The BYU QuikScat/SeaWinds Wind/Rain Product

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Abstract

The SeaWinds scatterometers onboard the QuikSCAT and ADEOS II satellites measure ocean winds on a global scale via the relationship between the normalized radar backscattering cross-section of the ocean and the vector wind. Conventional wind retrieval method ignores scattering and attenuation of ocean rain which alter backscatter measurements and corrupt retrieved winds. Using a simple rain backscatter and attenuation model, a new method for improving wind estimation in the presence of rain has been developed. Based on a wind/rain model function and maximum likelihood estimation, the wind and rain are simultaneously estimated. The new retrieval technique has been validated via simulation and with NCEP and TRMM PR data. The simultaneous wind/rain estimation method is most accurate in the "sweet spot" of SeaWinds' swath and not usable on the outer-beam edges of the swath. This document briefly describes the new wind/rain product developed and produced at the Brigham Young University (BYU) Microwave Earth Remote Sensing (MERS) Laboratory from SeaWinds data.

1 BYU Simultaneous Wind/Rain Retrieval Product User Notes

The QuikScat/Seawinds scatterometer (Qscat) provides measurements of the near-surface ocean wind field with unprecedented coverage and resolution. Qscat makes dual polarization measurements of the normalized radar cross section (σ^o) at both vertical and horizontal polarization using a conically scanning pencil-beam antenna. With the aid of a geophysical model function relating radar backscatter and wind, these measurements are used to estimate or retrieve the near-surface wind over the ocean. SeaWinds data has been found to be highly accurate in non-raining, moderate wind speed areas [1, 2]. However, the quality of SeaWinds retrieved winds is degraded by rain contamination, especially in storm regions [10, 1]. Globally, rain is estimated to affect between 4% and 10% of SeaWinds data. Although some rain flagging techniques have been developed [6, 9], the current wind retrieval method does not incorporate rain effects. As a result, rain attenuation and backscatter are interpreted as wind-induced features [16]. Rain corrupts the wind retrieval process by altering the wind-induced radar backscatter signature.

The Brigham Young University (BYU) Microwave Earth Remote Sensing (MERS) Laboratory has developed a standard set of Qscat land/ice image products for distribution. This report describes these products. Both conventional and enhanced resolution products are included in the product suite. The following sections provide additional specific details regarding the generation and application of the BYU L2R product.

2 Data Set Overview

2.1 Data Set Identification

Brigham Young University (BYU) SeaWinds Level 2A/2B-Derived Simultaneous Wind/Rain Retrieval Product

2.2 Data Introduction

Each file contains one rev of wind and rain data grouped by rows of wind vector cells aligned with the along-track and cross-track axes of the spacecraft measurement swath. Level 2B wind vector cells are 25 km squares. Each wind vector cell row corresponds to a single cross- track cut of the SeaWinds measurement swath. Full coverage of the earth's circumference requires 1624 wind vector cell rows.

2.3 Ojective/Purpose

Like the SeaWinds Level 2B product, this data set provides wind and rain estimates for use in research such as global climatic change and air-sea interaction.

2.4 Summary of Parameters

The following key parameters are contained in the L2R product:

1. Wind speed and direction ambiguities from BYU simultaneous wind/rain retrieval
2. Rain rate estimates associated with wind ambiguities
3. Maximum likelihood values from BYU simultaneous wind/rain retrieval
4. Various ambiguity selection flags
5. Wind speed and direction ambiguities from conventional JPL L2B data file
6. A wvc data quality flag
7. A flag containing an estimate of which wind/rain regime each wvc falls into
8. A rain estimate confidence flag.

2.5 Discussion

Each SeaWinds Level 2B-Derived L2R Wind/Rain data file contains one 'rev' or less of SeaWinds data. A complete rev includes all of the data that pertains to one full orbital revolution of the spacecraft. By convention, all SeaWinds revolutions begin and end at the southernmost orbital latitude.

The SeaWinds Level 2B Processor generates a grid of wind vector cells (WVC) in alignment with the along-track and cross-track axes of the spacecraft measurement swath. Each WVC is a 25 km square. Every data element in the L2R product referenced by the wind vector cell's cross-track and along-track indices. The SeaWinds instrument's measurement swath extends 900 km on either side of the satellite nadir track. Thus, each WVC row must contain at least 72 WVC values. To accommodate occasional measurements that lie outside the 900 km swath, the Level 2B data design includes two additional WVC values at each end of each row. Each Level 2B WVC row therefore contains a total 76 WVCs.

HDF Scientifical Data Sets (SDS) objects store every data element in the BYU Level 2R product. The SDS elements are organized similarly to the JPL Level 2B data files.

2.5.1 Related Data Sets

The following related data sets are available at the JPL PO.DAAC:

1. SeaWinds on QuikSCAT Level 2A Ocean Wind Vectors in 25 Km Swath Grid (JPL) JPL PO.DAAC Product xxx

2. SeaWinds on QuikSCAT Level 2B Ocean Wind Vectors in 25 Km Swath Grid (JPL) JPL PO.DAAC Product 108

3. SeaWinds on ADEOS-2 Level 2A Ocean Wind Vectors in 25 Km Swath Grid (JPL) JPL PO.DAAC Product xxx

4. SeaWinds on ADEOS-2 Level 2B Ocean Wind Vectors in 25 Km Swath Grid (JPL) JPL PO.DAAC Product xxx

3 Investigator:

The SeaWinds Project is a mission of the NASA Jet Propulsion Laboratory (JPL). Further information on the SeaWinds Project is available on-line at `http://winds.jpl.nasa.gov`.

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4 Theory of Measurements

"Spaceborne scatterometers transmit microwave pulses to the ocean surface and measure the backscattered power received at the instrument. Since the 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 radar cross-section (sigma-0) 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 sigma-0 and near-surface winds. This relationship is known as the geophysical model function." [11]

However, the quality of SeaWinds retrieved winds is degraded by rain contamination, especially in storm regions. Globally, rain is estimated to affect between 4% and 10% of SeaWinds data.

Rain corrupts the wind retrieval process by altering the wind-induced radar backscatter signature. Thus, rain attenuation and backscatter may be interpreted as wind-induced features.

By synergistically combining TRMM PR and SeaWinds data, Long and Draper [2] demonstrated that a simple low-order model is adequate for describing the wind/rain interaction as a function of rain rate and non-raining effective wind $\sigma°$. Their analysis suggests that the surface perturbation due to rain striking the water dominates the total scattering from rain for low to moderate rain rates ($<$ 10 km mm/hr). Since backscatter from rain-induced waves significantly contribute to the total backscatter, surface effects must be included in the wind/rain model.

In the wind/rain model, there are three distinct regimes. In the first regime, the rain dominates. It may be possible to directly calculate the rain rate from data in this regime. In the second regime, the signal from the rain and the wind are on the same order. Data from the second regime may be used to simultaneously retrieve wind and rain. In the third regime, the signal from the wind dominates and current wind retrieval techniques are adequate. These regimes help us understand where rain has minimimal impact on wind estimates, where rain can be retrieved and where rain-contaminated wind can be corrected.

The degradation of SeaWinds scatterometer accuracy during rain prompted development of a probability-based rain flag given several rain-sensitive parameters, known as the Multi-dimensional Histogram (MUDH) rain flag [6]. Besides the MUDH flag, a variety of other rain flags for SeaWinds have been suggested, e.g. [7, 8, 9, 10], but no formal attempt has been made to correct rain-corrupted wind vectors.

A simultaneous wind/rain retrieval algorithm has been developed [3] and validated [4] by Draper and Long. SeaWinds simultaneous wind/rain retrieval has been shown by simulation to give the best results in the swath sweet spot, and perform with reduced accuracy on the swath edges (the outer 9 WVCs on either side of the swath) [4]. Simulation has demonstrated that wind speeds from simultaneous wind/rain retrieval are nearly unbiased, while the wind-only retrieval produces increasingly biased estimates as rain increases. However, in zero-rain conditions, the inclusion of the rain rate parameter into the retrieval process can give rise to spurious rain rate estimates and correspondingly lower wind retrieval accuracy at those WVCs. It is thus most beneficial to perform simultaneous retrieval only in raining areas. To this end, a combined wind-only and simultaneous wind/rain retrieval ambiguity selection algorithm has been developed [4].

4.1 Equipment:

See JPL Level 2B documentation [11].

4.2 Data Acquisition:

See JPL Level 2B documentation [11].

4.3 Observations:

4.3.1 Data Notes:

No additional notes.

4.3.2 Field Notes:

No additional notes.

5 Data Description

5.1 Spatial Characteristics

Identical to JPL Level 2B. See JPL Level 2B documentation [11].

5.2 Temporal Characteristics

Identical to JPL Level 2B. See JPL Level 2B documentation [11].

6 Data Characteristics:

6.1 Data Granularity:

The basic granule is one data file. Each data file contains the data for one rev. A general description of data granularity as it applies to the Earth Observing System Data Gateway (EDG) appears in the EOSDIS Glossary.

6.2 Data Format:

The BYU L2R files are essentially "overlay" files for the JPL L2B files. Each file consists of a single satellite rev stored in Hierarchial Data Format (HDF). HDF is a self- describing data format developed by the National Center for Supercomputing Applications (NCSA) at the University of Illinois. HDF is the standard data format for Earth Observing System (EOS) satellites. HDF can store large varieties of data structures, which are portable to a large number of computing platforms and are equally accessible to routines written either in C or in FORTRAN. All access to SeaWinds data products using either C or FORTRAN should utilize the NCSA HDF interface library routines.

Each of the SeaWinds Level 2A, 2B, and 2R data products is divided into discrete files that are defined by spacecraft 'revs'. One rev includes all of the data acquired during a single orbital revolution of the spacecraft. By convention, all SeaWinds revolutions begin and end at the southernmost orbital latitude. Each data product file includes a header. The product header contains multiple metadata elements. The conditions specified by the metadata apply to the entire set of data in the file. The remainder of the file contains either those data acquired by the SeaWinds instrument over the spacecraft measurement swath, or those data that were generated by the processing software. BYU L2R files use the same HDF conventions described in the L2B software [11].

Table 1 shows the header of the BYU L2R product HDF file.

Table 2 summarizes the SDS contents of the file. The individual SDS elements are described below.

The wind_speed, wind_dir, max_likelihood_est, and num_ambigs array are similar to the arrays of the same name from the corresponding L2B file, but contain the wind/rain ambiguities. Simultaneous wind retrieval is not done for the outer (V-pol only) swath. In this case the rain_rate is set to zero and the reported wind ambiguities are from wind-only retrieval. (Thus, in the far swath the wind_speed and wind_speed1 values are identical.) Also, the wind-only retrieval is reported if the average wind speed of the wind-only ambiguities is less than 4 m/s. Note that wvcs with high rain rates may result in zero wind speed ambiguities.

The wind_speed1, wind_dir1, and num_ambigs1 are the wind-only retrieval wind ambiguities and are copies of the L2B wind ambiguities.

The various data sets contain:

Table 1: Header Structure for BYU L2R Product. Sample values shown.

Element Name	**Definition**	**Max Array Size**
LongName	QuikSCAT Level 2B Ocean Wind Vectors and Rain Rate in 25km Swath	[1]
ShortName	QSCATL2R	[1]
producer_institution	Brigham Young University (BYU), Microwave Earth Remote Sensing (MERS) Laboratory	[1]
InstrumentShortName	SeaWinds	[1]
PlatformLongName	NASA Quick Scatterometer	[1]
PlatformShortName	QuikSCAT	[1]
data_format_type	NCSA HDF	[1]
L2Rfilename	QS_S2R03221.20001592043	[1]
L2Afilename	QS_S2A03221.20001592043	[1]
L2Bfilename	QS_S2B03221.20001592046	[1]
WindModel	QS_MODL0003	[1]
RainModel	BYU V6 Quadratic	[1]
RainThresholds	BYU_rainflag_thresholds_V0.txt	[1]
Investigator	David G. Long, long@ee.byu.edu (801) 422-4383	[1]
build_id	1.000/2004-01-01	[1]

Table 2: HDF SDS arrays within the BYU L2R Product

Dataset/Name	Rank	Dimensions			Scale	Offset	Type
wvc_row	1	1624	0	0	1.000	0.0	int*2
wind_speed	3	4	76	1624	0.010	0.0	int*2
wind_dir	3	4	76	1624	0.010	0.0	uint2
rain_rate	3	4	76	1624	0.010	0.0	int*2
max_likelihood_est	3	4	76	1624	0.001	0.0	int*2
num_ambigs	2	76	1624	0	1.000	0.0	byte8
wvc_selection	2	76	1624	0	1.000	0.0	byte8
percent_rain	3	4	76	1624	0.010	0.0	int*2
wind_speed1	3	4	76	1624	0.010	0.0	int*2
wind_dir1	3	4	76	1624	0.010	0.0	uint2
num_ambigs1	2	76	1624	0	1.000	0.0	byte8
wvc_selection1	2	76	1624	0	1.000	0.0	byte8
regime	3	4	76	1624	1.000	0.0	byte8
wvc_selection_opt	2	76	1624	0	1.000	0.0	byte8
set_selection_opt	2	76	1624	0	1.000	0.0	byte8
wvc_quality_flag	2	76	1624	0	1.000	0.0	int*2
rain_confidence_flag	2	76	1624	0	1.000	0.0	byte8

1. **wvc_row**: (copy of L2B wvc_row variable) wvc row number
2. **wind_speed:** wind speed ambiguities (m/s), in MLE value order
3. **wind_dir:** wind direction ambiguities (deg), in MLE value order
4. **rain_rate:** rain rate ambiguities (km mm/hr), in MLE value order
5. **max_likelihood_est:** MLE value from wind or wind/rain retrieval (units arbitrary)
6. **num_ambigs**: number of ambiguities at each wvc (max=4)
7. **wvc_selection:** index (1..4) of selected simultaneous wind/rain ambiguity based on median-filter-based ambiguity removal
8. **percent_rain:** inferred wvc rain fraction (percent) for each ambiguity
9. **wind_speed1:** wind-only wind speed ambiguities (m/s), in corresponding MLE value order (copy of L2B wind_speed variable)
10. **wind_dir1:** wind-only wind direction ambiguities (deg), in corresponding MLE value order (copy of L2B wind_dir variable)
11. **num_ambigs1**: number of wind-only ambiguities at each wvc (max=4) (copy of L2B num_ambigs variable)
12. **wvc_selection1**: index (1..4) of selected wind-only ambiguity based on median-filter-based ambiguity removal (copy of L2B wvc_selection)
13. **regime**: estimated wind/rain retrieval regime
    0 - Estimated rain does not significantly affect wind (rain estimate poor)
    1 - Estimated rain and wind backscatter are of same order (both rain and wind estimate OK)
    2 - Estimated rain dominates wind (wind estimate quality poor)
14. **wvc_selection_opt:** ambiguity selection index (1..4) from combined simultaneous wind/rain and wind-only retreival. Index is for simultaneous wind/rain ambiguities (wind_speed) where **set_selection_opt**=0 or from wind-only ambiguities (wind_speed1) where **set_selection_opt**=1
15. **set_selection_opt**: flag to indicate which retrieval method is used for each wvc. Used with **wvc_selection_opt**.
    0 - index value **wvc_selection_opt** for simultaneous wind/rain retrieval,
    1 - index value **wvc_selection_opt** for wind-only retrieval
16. **wvc_quality_flag:** copy of L2B wvc_quality_flag
17. **rain_confidence_flag:** rain estimate quality confidence flag
    0 - Low confidence in estimated rain
    1 - High confidene in estimated rain

6.3 File Names

Like JPL L2B files, the BYU L2R data file names are 23 characters in length with the convention (for QuikSCAT and SeaWinds): Level 2B: QS_S2Bnnnnn.yyyydddhhmm where nnnn is the orbit rev number and yyyydddhhmm is the L2A product generation time file extension.

7 Errors:

7.1 Sources of Error:

The normalized standard deviation of sigma-0, known as Kp, is computed to give an estimate of the measurement uncertainty of the backscatter. For BYU Simultaneous wind/rain retrieval there are four major sources of Kp in the scatterometer system:

1. the uncertainty in the receiver noise, known as communication Kp or Kpc
2. the uncertainties in the geometric and gain parameters, known as retrieval Kp or Kpr
3. the uncertainty associated with the *wind* geophysical model function, known as model Kp or Kpm
4. the uncertainty associated with the *rain* geophysical model function, known as Kprain

Other sources of error include attitude pointing uncertainty, instrument processing, and various bias errors.

7.2 Quality Assessment:

See discussion in Draper and Long (2003) [4].

8 Notes:

8.1 Limitations of the Data:

Ambiguity selection is imperfect. Errors in ambiguity selection may cause errors in the wind and/or rain rate estimates.

Radar returns from land and ice correspond to different scattering processes than those over open ocean, and can contaminate wind vector/rain estimates. A land mask has been applied to the data in order to negate most contamination due to land and ice.

8.2 Known Problems with the Data:

8.3 Usage Guidance:

Wind direction convention
The oceanographic, or flow vector, convention for wind direction is adopted for SeaWinds on QuikSCAT. Under this convention, a wind direction of 0 implies a flow toward the north.

Reference Height for Surface Winds
The adopted reference height for all wind vectors is 10 meters.

Rain Rate
Units of rain rate are km-mm/hr as used by the TRMM PR.

9 Any Other Relevant Information about the Study:

None.

9.1 Application of the Data Set:

1. global and regional climate studies
2. atmospheric forcing, ocean response and air-sea interaction mechanism research
3. input to numerical weather- and wave-prediction models

10 Future Modifications and Plans:

Improvements in the ambiguity selection are in progress.

11 Software:

Only Matlab readers are currently available.

12 Data Access:

12.1 Contact Information:

TBD

13 Output Proucts and Availability:

TBD

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