when bit is 1
flags	0	adequate_sigma0_flag	Fewer than 4 sigma-0 values in wind vector

			cell, winds not retrieved
flags	1	adequate_azimuth_diversity_flag	Less than 20 degrees of azimuth diversity, winds not retrieved
flags	2	radiometer_does_not_exist_flag	No external radiometer information was collocated with this wvc.
flags	3	radiometer_rain_flag	External collocated radiometer detects rain
flags	4	undefined	
flags	5	undefined	
flags	6	wind_retrieval_likely_corrupted_flag	Recommended flag, flags 3% of data when either sea_ice, or rain is present.
flags	7	coastal_flag	At least one measurement in wind vector cell within 20 km of land.
flags	8	ice_edge_flag	At least one measurement in cell determined to be sea-ice contaminated
flags	9	winds_not_retrieved_flag	No wind vector retrieved
flags	10	high_wind_speed_flag	Retrieved wind speed greater than 30 m/s
flags	11	low_wind_speed_flag	Retrieved wind speed less than 3 m/s
flags	12	rain_impact_flag_not_usable_flag	Rain impact (IMUDH) flag is not

			computed, presence of rain unknown
flags	13	rain_impact_flag	Rain impact (IMUDH) flag, rain detected in cell
flags	14	missing_look_flag	At least one of the four azimuth looks is unavailable for this cell
flags	15	undefined	
eflags	0	rain_correction_not_applied_flag	Rain correction was not applied, this is typical when no rain is present
eflags	1	correction_produced_negative_spd_flag	Rain correction produced a negative speed
eflags	2	all_ambiguities_contribute_to_nudging_flag	All of the ambiguities in the cell were used during nudging
eflags	3	large_rain_correction_flag	Rain correction to wind speed was larger than 1.0 m/s
eflags	4	coastal_processing_applied_flag	Wind vector cell is close to the coast and coastal processing was performed. Always zero .
eflags	7-5	Radiometer_sat_id_bits	Three bit field that identifies coincident radiometer (e.g WindSAT = 100 (bit7,bit6,bit5))

eflags	8	rain_nearby_flag	Rain detected within 50 km of cell.
eflags	9	ice_nearby_flag	Sea ice detected within 50 km of cell
eflags	10	significant_rain_correction_flag	Rain speed correction was larger than 0.1 m/s
eflags	11	rain_correction_applied_flag	Rain correction was applied, inverse of bit 0.
eflags	12	wind_retrieval_possibly_corrupted_flag	Strict flag, flags 15% of data for which rain or sea ice is nearby or neither rain flag is usable
eflags	13 - 15	undefined	

8. Known Issues and Source of Error:

A grid cell location is defined to be the average centroid of the measurements used to retrieve wind in that cell. Latitude and longitude locations are computed for grid cells in which winds are not retrieved (i.e., null WVCs over land). Locations of WVCs without winds are determined independently of the measurement locations. For this reason, there is commonly a noticeable discontinuity in grid locations near land. The wind_obj dataset is included to provide information useful for data producers, but is not especially informative to users. Users should instead use the ambiguity_obj data set which contains the objective function values for all of the ambiguities.

Due to the multi-operational roles of ISS, disruptions in the data flow and data retrieval for RapidScat occur much more frequently than stand-alone remote sensing platforms. Users depending on the availability of data within the last 14 days are therefore advised to defer to the near-real time updates provided by the following link at NOAA for adequate and timely information regarding any planned or ongoing data outages: http://manati.star.nesdis.noaa.gov/rscat_images/monitor/RapidScat_Scheduled_Outages.txt

Concerned data users should also strongly consider registering to the PO.DAAC email list by contacting podaac@podaac.jpl.nasa.gov to received timely updates regarding any significant data outages or data flow disruptions due to a data quality concern.

9. Data Access:

9.1 Obtaining Data, Documentation and Read Software:

The data, read software, and documentation are freely available for public download via anonymous FTP and OPeNDAP. For immediate access, please visit:

a) FTP: ftp://podaac.jpl.nasa.gov/allData/rapidscat/L2B12/

b) OPeNDAP: http://opendap.jpl.nasa.gov/opendap/allData/rapidscat/L2B12/

Note: the documentation (/doc) and read software (/sw) are located one directory level above the /v3 data directory.

All data granules for L2B prior to Version 2.0 are compressed using the industry standard GNU Zip compression utility. To learn more about the GNU compression utility, please visit the GZIP home page: https://www.gzip.org/. Beginning with L2B Version 4.0, the netCDF files incorporate internal compression that doesn't require any additional software to decompress the data.

MD5 checksum files are also available for all datasets in the data directories to assist you in verifying the integrity of each data file/granule. To learn more about MD5 checksums, you may visit: https://en.wikipedia.org/wiki/MD5.

The PO.DAAC Drive HTTPS service is now available to access all data. To use PO.DAAC Drive, you may visit: https://podaac-tools.jpl.nasa.gov/drive/.

For general news, announcements, and information on this and all other ocean and sea ice datasets available at PO.DAAC, please visit the PO.DAAC web portal: https://podaac.jpl.nasa.gov/.

9.2 Contact Information:

Questions and comments concerning RapidScat Version 2 L2B (as well as all previous processing versions) should be directed to the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA Jet Propulsion Laboratory (JPL). Please note that email is always the preferred method of communication.

E-Mail: podaac@podaac.jpl.nasa.gov
WWW: http://podaac.jpl.nasa.gov/DATA_CATALOG/ccmpinfo.html
Mail: PO.DAAC User Services Office
Jet Propulsion Laboratory
M/S T1721-202
4800 Oak Grove Drive
Pasadena, CA 91109

10. Read Software:

Sample software readers are currently available in IDL, MATLAB, R and Python at:
https://podaac-tools.jpl.nasa.gov/drive/files/allData/quikscat/L2B12/sw

11. Citation:

Citation of this dataset should follow the following formats, which depend on the version of the dataset being used.

11.1 RapidScat L2B Version 1.1 – Citation Template

RapidScat Project. 2015. RapidScat Level 2B Ocean Wind Vectors in 12.5km Slice Composites Version 1.1. Ver. 1.1. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at http://dx.doi.org/10.5067/RSX12-L2B11.

11.2 RapidScat L2B Version 1.2 – Citation Template

RapidScat Project. 2016. RapidScat Level 2B Ocean Wind Vectors in 12.5km Slice Composites Version 1.2. Ver. 1.2. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at http://dx.doi.org/10.5067/RSX12-L2B12.

11.3 RapidScat L2B Version 1.3 – Citation Template

RapidScat Project. 2016. RapidScat Level 2B Ocean Wind Vectors in 12.5km Slice Composites Version 1.3. Ver. 1.3. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at http://dx.doi.org/10.5067/RSX12-L2B13.

11.4 RapidScat L2B Climate Version 1 – Citation Template

RapidScat Project. 2016. RapidScat Level 2B Climate Ocean Wind Vectors in 12.5km Footprints. Ver. 1.0. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at http://dx.doi.org/10.5067/RSX12-L2C11.

11.5 RapidScat L2B Climate Version 2 – Citation Template

RapidScat Project. 2018. RapidScat Level 2B Climate Ocean Wind Vectors in 12.5km Footprints Version 2.0. Ver. 2.0. PO.DAAC, CA, USA. Dataset accessed [YYYY-MM-DD] at http://dx.doi.org/10.5067/RSX12-L2C20.

11.5 General Data Citation Information

For more information on how to cite PO.DAAC data in presentations or publications, please read:
http://podaac.jpl.nasa.gov/CitingPODAAC

12. References:

A majority of the document material was provided by Bryan Stiles and Alex Fore, both through direct co-authorship and oral communication. This document also contains recycled material from previous QuikSCAT user guides. The references below pertain to peer-reviewed publications which formulated the basis for a substantial amount of the material within the *Processing Methodology* and *Calibration and Validation* sections of this guide document. Please be cautioned that this is not a complete list of peer-reviewed references, but merely what is considered at the present time to be the most authoritative and contemporaneous basis of fundamental knowledge pertaining to the creation and validation of the RapidScat L2B data record.

[1] Fore, A.G., B.W. Stiles, A.H. Chau, A.H., B.A. Williams, R.S. Dunbar, and E. Rodríguez, “Point-wise Wind Retrieval and Ambiguity Removal Improvements for the QuikSCAT Climatological Data Set,” Accepted for publication in IEEE Trans. Geoscience and Remote Sensing. doi:10.1109/TGRS.2012.2235843, 2013.

[2] Jaruwatanadilok, S., B.W. Stiles and A.G. Fore, "Cross-Calibration Between QuikSCAT and Oceansat-2," in IEEE Transactions on Geoscience and Remote Sensing, vol. 52, no. 10, pp. 6197-6204, Oct. 2014. doi: 10.1109/TGRS.2013.2295539.

[3] Stiles, B.W., B. Pollard, and R.S. Dunbar, “Direction interval retrieval with thresholded nudging: a method for improving the accuracy of quikscat winds,” Geoscience and Remote Sensing, IEEE Transactions on, vol. 40, no. 1, pp. 79–89, doi:10.1109/36.981351, 2002.

[4] Stiles, B.W., R.E. Danielson, W.L. Poulsen, M.J. Brennan, S. Hristova-Veleva, S. Tsae-Pyng, and A.G. Fore, "Optimized Tropical Cyclone Winds From QuikSCAT: A Neural Network Approach," Geoscience and Remote Sensing, IEEE Transactions on, vol.52, no.11, pp.7418,7434, Nov. 2014 doi: 10.1109/TGRS.2014.2312333.

[5] Stiles, B.W. and R.S. Dunbar, “A Neural Network Technique for Improving the Accuracy of Scatterometer Winds in Rainy Conditions,” IEEE Transactions on Geoscience and Remote Sensing, 2010, Vol 48, No. 8, pp 3114-3122.

[6] Meissner, T. and F.J. Wentz, "Wind-Vector Retrievals Under Rain With Passive Satellite Microwave Radiometers," Geoscience and Remote Sensing, IEEE Transactions on , vol.47, no.9, pp.3065,3083, Sept. 2009 doi: 10.1109/TGRS.2009.2027012.

[7] Wang, Z., A. Stoffelen, F. Fois, A. Verhoef, Z. Chaofang, M. Lin, and G. Chen, "SST Dependence of Ku- and C-Band Backscatter Measurements," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 10, no. 5, pp. 2135-2146, May 2017. doi: 10.1109/JSTARS.2016.2600749.

13. Acronyms:

ADEOS: Advanced Earth Observing Satellite
ASCAT: Advanced Scatterometer (from MetOp series)
CCSDS: Consultative Committee for Space Data Systems
CF: Climate and Forecast (CF) Metadata Convention
DIR: Directional Interval Retrieval
ECMWF: European Centre for Medium-Range Weather Forecasts
ERS: Earth Remote Sensing
EUMETSAT: European Organization for the Exploitation of Meteorological Satellites
FTP: File Transfer Protocol
GMF: Geophysical Model Function
GMT: Greenwich Mean Time (also known as Zulu or UTC time)
H-Pol: Horizontally (HH) Polarized
IDL: Interactive Data Language
ISS: International Space Station
JPL: Jet Propulsion Laboratory
L2B: Level 2B
MD5: Message-Digest Algorithm
MetOp-A/B: Meteorological Operational Satellite series A, B and C
NASA: National Aeronautics and Space Administration
NetCDF: Network Common Data Form
NRCS: Normalized Radar Cross-Section
OPeNDAP: Open-source Project for a Network Data Access Protocol
PO.DAAC: Physical Oceanography Distributed Active Archive Center
QuikSCAT: NASA Quick-recovery Scatterometer
RMS: Root-Mean-Square
SASS: Seasat-A Satellite Scatterometer
SNR: Signal-to-Noise Ratio
SSM/I: Special Sensor Microwave Imager
V-Pol: Vertically (VV) Polarized
WVC: Wind Vector Cell

14. Document History

14.1 Document Draft Date:

29 March 2016

14.2 Latest Document Revision Date:

6 February 2019

14.3 Change Log:

Revision	Date	Change Notes	Authors
1.0	29 March 2016	First release of user guide drafted and finalized.	David F Moroni, Bryan Stiles, Alex Fore. Additional inputs provided by Doug Tyler.
2.0	6 February 2019	Second release of user guide. Updated dataset description, RapidScat performance information and list of references.	David F Moroni, Bryan Stiles, Alex Fore. Additional inputs provided by Alexander Wineteer.

14.4 Document Location:

https://podaac-tools.jpl.nasa.gov/drive/files/allData/rapidscat/L2B12/docs/