NASA Quick Scatterometer

QuikSCAT Science Data Product

User's Manual

Overview & Geophysical Data Products

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Table of Contents

List of Figures

List of Tables

1   Introduction

The purpose of the QuikSCAT Science Data Product User's Manual is to provide assistance to investigators so they can make effective use of the SeaWinds on QuikSCAT Science Data Products, which are produced by the NASA Scatterometer Projects and distributed by the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory. This User's Manual provides investigators a description of the content and format of the data products. In addition, it provides investigators with a discussion of the QuikSCAT geophysical processing algorithms and how they relate to the data products. The algorithm and data descriptions presented in this User's Manual cover the σ_o and geophysical data products (Levels 1B, 2A, and 2B). Examples of data usage are also presented. An overview of the QuikSCAT mission and an introduction to the operation of the instrument and ground data systems are provided for new investigators.

1.1   How to Use this Document

For experienced users of scatterometer data, the key parts of this guide are Sections 3, 5, 6 and 7. Section 3 should be reviewed as it introduces the design and operating characteristics of the QuikSCAT scatterometer, including key engineering parameters required to understand the data. Section 5 provides a more in-depth summary of the data processing algorithms, with specific references to the data elements in the data products. Section 6 provides a complete description of the data product contents and format. This includes a description of the Hierarchical Data Format, (HDF). In addition to the science data products, two key ancillary data files, the Spacecraft Ephemeris and the Geophysical Model Function table, are described. A practical guide to the use of the QuikSCAT science data is given in Section 7. This section includes information on how to obtain the data and on reading the tapes [does anyone still get tapes?], usage of data flags for editing, typical coverage and limitations, other HDF utilities, World Wide Web access for mission and processing status news, and points of contact.

Less experienced or newer users of scatterometer data should read all sections, including the introductory sections, of this guide prior to using the data products. Section 2 gives an overview of the mission, including the science requirements and goals, a description of the QuikSCAT spacecraft, the SeaWinds scatterometer instrument on the satellite, and a brief description of the overall QuikSCAT ground system segment. Section 4 describes the QuikSCAT Ground Data Processing system at JPL, and gives a high-level functional walkthrough of the data processing and quality assurance stages. Newer users will find the practical guide given in Section 7 of particular help in analyzing QuikSCAT data.

Ancillary information, of potential interest to all users, is presented in Sections 8 and 9. An overview of the Calibration/Validation process done by various elements of the QuikSCAT Project is presented in Section 8. The group of appendices, which make up Section 9, covers definitions of commonly used terms, acronyms, and a list of scatterometry-related references.

1.2   Conventions

1.2.1   Units

All quantities reported in the data products data are computed and expressed in MKS units. Distances are reported in meters, speeds in meters per second, and powers are in watts (or decibels relative to 1 watt). Ratio quantities including the radar backscatter (σ_o) are generally reported in decibels (dB), particularly when they cover a wide dynamic range of values.

Antenna azimuths are measured clockwise from the spacecraft-heading vector. Beam and cell azimuths and wind directions are in degrees measured clockwise from North. Longitudes are measured eastward

from the Greenwich meridian. Incidence angles are computed relative to the local normal to the Earth ellipsoid.

All time tags on data records are given in Coordinated Universal Time (UTC), in a standard ASCII CCSDS format (yyyy-dddThh:mm:ss.sss). Where times are also given in seconds (as in the Level 1B record), the reference epoch is 1 January 1993 at 00h00 UTC.

Indices of quantities in examples are given as zero-based, even though counts are obviously one-based. For example, 25 km wind vector cells run from 1 to 76 across the swath, but wvc indices go from 0 to 75. Flag bit references and definitions start with bit 0.

1.2.2 Resolution

Quoted resolutions for σ_o measurements are defined as the dimension of the equivalent-area square footprint, which can be practically estimated as the square root of the cell area.

SeaWinds on QuikSCAT is capable of generating σ_o measurements at a variety of resolutions, including the "spot" or "egg" footprint of the full beam, the "slice" footprint of individual range-resolution elements, and "composite" footprints made up of multiple slices falling in a wind vector cell. These different types of measurements and their derivation are described in Section 5.

The SeaWinds antenna footprint is an ellipse approximately 25-km in azimuth by 37-km in the look (or range) direction. Signal processing provides commandable variable range resolution of approximately 2- to 10-km.

The wind retrieval resolution is defined as the dimension of a wind vector cell in which σ_o measurements have been grouped. For QuikSCAT, wind vector cell grids at resolutions of of 25 km x 25 km and 12.5 x 12.5 km, along- and cross-track, are provided.

1.2.3 Wind Direction Convention

The oceanographic, or flow vector, convention for wind direction is adopted for QuikSCAT. Under this convention, a wind direction of 0° implies a flow *toward* the north. This is in contrast to the meteorological, or "out of", convention, for which a "north" wind (0° direction) flows *from* the north. Conversion between the two conventions is performed by simply reversing the directions (adding 180° *modulo* 360°).

1.2.4 Reference Height for Surface Winds

The adopted reference height for all wind vectors is 10 meters.

1.2.5 Data Flagging and Editing

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. As is explained in the Software Interface Specification (SIS) documents, 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.

Please refer to Section 9.6 or to the SIS documents for the dependency tables.

1.3 Applicable Documents

1.3.1 Software Interface Specifications

Level 0 Data Software Interface Specification, Project Document 686-644-4, JPL D-16075, August 1998.

Level 1A Data Software Interface Specification (QuikSCAT Era), Project Document 686-644-5 Rev A, JPL D-16076, April 2000.

Level 1B Data Software Interface Specification (QuikSCAT Era), Project Document 686-644-1 Rev B, JPL D-16077, September 2006. .

Level 2A Data Software Interface Specification (QuikSCAT Era), Project Document 686-644-2 Rev B, JPL D-16078, September 2006. .

Level 2B Data Software Interface Specification (QuikSCAT Era), Project Document 686-644-3 Rev B. JPL D-16079, September 2006. .

Processing Tables Software Interface Specification (QuikSCAT Era), Project Document 686-644-6 Rev A, JPL D-16080, July 2000.

1.3.2 Related Documents

QuikSCAT Mission Requirements, M. H. Freilich (Science requirements)

Science Algorithm Specifications for SeaWinds, Project Document 686-631, JPL D-21978, October 5, 2001. To be updated October 2006.

SeaWinds Experiment Implementation Plan, Volume III: Ground System Technical Management, October 1994, JPL D-8743, PD 686-010.

SeaWinds Experiment Functional Requirements, April 1998, JPL D-TBD, PD 686-210A.

SeaWinds Experiment Science and Mission Requirements, January 1995, JPL D-10965, PD 686-050.

SeaPAC System Functional Requirements, Project Document   686-610 Rev A, JPL D-16073, September 2000.

Planetary Science Data Dictionary Document, July 15, 1996, JPL D-7116, Rev. D, V6 MGSO0099-05-00.

Science Data Processing Segment (SDPS) Database Design Schema Specification for the ECS Project, EOSDIS Core System Project, Hughes Information Technology Systems, Upper Marlboro, Maryland, December, 1995, 311-CD-002-004.

Getting Started with HDF, Version 3.2, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, May, 1993.

HDF Reference Manual, Version 4.1r5, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, November, 2001.

3

HDF User's Guide, Version 4.1r5, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, November, 2001.

1.4   Change Control

This document is maintained by PO.DAAC and will be kept current to reflect changes in algorithms and data products content. Algorithm specifications and software changes are controlled by the QuikSCAT Change Control Board (QCCB).

2   QuikSCAT Mission Overview

2.1   Mission Description

The SeaWinds on QuikSCAT mission is a "quick recovery" mission to fill the gap created by the loss of data from the NASA Scatterometer (QuikSCAT), when the ADEOS-1 satellite lost power in June 1997. QuikSCAT was launched from California's Vandenberg Air Force Base aboard a Titan II vehicle on June 19, 1999. It will continue to add to the important ocean wind data set begun by NSCAT in September 1996. A similar version of the SeaWinds instrument flew on the Japanese ADEOS-II spacecraft, launched in December 2002. The ADEOS-II mission ended prematurely due to a spacecraft power subsystem failure on October 24, 2003. The QuikSCAT mission has continued to provide data of high quality over more than seven years since launch. The mission will be continued through the Senior Review process until it is deemed to no longer provide scientifically useful data.

The SeaWinds instrument on the QuikSCAT satellite is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans. 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.

As the only remote sensing systems able to provide accurate, frequent, high-resolution measurements of ocean surface wind speed and direction under both clear sky and cloudy conditions, scatterometers will play an increasingly important role in oceanographic, meteorological and climatic studies during the 1990s and beyond. 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. A single-swath scatterometer operating at C-band is presently flying on the European Space Agency's Earth Remote Sensing (ERS-2) mission, continuing the (now 7-1/2 year) time series of C-band wind scatterometer measurements begun with ERS-1. 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.

5

2.1.1 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 interannual variability.

Table 2.1 QuikSCAT Technical Mission Requirements

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% of ice-free ocean every day	
Mission duration	36 months	

2.2 Satellite Description

The NASA Quick Scatterometer (QuikSCAT) mission employs a variation of the Ball Commercial Platform 2000 (BCP 2000 "QuikBird") bus. QuikSCAT was selected through the NASA Rapid Spacecraft Acquisition program, which required a stable and highly accurate Earth remote-sensing platform. Ball integrated and tesed the total space segment consisting of the BCP 2000 spacecraft bus and the JPL-supplied scatterometer payload. Ball was responsible for integration of the spacecraft to the launch vehicle and launch support. Ball also provides mission control and operations following launch.

Modifications to the basic BCP 2000 design for this mission were minimal and included a larger propellant tank (76 kg), CCSDS compatible uplink and science data downlink, S-band telemetry downlink, reduced capacity solid-state recorder (8 Gbit), and minor configuration modifications to support payload boxes and the Titan II launch vehicle.

The QuikSCAT satellite was launched into a sun-synchronous, 803-kilometer, circular orbit with a local equator crossing time at the ascending node of 6:00 A.M. ± 30 minutes. Data acquisition will be done by NASA Ground Network using several stations including Wallops Flight Facility (WFF), Poker Flats (AGS), Wallops Flight Facility (WGS), Svalbard (SGS), and McMurdo (MGS). Electronic file transfer through the Central Autonomous File Service (Central SAFS) at the Goddard Space Flight Center (GSFC) distributes science data to NOAA-Suitland for operational uses and to JPL for science processing. Near real-time wind data will be made available to weather forecasting agencies from NOAA within three hours of observation. Japan's National Space Development Agency can support the mission by providing science and instrument adjustment support, as well as backup for tracking stations.

2.2.1 Nominal Orbital Parameters

The nominal orbit for QuikSCAT is defined by the following parameters:

Table 2.2 Nominal Orbital Parameters

Recurrent period	4 days (57 orbits)
Orbital Period	101 minutes (14.25 orbits/day)
Local Sun time at Ascending node	6:00 A.M. ± 30 minutes
Altitude above Equator	803 km
Inclination	98.616°

2.3 Ground System

The ground system computers produce wind measurements within 3 days of receiving raw QuikSCAT data from the spacecraft, with no backlog. QuikSCAT data products currently include global backscatter data and 25and 12.5 km resolution ocean wind vectors in the measurement swaths. A Level 3 spatially gridded daily wind field map is also produced. Science Team members make available other special products.

2.4 Science Team

As part of the QuikSCAT project, NASA is also sponsoring a team of scientific investigators who served as project advisors during the development of the instrument and ground data processing system and who conduct research based on QuikSCAT data. Their studies are expected to lead to improved methods of global weather forecasting and modeling and to a better understanding of environmental phenomena (such as El Niño, tropical cyclones, the effects of winds on ocean biology) that greatly affect world economies.

3   QuikSCAT Sensor Overview

The SeaWinds instrument on QuikSCAT is an active microwave radar designed to measure electromagnetic backscatter from wind roughened ocean surface. The SeaWinds instrument uses a rotating dish antenna with two spot beams that conically sweep producing a circular pattern on the surfeace. The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions on Earth's surface. The instrument collects data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band centered on the spacecraft's nadir subtrack, making approximately 1.1 million ocean surface wind measurements and covering 90% of Earth's surface each day. 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 it provides superior coverage.

3.1   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 radar cross section (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 – this relationship is known as the geophysical model function.

The SeaWinds scatterometer design used for QuikSCAT is a significant departure from the fan-beam scatterometers flown on previous missions (Seasat SASS and NSCAT). QuikSCAT 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 incidence angles of 46° (H-pol) and 54° (V-pol). 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 is commandable between 2 km and 10 km, with the nominal value set at about 6 km. The nominal pulse repetition frequency is 187.5 Hz (also commandable). 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).

QuikSCAT generates an internal calibration pulse and associated load pulse every half-scan of the antenna. In ground processing, the load pulses are averaged over a 20-minute window, and the cal 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.

QuikSCAT "programmability" includes commanding of major mode selection and range resolution, antenna spin rate and PRF, and the ability to uplink new Doppler compensation and range tracking tables as changes in the orbit occur, or to conduct special engineering tests. Mode changes were made occasionally to obtain additional calibration data. Special command sequences were used, during the early Cal/Val checkout phase.

3.2   Operating Modes

Mode 0:   Wind Observation Mode

Wind observation mode is the primary science mode for QuikSCAT, and will be in effect more than 95% of the time.

Mode 1:   Receive-Only Mode

In Receive-only mode, the transmitter is turned off while the receiver collects data at the antenna ports. This mode was used during Cal/Val to assess radio frequency interference and internal receiver biases, and also to protect the instrument during several Leonids meteor shower events. No science data is returned.

Mode 2:   Continuous Calibration Mode

In Continuous Calibration mode, QuikSCAT performs only calibration/load cycles in place of normal pulse transmission cycles. This mode provides the most accurate receiver calibration data, and will be used periodically throughout the mission. No science data is returned.

Mode 3:   Standby Mode

Standby mode is the initial power-on mode of the QuikSCAT instrument. The high-voltage power supply (HVPS) is turned off, and therefore no science data is returned.

3.3   Range Resolution Modes

The SeaWinds antenna footprint is an ellipse approximately 25-km in azimuth by 37-km in the look (or range) direction. Signal processing provides commandable variable range resolution of approximately 2- to 10-km.

The nominal resolution is approximately 5 km—an effective range gate of 0.3 msec. Table 3.1 illustrates that the actual range resolution is different for the inner and outer beams. Note that there are two other default resolutions if the instrument resets.

Table 3.1 Range Resolution Modes

SES FFT Binning Table

Binning arrangement: 10 Center slices at 1 resolution, 2 "guard" slices at edges to give >~ 150 kHz BW.

Bin BW = 0.46   B bin Res = 0.34   A bin Res = 0.39

ECR agrred w/ E-Sys 11/04

Eff Gate Width (msec)	Bins/Centr 10	Bins/Guard Slice	BW of Centr 10 (kHz)	BW of Guard (kHz)	Total BW (kHz)	B, Centr Res (km)	B, Guard Res (km)	A, Centr Res (km)	A, Gurad Res (km)	B, # Cen slices in 35 km	A, # Cen Slice in 35 km
0	1	1	4.62	0.92	5.54	0.34	0.34	0.39	0.39	103.5	90.8
0.1	5	125	23.10	115.48	138.57	1.69	42.29	1.93	48.16	20.7	18.2
0.2	10	125	46.19	115.48	161.67	3.38	42.29	3.85	48.16	10.3	9.1
**0.3	15	100	69.29	92.38	161.67	5.07	33.83	5.78	38.53	6.9	6.1
* 0.4	28	75	129.33	69.29	198.62	9.47	25.37	10.79	28.90	3.7	3.2
0.5	18	100	83.14	92.38	175.52	6.09	33.83	6.94	38.53	5.7	5.0
3*0.6	23	85	106.24	78.52	184.76	7.78	28.76	8.86	32.75	4.5	3.9
4*0.7	28	75	129.33	69.29	198.62	9.47	25.37	10.79	28.90		

Effective Gate Width = Range Gate - Pulse Length.

* SES Default (instrument startup; SES reset?)

** "Nominal" (6 km)

3* CDS Default (startup/POR)

4* Undefined states go to Default = (?, 0.6[3*])

4   Data Processing Overview

This section describes the overall design and functionality of the ground processing system for the SeaWinds data from QuikSCAT. The data flow diagram in Figure 4.1 shows the principal segments of the ground system, which consist of the NASA Ground Network, the Mission Operations Center (MOC), the SeaWinds Processing and Analysis Center (SeaPAC) at JPL, and the PO.DAAC.

Figure 4-1 QuikSCAT Data Flow

Overall SeaWinds Data Flow
QSCAT Era Nominal Operations
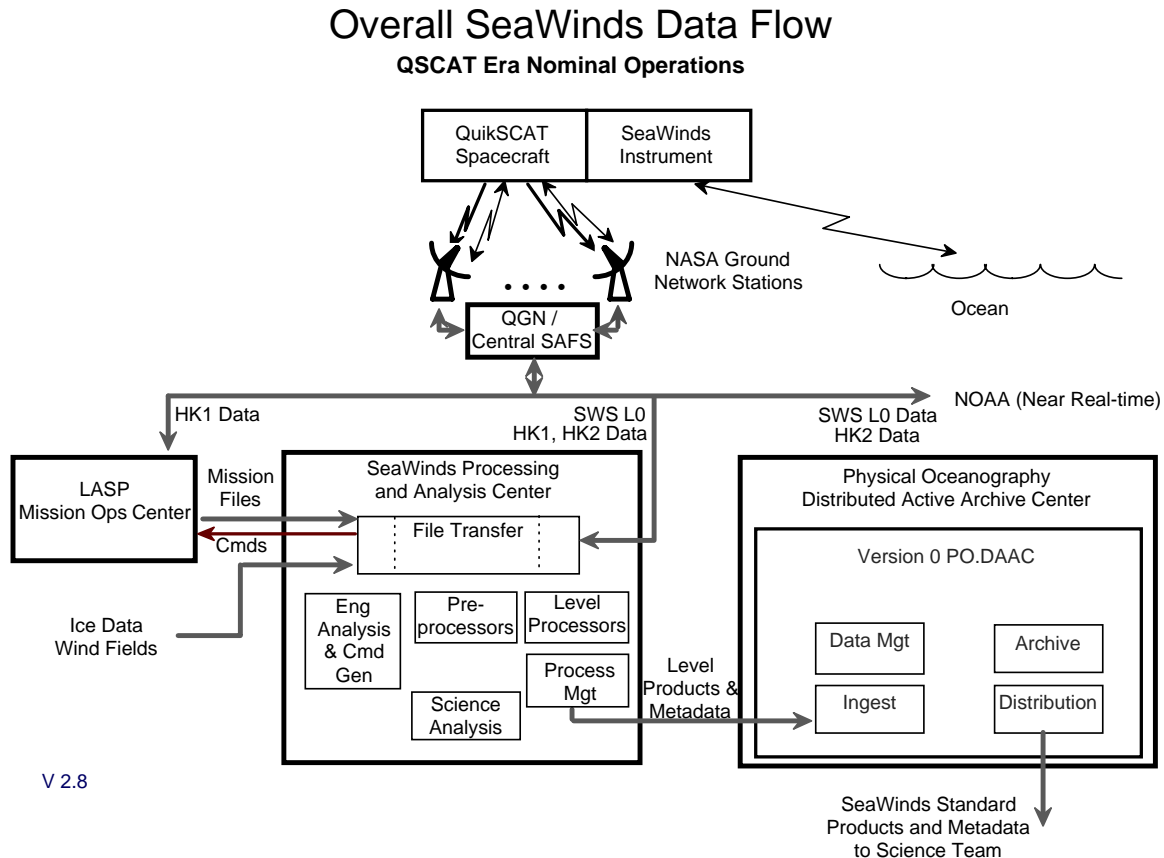
4.1   NASA Ground Network and Mission Operations

The NASA Ground Network consists of four main receiving stations at Poker Flats, Alaska, Svalbard, Norway, McMurdo Station in Antarctica, and Wallops Flight Center in Virginia. The spacecraft and instrument telemetry is collected at these stations and forwarded via network to the Central SAFS at Goddard Space Flight Center. From Central SAFS, the spacecraft housekeeping (HK1) data are forwarded to the MOC at LASP in Boulder, Colorado, and the science telemetry (Level 0 and HK2) are sent to JPL and NOAA-NESDIS for science and near-real-time data processing.

4.2   Mission Operations Center

The Mission Operations Center at LASP has the principal responsibility for monitoring and commanding the QuikSCAT spacecraft. Instrument commands generated by Engineering Analysis at JPL are forwarded to the MOC for scheduling and uplinking. The MOC is responsible for assessing and maintaining the spacecraft orbit and pointing, sending commands for maneuvers as needed. Orbit

predictions used for scheduling data downlinks and orbit determination from tracking data are performed by the MOC.

4.3   SeaWinds Processing and Analysis Center (SeaPAC)

The SeaWinds Processing and Analysis Center (SeaPAC) at JPL is responsible for the reception of telemetry data, production and analysis of the science data products, and for delivery of the science products to the PO.DAAC for distribution. The SeaPAC consists of six principal subsystems, described in the following sections.

4.3.1   File Transfer Subsystem (FX)

The FX subsystem is responsible for all external data transfers into the SeaPAC. These include the reception of the science telemetry data from the Central SAFS at GSFC, collection of ice edge data from the National Ice Center, and collection of NWP wind field data from NCEP. While the FX software can be run manually, most of its functions are completely automated.

4.3.2   Process Management Subsystem (PM)

The PM subsystem performs the database and automatic job scheduling functions for the SeaPAC, as well as providing a user interface for the SeaPAC operator. Using a rule-based algorithm PM is able to determine when all of the necessary input data for a particular job have become available, and can start that job automatically or inform the operator that the job is ready to be run manually.

4.3.3   Preprocessor Subsystem (PP)

The PP subsystem does initial processing of the HK2 and Level 0 science telemetry, creating the basic input products for initiating the main science data processing. PP creates time correlation, ephemeris, and attitude files from the HK2, creates the QuikSCAT Level 0 files that are the input to the Level 1A processor, and also extracts and converts NWP data to the format needed by the Level 2B processor

4.3.4   Level Processor Subsystem (LP)

The LP subsystem is the heart of the science processing, implementing the conversions from Level 0 telemetry up through the Level 2B wind vector products. LP consists of four main programs, one each to produce L1A, L1B, L2A, and L2B data in sequence. LP software incorporates and implements all of the science algorithms, and creates the HDF data products that are delivered to PO.DAAC and to the science community.

4.3.5   Engineering Analysis Subsystem (EA)

The EA subsystem has the primary responsibility to monitor the instrument health and safety. EA focuses mainly on the HK2 and Level 1A data to perform trend analyses on key instrument and spacecraft temperatures, voltages, and other engineering parameters.

4.3.6   Science Analysis Subsystem (SA)

The SA subsystem performs the primary QA and data analysis functions for the SeaPAC. SA is concerned with assuring that the science algorithms as implemented in the LP are performing correctly, and making algorithm corrections and refinements as needed.   SA monitors the science data quality throughout the mission. QA reports are provided with all data products.

4.4 Physical Oceanography DAAC

The Physical Oceanography Distributed Active Archive Center, (PO.DAAC), receives the science data from the SeaPAC, archives the data, and distributes Level 1B, Level 2A, Level 2B and higher level data products to the QuikSCAT science community. PO.DAAC also acts as the principal long-term archive for all telemetry, Level 0, Level 1A and ancillary files collected during the QuikSCAT mission.

5   Geophysical Algorithm Overview

5.1   Telemetry Processing

The principal inputs delivered to SeaPAC by the Central SAFS are the science telemetry packet file and the science housekeeping (HK2) file. The science telemetry packet file contains the raw telemetry produced by the scatterometer, consisting of status and engineering data, antenna position data and received power data. The HK2 file contains spacecraft telemetry, including GPS time correlation information, GPS ephemeris, and spacecraft attitude data.

5.1.1   Science Telemetry Processing (Level 0)

The SeaWinds mission telemetry is packetized by the CDS (Command and Data Subsystem). Each 100-pulse frame of Level 0 telemetry is contained in three consecutive telemetry packets. Level 0 processing by SeaPAC consists of checking for bad or missing packets, assembling the corresponding packet triplets into frame-records, and assigning a frame quality flag. No other data conversions are performed at this level.

5.1.2   Science Housekeeping (HK2) Processing

The HK2 telemetry chiefly contains spacecraft engineering and flight data. For the purposes of the science processing, the HK2 is needed because it includes three critical sets of information:

- UTC Time Correlation: The data provided gives the relationship between the spacecraft clock and UTC; the latter is provided by the GPS. A linear fit of the GPS time versus the spacecraft vehicle time code word (VTCW) is computed, giving a base time and a clock drift rate needed for later time-tagging of science data frames.

- GPS state vectors (spacecraft ephemeris): this is provided as both the "raw" GPS vectors (with 64-bit precision) and a "smoothed" version produced by an on-board orbit propagator (at 16-bit precision).

- Spacecraft attitude: The attitude is provided as a set of four quaternions, which are converted to the classic roll, pitch, and yaw angles for subsequent processing.

The HK2 preprocessor produces the ephemeris and attitude files required for L1A and L1B processing adds a one-line time correlation record to the SCLK_UTC (spacecraft clock-UTC) file, and reformats the HK2 data itself into HDF for use by Engineering Analysis.

5.1.3   Level 1A Processing

The Level 1A processing functions include time tagging of science telemetry frames, assignment of ephemeris and attitude information to each frame, conversion of data to engineering units, and extraction of calibration pulse data.

5.1.3.1   UTC Time Tagging

The process of deriving UTC time tags for instrument frames uses the GPS time correlation information obtained from the HK2 file (clock rate and base time) plus three entries contained in the status information for each frame: (1) the instrument time for the frame, which corresponds to the transmit time of the first pulse in the frame; (2) the most recent value of the vehicle time code word (VTCW); and (3) the instrument time value that corresponds to the VTCW (the instrument time value that is latched at

the time the spacecraft time is reported). Given these five inputs, the UTC time tag, in seconds, is given by:

$$UTC(frame) = base\_time + clock\_rate * VTCW * 1x10^{-6} + (instrument\_time - corr\_instr\_time) / 32$$

Note that the instrument timer is a 4-byte 32-Hz counter, and the VTCW is a 6-byte 1-MHz counter. Neither counter is expected to roll over during the lifetime of the mission, however both may be reset in the event of a spacecraft anomaly.

5.1.3.2   Ephemeris and Attitude Processing

Once the UTC time of the frame is known, the spacecraft location, velocity, and attitude at the frame time can be determined from the ephemeris and attitude files. Due to the occasional occurrence of gaps in the HK2 telemetry, the ephemeris (with a nominal interval of 2 seconds) is interpolated by means of a cubic spline. This can tolerate up to a 5-minute gap in the data without loss of accuracy (typically, the HK2 gaps are no more than 5-6 seconds), and provides an estimate of the accuracy of the interpolation. The attitude data (also with a nominal interval of 2 seconds) is assigned using a "latest-available data" (LAD) algorithm. If the LAD entry is older than 4 seconds, the appropriate frame quality flag bit is set and the values for roll, pitch, and yaw are set to zero.

5.1.3.3   Engineering and Science Data Conversion

The Level 0 telemetry data that are needed for subsequent science processing are converted from the packed values to "real" values for the Level 1A output. Key information in the instrument status and engineering data (modes, voltages, temperatures, cal pulse locations, etc.) are extracted. The antenna position data (stored in telemetry as full 16-bit data number (DN) values for pulses 1 and 51, and as 8-bit differences for the remaining pulses) are converted to full DN values for the L1A output. The science data for the slice powers (stored as 12-bit pseudo-floating point values) are converted to full 32-bit integer DN values, and the noise data (stored as 16-bit pseudo-floats) are also converted to 32-bit integer DN's.

5.1.3.4   Calibration Pulse Products

An important internal product generated by the L1A processor is the Calibration Pulse file. The calibration pulse data embedded in the science data is used to obtain the current values of the receiver gain via the loopback and cold load data. These data are inherently noisy, and must be averaged before they can be used in the L1B σ_o computation. To simplify the processing at L1B, and to provide a useful engineering analysis product that avoids the need to re-extract the calibration data from telemetry, the calibration pulse file is generated by the L1A processor. Each record of the cal pulse file contains information about an individual calibration pulse/load pulse pair.

5.2   Level 1B Processing

5.2.1   Spacecraft Location and Attitude

The spacecraft location and velocity are determined from the ephemeris files. The same cubic-spline ephemeris interpolator algorithm that is also used in the L1A processing is used for L1B. The ephemeris is interpolated for the N-th pulse (N=1…100) at the "landing time", i.e. when the pulse reaches the Earth's surface:

$$Pulse\_time(N) = Frame\_time + N * PRF\_Cycle\_Time + slant\_range / 2c$$

where c is the speed of light; the last term is the one-way travel time from the spacecraft to the surface. Because of the circular scan pattern of the instrument, the values of slant_range used for this calculation

are essentially constant for each beam, to the level of accuracy required, so the value for the previous pulse are actually used.

The attitude provided by the onboard attitude control system is downlinked via the HK2 data and applied to the L1A data. The onboard attitude reflects the satellite's ability to navigate itself such that the SeaWinds instrument spin axis always points to the local nadir on the Earth ellipsoid. During the original processing of the QuikSCAT mission, the onboard attitude was been used for scatterometer geolocation computations.

The echo tracking algorithm, used for SeaWinds/ADEOS-II and described in detail in the algorithm specifications, determines the spacecraft pointing by using the scatterometer echo data. This attitude determination is being used in reprocessing QuikSCAT (July – December 2006) and will be used in future processing. The frequency shift in the echo channel induced by pointing errors relative to nadir can be measured by averaging over several scans and parametrized as "pitch", "roll", and "yaw" errors. By using the echo-tracked attitude estimates it is possible to reduce or eliminate systematic attitude biases caused by time-dependent star catalog errors on the spacecraft (the star catalog used with the star trackers for attitude determination has positions for a fixed precession epoch). Echo tracking will be used for the reprocessed QuikSCAT data starting in July 2006.

5.2.2   Antenna and Cell/Slice Geometry

The SeaWinds antenna footprint is an ellipse approximately 25-km in azimuth by 37-km in the look (or range) direction. Signal processing provides commandable variable range resolution of approximately 2- to 10-km. Once the spacecraft location and attitude have been determined, the location of the pulse footprint on the Earth's surface can be computed. The antenna azimuth is measured clockwise from the forward direction (spacecraft X-axis). The antenna feeds point at look angles (relative to the nadir, Z-axis of the spacecraft) of 39.876^o and 45.890^o for the inner (H-pol) and outer (V-pol) beams, respectively. The boresight vectors for each feed are determined in the Earth Centered Rotating (ECR) coordinate system after correction for the spacecraft attitude. The intersection of the boresight vector with the Earth's surface determines the location of the whole-pulse, or "egg" center. The resulting incidence angles for the two beams are approximately 45° for the inner beam, and 53.6^o for the outer beam.

The location of the slice centers involves information about the resolution mode, the frequencies of the slice boundaries in the echo channel, and the shape of the antenna pattern. Starting from the boresight location, an iterative search algorithm is used to find the intersections of the slice boundaries with the peak "spine" of the along-beam antenna pattern. Once the boundary points are known, the locations of the slice centers can be interpolated, weighting by antenna gain to get the radiometric centroid of the slice.

SeaWinds on QuikSCAT is capable of generating σ_o measurements at a variety of resolutions, including the "spot" or "egg" footprint of the full beam, the "slice" footprint of individual range-resolution elements, and "composite" footprints made up of multiple slices falling in a wind vector cell.

5.2.3   Sigma0 and Kp

The computation of the radar backscattering coefficient, σ_o, is performed for each power measurement provided in the Level 1A data.

5.2.3.1   QuikSCAT/SeaWinds Instrument and Power Detection

The scatterometer transmits a sequence of RF pulses (5.4 msec interval) and measures the returned energy from the Earth surface plus the instrument thermal noise (signal-plus-noise energy). In order to estimate

an accurate σ_o, it is necessary to extract the signal-only energy by subtracting the noise-only energy from the signal-plus-noise energy.

In the QuikSCAT/SeaWinds design, the signal-plus-noise and noise-only energies are measured simultaneously by the two receiving channels (also refer to as filters): echo and noise. The instrument periodically performs a calibration measurement sequence ("cal-pulse") in which the transmit power is fed into the receiver through loop a-back calibration and a cold load is measured for thermal noise estimation. The cold load measurements relate echo channel noise-only energy to the noise channel noise-only energy. This reduces the number of unknown variables to signal-only energy and noise-only energy of the echo channel, which can be solved by two independent signal-plus-noise energy measurements. The noise filter bandwidth is 1 MHz and the echo filter bandwidth can vary from about 5.5 KHz to 198.6 KHz.

5.2.3.2   Signal Processing for High Resolution

The QuikSCAT/SeaWinds instrument achieves a resolution higher than the antenna footprint by transmitting a linear frequency-modulated chirp (LFMC, "chirp") signal. The returned signal is a superposition of scattering contributions from every point in the area illuminated by the antenna beam. Each contributing source is delayed by a slant range difference, which can be related to frequency by the chirp rate. The summed waveform, (i.e. the echo signal), is then multiplied by a LFMC reference signal with a conjugate phase. This step maps a distinct time delay of a received waveform to a corresponding baseband frequency shift in the echo filter.

The extent of the baseband frequency shift allowed depends on the difference of the two commanded parameters: pulse width and echo gate width. The echo gate width minus the pulse width is termed effective gate width and this determines the resolution. By design, the echo filter is divided into 12 bands. The center 10 are equally spaced, and the two outer edge bands are wider. The inner 10 bands are called slices. Figure 5.1 illustrates the noise filter and divisions of the echo filter. Also, see Table 3.1.

Full-pulse ("egg") σ_o are composites of all 10 center slices. In the L1B product, slice σ_o data are retained for the "best" 8 of the 10 slices, centered on the peak gain frequency within the echo filter. Flag bits in the sigma0_qual_flag (bits 10-11) indicate which contiguous set of eight slices have been retained in the product.
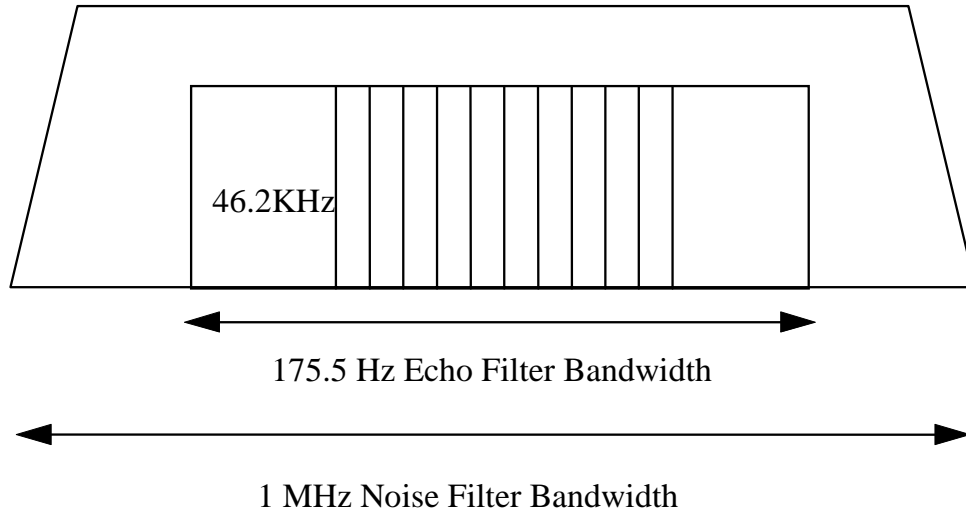
Figure 5-1 Illustration of Slice Resolution for 0.5msec Effective Gate Width

5.2.3.3 The Radar Equation and X-factor

The radar equation, which relates the radar return energy to the transmitted energy, the σ_o, and various electrical and geometric factors, is the basic relation used to compute σ_o. The critical problem is to extract σ_o, given the other parameters, by inverting the radar equation.

The radar equation consists of an integral over the scattering surface where the antenna gain, the receiver response, the slant range vary from point to point. As a first approximation, if σ_o is assumed constant over this range (essentially, a mean value), then the σ_o can be solved as a function of the return/transmit energy ratio and the gain-slant range integral. To avoid cumbersome numerical integration for every pulse in L1B processing, the integration is pre-computed and tabulated based on nominal orbit parameters and antenna measurement geometry. In conceptual terms, σ_o is given by:

$$\sigma_o = ((\text{signal+noise energy}) - \text{noise energy}) \, (X\_int + \Delta fX_{\Delta f}) \, X\_cal$$

where $\Delta fX_{\Delta f}$ is a first order correction to the nominal X_factor table accounting for attitude errors and deviations of the orbit from the nominal.

In addition, a perturbation table that can compensate for the errors in the integration due to the difference between the nominal and the actual geometric parameters (orbit and antenna geometry) is pre-computed. The combined nominal and perturbation table value gives the integral part of the X_factor, X_int. The calibration term of the X_factor, X_cal, together with X_int gives a complete conversion factor to relate the received energy to σ_o. This table-driven processing approach is very accurate and significantly reduces L1B processing time. These tables are a function of beam number, antenna azimuth angle, orbit position, slice number, and resolution mode.

5.2.3.4 The Kp Equation for SeaWinds

When a scatterometer measures the backscattering coefficient, σ_o, of the ocean surface, it does so with imperfect precision. Due to the instrument thermal noise and radar signal fading effects, the estimates of σ_o will be noisy. In scatterometry, measurement variations of this type are referred to as "communication noise". A parameter commonly used to indicate the magnitude of the communication noise is Kpc, which is defined as the normalized standard deviation of the echo return energy:

$$kpc = \frac{\{Var[P_s]\}^2}{\overline{P}_s} \tag{1}$$

where P_s is the expected echo return energy and $\mathrm{Var}[P_s]$ is the variance of the echo return energy.

Kpc is a function of the instrument signal processing parameters and the return signal-only to noise-only energy ratio (SNR). It can be written as:

$$kpc^2 = kpc\_A + \frac{kpc\_B}{SNR} + \frac{kpc\_C}{SNR^2} \ . \tag{2}$$

Kpc_A, kpc_B, and kpc_C are known as the Kpc coefficients. They are functions of the instrument antenna pattern, illumination geometry, modulation format, transmit pulse modulation, and receiver filter characteristics.

Although there are some small corrections for the digital processing used in SeaWinds, the analog Kpc model is adequate and clearer for explanatory purposes.

The analog Kpc coefficient derivation, as employed in the Seasat scatterometer (2), assumes that the bandwidth of each individual slice is narrow so that the power spectral density is flat over the slice bandwidth. Then it can be shown that the Kpc_A, Kpc_B, and kpc_C can be well approximated by the following expressions:

$$kpc\_A = \frac{1}{B_s T_p} \tag{3}$$

$$kpc\_B = \frac{2}{B_s T_g} \tag{4}$$

$$kpc\_C = \frac{1}{B_s T_g} \sqrt{\left(1 + \frac{B_s}{B_n}\right)} \tag{5}$$

where,

B_s = Bandwidth of the individual slices.

B_n = Bandwidth of the noise filter (1MHz nominal).

T_p = Transmit pulse width.

T_g = Range gate width.

The egg Kpc formula results from a similar derivation and approximations:

$$kpc\_A = \frac{1}{B_{3dB} T_p} \tag{6}$$

19

$$kpc\_B = \frac{2}{B_{egg}T_g} \tag{7}$$

$$kpc\_C = \frac{1}{B_{egg}T_g}\sqrt{\left(1 + \frac{B_{egg}}{B_n}\right)} \tag{8}$$

where:

B_{3dB} = the 3dB bandwidth of the egg.

B_{egg} = the sum of the individual slice bandwidths comprising an egg (nominally there are 10 slices in an egg).

5.2.4   QuikSCAT Radiometer (QRad) Brightness Temperatures

During the Calibration/Validation phase of the QuikSCAT mission, a complete characterization of the instrument noise sources led to the development of a model for transforming the instrument noise measurement for each scatterometer pulse into an apparent brightness temperature (Tb). Much of the data used for this characterization was obtained during two periods when the instrument was commanded into Receive-Only mode, one early in the mission (early July 1999) and one two-day period in November 1999 (during the Leonid meteor shower). These Tb measurements at both H-pol (from the inner beam) and V-pol (from the outer beam) are relatively noisy due to the fact that the scatterometer is not an optimal radiometer (limited to 1 MHz bandwidth); however, they are sufficiently accurate to aid in rain detection and rain flagging in later wind processing, and to distinguish ice from ocean (and even first-year ice from multi-year ice).

The QRad brightness temperature model is applied during the Level 1B processing, when the Level 1A noise measurements and calibration data are available, along with various other instrument calibration parameters that are needed in the model. The Tb measurements are provided for the full pulses (all slices combined within each pulse) only.

5.3   Geophysical Product Processing

The Level 2A and 2B processing algorithms accept wind observation mode data only.

5.3.1   Level 2A Algorithms

The Level 2A algorithm processing can use either the pulse σ_o data or the range-resolved "slice" σ_o measurements from the Level 1B file. In the former case the σ_o pulses are grouped into wind vector cells. In the case of the "slice" σ_o data, a further step of "compositing" is done to synthesize σ_o measurements at approximately the resolution of the WVC grid. This is the case for the 12.5 km products. In addition to grouping, each σ_o is given an attenuation correction, and land or ice flags, as determined from maps.

5.3.1.1   Sigma0 Grouping

The σ_o grouping algorithm prepares the SeaWinds σ_o data for wind retrieval processing. The data contained in the Level 1B product is grouped by geographic location into wind vector cells (WVC). The grouped σ_o data is saved in WVC rows in the Level 2A product.

The primary function of the σ_o grouping algorithm is to re-order the Level 1B sensor data from time-ordered data frames into a primarily spatially-ordered (also time-ordered, but in a average sense) data set. The first step is to compute subtrack bin coordinates WVC_I and WVC_J for each σ_o cell. These coordinates describe the location of each σ_o cell on the spacecraft swath in terms of along-track and cross-track distances. The (WVC_I,WVC_J) pairs, computed for a 25 km resolution grid, are used to assign σ_o data to particular locations on the wind vector cell grid in preparation for wind retrieval. Unlike NSCAT, the expected number of σ_o cells per WVC is not constant, due to the circular scan of the SeaWinds instrument. To minimize the L2A data volume, the σ_o cell data are stored as "lists" for each WVC row, with each list indexed by the "cell_index" array to indicate the cross-track WVC membership of the data.

5.3.1.2   Sigma0 Compositing

The σ_o slices <u>from the same pulse,</u> which are assigned to the same WVC, are assembled into "composite" σ_o values. The compositing process is essentially a weighted average of the slice σ_o data using the X-factor values generated in the Level 1B processing for each slice. Similarly, composite cell locations, azimuth angles, incidence angles, and Kp coefficients are averaged to produce the full set of auxiliary data for each composite σ_o required by the wind retrieval algorithm. Full details of the σ_o compositing algorithm can be found in the <u>SeaWinds Algorithm Specifications</u>.

5.3.1.3   Climatological Atmospheric Attenuation

The radar signal is attenuated as is passes through the Earth's atmosphere. To correct for this effect, an atmospheric attenuation correction, based on the climatology provided by Wentz (1996), is applied to the σ_o values. In SeaWinds L2A processing, the monthly 1°×1° mean two-way nadir attenuation is spatially and temporally interpolated to the σ_o location and converted to a line-of-sight attenuation.

The Wentz climatology is based on eight years of SSM/I ocean data. These passive microwave observations were used to estimate the mean monthly columnar water vapor, which was converted to water vapor attenuation. To obtain total atmospheric attenuation, oxygen and cloud attenuation, both rather small, were added to the water vapor attenuation. Atmospheric attenuation over land and ice were obtained from the NASA Water Vapor Project data set. By combining the ocean and land/ice attenuations, a monthly climatology of global mean atmospheric attenuation was produced. Details can be found in Wentz (1996). It should be noted that the effects of rain are not included in this correction.

The atmospheric attenuation, in dB, is computed in L2A and used in L2B to correct the σ_o values prior to wind retrieval. The correction is listed in the L2A product as a separate item, but is <u>not applied to the σ_o data</u> in the L2A product.

5.3.1.4   Surface Flags

After the σ_o data have been assigned to a WVC, each cell is checked for land and sea ice. Both the land and ice flagging algorithms check the center of the σ_o cell (pulse or slice) against the land-sea map and the ice mask. For composite σ_o data, the surface flags on the slices that make up the composite are examined; if any one slice is flagged as non-ocean, the entire composite is similarly flagged.

Starting with the reprocessed QuikSCAT data in July 2006 the land flags will be determined using a land-sea mask at higher spatial resolution (2 arc-min in lat/lon) than previously was used (CIA land map used for NSCAT). The sea ice masks will be generated directly from QuikSCAT data using high-resolution ice sigma0 imaging and masking techniques developed by D. Long (BYU). The original QuikSCAT processing used a sea ice mask generated from weekly National Ice Center ice edge data. The 25 km L2A product land flags will use a 30 km coastal mask as before; all 12.5 km products will use a 20 km coastal mask for the higher-resolution slice-composite sigma0.

5.3.1.5 QRad Brightness Temperatures

The QRad brightness temperatures (Tb) from the Level 1B data are grouped on the wind vector cell grid in the same way as the sigma0 and related data. In order to reduce the inherent relative noisiness of the Tb data, the Tb measurements within a WVC are averaged by beam (polarization). There are typically 4-8 Tb measurements of each polarization in each WVC. In addition to the mean Tb values thus obtained, the standard deviations and the number of measurements for each polarization are provided in the Level 2A data.

The locations of the Tb measurements are not explicitly provided in the Level 2A product; however, the locations may be generated from the Level 2A data by averaging the locations of the sigma0 data within the WVC, which are provided in the data. Alternatively, the WVC locations from the Level 2B data, which are those same sigma0 centroid locations, may be used in conjunction with the Level 2A Tb data.

5.3.1.6 Sigma0 Frame/Pulse Index

A new dataset in the L2A product has been introduced to facilitate the use of L2A and L1B data together. The frame_pulse_index is computed for each σ_o measurement in the L2A to point back to the L1B frame and pulse from which the L2A σ_o was derived. The frame_pulse_index (FPI) is computed by:

FPI = frame*100 + (pulse – 1)

To recover the frame and pulse from the FPI:

Frame = int(FPI/100)

Pulse = (FPI mod 100) + 1

5.3.2 Level 2B Processing

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.

5.3.2.1 Wind Retrieval

The radar backscatter (σ_o) describes the state of the scattering surface observed at the particular geometry (azimuth, incidence angle). Two or more observations at different look angles are required to determine a finite set of wind vector solutions.

The model function relating σ_o and near-surface wind velocity can be written as

$$\sigma_o = F(|U|, \chi,...; f, p, \theta)$$

Where σ_o is the normalized radar cross-section of the ocean surface, $|U|$ is wind speed, χ is the azimuth angle in the horizontal plane between the vector wind and the radar look direction, and (...) represents the (presumed small) influences of other geophysical phenomena on σ_o. The parameters f, p, and θ are the radar frequency, polarization (horizontal or vertical), and incidence angle (the angle in the vertical plane between the incident radiation and the local vertical), respectively.

The azimuthal modulation of σ_o allows scatterometers to measure wind direction as well as wind speed. The largest azimuthal variations of σ_o are the "upwind-crosswind modulation", resulting in backscatter cross-sections that are largest at upwind and downwind and smallest at crosswind angles, and the "upwind-downwind asymmetry", resulting in different cross-sections for upwind versus downwind (with upwind values generally larger). As σ_o at fixed $|U|$ and theta must be periodic with respect to χ (with period 2π), it is natural to model the azimuthal modulation as a Fourier series in χ.

The upwind-downwind modulation of σ_o, coupled with at least three collocated observations of σ_o differing in azimuth angle and/or incidence angle, in principle allows determination of a unique wind vector. In the case of $A_1=0$, corresponding to perfect upwind/downwind symmetry, a 180° ambiguity in wind direction cannot be eliminated. Even for small but nonzero values of A_1, model function uncertainties and noise in the σ_o measurements lead to only moderate point-by-point skill in resolving directional ambiguities.

An accurate model function is essential to deriving ocean wind vectors from scatterometer measurements. Varieties of Ku-band models exist, some of which are derived from scattering theory, and some which are empirically derived. The tabular form of the model function, using a table of real-space (non-dB) σ_o values, is used for SeaWinds, with modifications for the incidence angle range and the resolution of the table in azimuth and incidence angle. The initial post-launch model function used for QuikSCAT was the **NSCAT-2** model. Starting with version 2.0 of the data set (release starting 2 May 2000), and up to June 2006, the model function used was the **QSCAT-1** model developed during the QuikSCAT calibration/validation phase. QSCAT-1 brought the QuikSCAT data into somewhat better agreement with numerical weather model winds. Based on recommendations from a science users, QSCAT-1 was recalibrated during 2006 for wind speeds above 16 m/s to speeds derived from SSM/I F13. This recalibrated model function called **QSCAT-1/F13** will be used for all L2B processing starting in July 2006.

The SeaWinds wind retrieval algorithm uses a maximum-likelihood estimator (MLE) as the objective function for determining wind vector solutions. The MLE is defined by:

$$J = -\left[\sum_{i=1}^{N} \frac{(\sigma_{oi} - \sigma_m(u, \chi_i))^2}{Var(\sigma_m)_i} + \ln(Var(\sigma_m)_i) \right]$$

23

where $\sigma_{o\ i}$ are the backscatter measurements, $\sigma_m(u, \chi_i)$ are the model backscatter values corresponding to the measurements, and $\text{Var}(\sigma_m)_i = \alpha\sigma_{mi}^2 + \beta\sigma_{mi} + \gamma = (K_{pi}^2\sigma_{mi}^2)$ are the measurement variances. The minus sign is chosen such that the local maxima of J correspond to wind vector solutions.

Due to the azimuthal variation of the model function, the objective function used to determine wind vector solutions has a number of local extrema, referred to as "ambiguities". These ambiguities correspond to solutions at approximately the same wind speed, but with different directions. The values of the objective function at these ambiguities characterize the goodness-of-fit between the σ_o measurements and the model function. From the standpoint of estimation theory, the ambiguity at the global extremum of the objective function is the "best" estimate of the wind.

The characteristics of the objective function also depend on the specifics of the instrument design. A scatterometer with only two orthogonal beams, as in the case of the Seasat SASS, will always have two global extrema (i.e. ambiguities with equal values of J) approximately 180° apart. Based on estimation theory alone, it is impossible to distinguish between these solutions, giving rise to a true upwind-downwind ambiguity. The introduction of additional azimuthal looks, as provided by the NSCAT mid-beam, or the azimuthal difference between the inner and outer beams for SeaWinds, helps to break this symmetry, yielding a single global extremum. For SeaWinds, the azimuth mix varies at each cross-track location due to the dual circular scans. The nadir region, formerly unavailable to either SASS or NSCAT, has fore and aft looks that are nearly 180° apart resulting in decreased directional accuracy. At the extreme edges of the swath, the outer beam fore and aft looks are all nearly in the same direction, making the extreme edges unsuitable for wind retrieval.

The concept of *azimuthal diversity* among the measurements, that is, the spread of azimuth looks among the σ_o measurements in the WVC, is applied in deciding the suitability of the WVC for wind retrieval. For SeaWinds, the azimuthal diversity criterion that is used is that the azimuth looks must have a range greater than or equal to 20° in order to allow wind retrieval to proceed.

5.3.2.2   Ambiguity Removal

The SeaWinds ambiguity removal algorithm uses a modified median filter technique to select a unique wind vector out of a set of ambiguous wind vectors at each wind vector cell.

The wind retrieval algorithm computes a set of wind vectors together with their relative likelihoods for each wind vector cell. The solution closest to the true wind is called the "closest" solution and all the wind vector solutions found in each WVC are referred to as "ambiguities". Based on simulated data, there are usually two to six ambiguities per WVC. Typically, around 60% of the most likely ambiguities are the closest and around 30% of the most likely ambiguities are opposite to the closest. The objective of the ambiguity removal algorithm is to choose the "closest" solution from the list of "ambiguities". This objective is equivalent to detecting cases where the ambiguity with the highest likelihood is not the closest solution and selecting the closest solution out of the rest of the ambiguities.

Simulations and analysis of QuikSCAT data show that in the nadir swath (200km either side of nadir), there are usually less than four ambiguities and occasionally there is only one ambiguity. The directional uncertainties in this nadir region can be rather large. This is a result of the σ_o distribution produced by the instrument design. In the nadir region, the "closest" direction may be rather far from the truth, but the true direction is usually within the uncertainty interval about the closest vector.

Median filter techniques were first introduced in 1974 to smooth time series data. They were later applied to image enhancement. The median of a group of data values is that value for which there are equal numbers of data values of greater magnitude and lesser magnitude. An important characteristic of the

median filter is that it ignores extreme values. Therefore, the median filter has the advantage of eliminating impulses while preserving edges. In an ambiguous wind field, the majority of the ambiguities with highest likelihood are either in the same direction or in the opposite direction as compared to the true wind. This is equivalent to an image with impulsive noise on which a median filter can be used effectively.

The conventional definition of the median can only be applied to non-circular (i.e. linear and scalar) data in which the ordering of the values is obvious. The pixel brightness levels in an image are an example. For circular data (such as directions) or vector data, the conventional definition of median fails because the order of numbers cannot be specified, and the median itself can be ambiguous. An alternative definition of median is used here. The median of a set of data $x(1)$, $x(2)$, ..., $x(N)$ is defined as the number $x(M)$ which minimizes:

$$\sum_{i=1}^{N} \left| x(M) - x(i) \right|$$

where $1 \leq M \leq N$.

This definition can be applied to circular and vector data as well as non-circular data. For non-circular data, it is equivalent to the conventional definition. The medians of circular and vector data calculated using the alternative definition have similar characteristics to the median of non-circular data, i.e. extreme and isolated data are ignored.

The measure used to describe the performance of the ambiguity removal algorithm is *ambiguity removal skill*, which is defined as the percentage of WVC values for which the wind vector selected by the ambiguity removal algorithm is also closest to the true wind. Likewise, *instrument skill* is defined as the percentage of WVC values for which the wind vector with the highest likelihood is the vector closest to the true wind. Instrument skill depends on the backscatter/wind model function, the wind retrieval algorithm, and design of the scatterometer (number of beams, signal-to-noise ratio, etc.).

In general, good ambiguity removal skill can be achieved when the average instrument skill is high. However, the overall skill alone does not provide detailed information. The success or failure of the ambiguity removal algorithm is determined by the occurrence of regions of low instrument skill. Broad patches of low instrument skill may occur in regions where the scatterometer SNR is low (far swath cells, low wind speeds) and/or at particular wind directions relative to the antenna beams where the model function and wind retrieval algorithm has difficulty distinguishing the relative likelihoods of the two principal ambiguities. This effect is referred to as "local" instrument skill; that is, how well the wind retrieval algorithm performs on smaller spatial scales.

For example, a uniform distribution of 60% local skill will result in an ambiguity removal skill of over 96%. On the other hand, a distribution composed of regions of half 40% and half 80% local skill may result in an ambiguity removal skill of 50%. In this case, the regions of 40% instrument skill resulted in 0% ambiguity removal skill and the regions of 80% instrument skill resulted in 100% ambiguity removal skill. Based on simulated NSCAT data, high algorithm skills (>96%) and randomly distributed errors can usually be reached when regions of low instrument skill are much smaller than the median filter window size.

The entire rev of data is maintained in memory at once, to prevent discontinuities in the selected fields. The algorithm begins with the field of "most likely" wind vectors as derived from the wind retrieval algorithm. The "most likely" vectors are those that represent the best fit to the model function. The wind vectors in a 7 x 7 filter window determine a median vector for the center cell. This median vector is

compared with the ambiguities in that cell, and the closest ambiguity to the median is selected for use in the next iteration. The entire rev is filtered in this way. The process continues until it converges, *i.e.*, when no new replacements of vectors have been made. The final selections are indicated in the Level 2B record by the WVC_selection entry. Tests of this algorithm with simulated wind data show that it selects the vector closest to the true wind 96% of the time, on average.

5.3.2.3   NWP Initialization of Ambiguity Removal

The baseline ambiguity removal algorithm for SeaWinds incorporates the Numerical Weather Product (NWP) initialization technique used for NSCAT-1 and NSCAT-2 processing.   In this "nudging" technique, the median filter algorithm is initialized with either the first or the second ranked wind vector solution, whichever is closer to the direction of the NWP analysis field. The median filter algorithm then proceeds as described above to generate the final wind vector selections.

5.3.2.4   DIRTH Algorithms

At far swath, ambiguity removal skill is degraded due to the absence of inner beam measurements, limited azimuth diversity, and boundary effects. Near nadir, due to nonoptimal measurement geometry (fore and aft looking measurement azimuths approximately 180° apart), there is a marked decrease in directional accuracy even when ambiguity removal works correctly. Two algorithms were developed to address these issues: direction interval retrieval (DIR) to address the nadir performance issue; and threshold nudging (TN) to improve ambiguity removal at far swath. The two algorithms work independently and need not be used together. However, both are used to obtain the DIRTH solutions, wind_speed_selection and wind_dir_selection, in the Level 2B product.

Please refer to Stiles [1999] for more information on the DIRTH algorithms.

5.3.2.5   Rain-Impact Detection (IMUDH)

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 wind vector cells in the 25km Level 2B product. A fuller description of the IMUDH development from SeaWinds and AMSR is provided in the SeaWinds Beta release document [2006].

The transfer of the IMUDH algorithm from SeaWinds to QuikSCAT 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 and QuikSCAT are nearly identical. It was found that the SeaWinds IMUDH algorithm table and spatial filter parameters could be transferred directly, and identically, to QuikSCAT.

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 QuikSCAT 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.

Users should note that the IMUDH algorithm was developed for the 25 km L2B <u>only</u>. For 12.5 km L2B products, the 25 km L2B IMUDH flags are applied to the corresponding cells of the 12.5 km data.

6   Geophysical Data Product Content & Format

QuikSCAT science data consists of 5 data products:

Level 2B Data –   Ocean Wind Vectors in 25 km and 12.5 km Swath Grid

Level 2A Data – Surface Flagged Sigma0s and Attenuations in 25 km and 12.5 km Swath Grid

Level 1B Data – Time-Ordered Earth-Located Sigma0s

This section presents an overview of the level data product information detailed in the Software Interface Specification (SIS) documents. (See Section 1.3 of this document for references.) The SIS documents should be consulted if more detailed information about the data products is required.

The products described herein, are presented in the order of expected use by most data users. The last subsection for each level data product presents important notes on data usage.

6.1   QuikSCAT Level 2B Product—Ocean Wind Vectors in 25-km and 12.5 km Swath Grid

The Level 2B product consists of ocean wind vector solutions organized by full orbital revolution of the spacecraft or 'rev'. Each Level 2B file represents one satellite rev.

6.1.1   Level 2B Header

The contents of the QuikSCAT Level 2B header are contained in metadata elements which are stored as HDF global attributes. The header data covers the entire contents of the file.

The name of each global attribute used for metadata storage matches the name of a metadata element. Each global attribute consists of ASCII characters and contains at least three lines of data. The information specified in each global attribute indicates the data type, the array size and contents of the metadata element.

6.1.2   Level 2B Header Structure

The following table lists all of the elements in the QuikSCAT Level 2B header. All of the header elements except skip_start_time and skip_stop_time must appear in every Level 2B Product file. These two optional elements delimit data gaps or regions of data that were not processed. These metadata elements appear only when sequences of data were missing from Level 2A data which were used to generate the Level 2B Product.

Table 6.1 Header Structure for L2B Product

Element Name	Definition	Max Array Size
LongName	"QuikSCAT Level 2B Ocean Wind Vectors in [25 km] [12.5 km] Swath Grid"	[1]
ShortName	"QSCATL2B"	[1]
producer_agency	"NASA"	[1]
producer_institution	"JPL"	[1]
InstrumentShortName	"SeaWinds"	[1]
PlatformLongName	"NASA Quick Scatterometer"	[1]
PlatformShortName	"QuikSCAT"	[1]
PlatformType	"spacecraft"	[1]
project_id	"QuikSCAT"	[1]
data_format_type	"NCSA HDF"	[1]
GranulePointer	A pointer to the output data granule	[1]
QAGranulePointer	A pointer to the quality assurance granule.	[1]
InputPointer	A pointer to the major input data granule.	[1]
ancillary_data_descriptors	An array of file names which specifies all of the ancillary data files which were used to generate the output product.	[10]
OrbitParametersPointer	A pointer to one data granule or a set of granules that provide the orbit parameters which are used to generate the data in this product.	[5]
sis_id	A character string that specifies which SIS document describes the organization and format of data in the file.	[1]
build_id	A character string that identifies the version of the SeaPAC software which was used to generate this data file.	[1]
HDF_version_id	A character string which identifies the version of the HDF software which was used to generate this data file.	[1]
ParameterName	"wind_speed"	[1]
QAPercentOutOfBoundsData	The percent of instances when a particular data element within the data product is out of bounds.	[1]
QAPercentMissingData	The percent of instances when a particular data element within the data product is missing.	[1]
OperationMode	"Wind Observation"	[1]
StartOrbitNumber	The orbit number which corresponds to the data at the beginning of the granule.	[1]
StopOrbitNumber	The orbit number which corresponds to the data at the end of the granule.	[1]
EquatorCrossingLongitude	The interpolated longitude of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingTime	The interpolated time of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingDate	The date of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
rev_orbit_period	The time between two consecutive ascending node crossings in the spacecraft orbital path.	[1]
orbit_inclination	The angle between the plane of the spacecraft's orbital path and the earth's equatorial plane.	[1]
orbit_semi_major_axis	The length of the semimajor axis of the QuikSCAT spacecraft orbit.	[1]
orbit_eccentricity	The eccentricity of the spacecraft orbital path.	[1]
rev_number	The assigned revolution number based on the spacecraft orbital history.	[1]
RangeBeginningDate	The initial date for data coverage within this QuikSCAT data product.	[1]

RangeEndingDate	The final date for data coverage within this QuikSCAT data product.	[1]
RangeBeginningTime	The initial time for data coverage within this QuikSCAT data product	[1]
RangeEndingTime	The final time for data coverage within this QuikSCAT data product.	[1]
ProductionDateTime	Wall clock time when this data file was created.	[1]
skip_start_time	A specific date and time which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment begins.	[10]
skip_stop_time	A specific date and time which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment ends.	[10]
sigma0_attenuation_method	"Attenuation Map" or "None"	[1]
median_filter_method	"Wind direction median" or "Wind vector median"	[1]
nudging_method	"None" or "NWP Weather Map"	[1]
ephemeris_type	"GPS", "EPHD" or "EPHP"	[1]
l2b_algorithm_descriptor	A set of character stings which list important details about the implementation of the L2B Processor algorithm which were used to generate this product.	[8]
l2b_actual_wvc_rows	The number of wind vector cell rows.	[1]
l2b_expected_wvc_rows	The expected number of wind vector cell rows.	[1]
sigma0_granularity	"whole pulses", "slice composites", "composites of composites", or "pulse slices"	[1]

6.1.3   Level 2B Data

The Level 2B data are grouped by rows of wind vector cells (WVC). Level 2B wind vector cells are squares of dimension 25 km or 12.5 km. 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 at 25 km resolution, and 3248 rows at 12.5 km resolution.

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 25 km WVCs or 144 12.5 km WVCs. To accommodate occasional measurements that lie outside of the 900 km swath, the Level 2B data design includes additional WVC values at each end of each row. Each Level 2B WVC row therefore contains a total 76 WVCs at 25 km resolution, and 152 WVCs in the 12.5 km product.

Except for the wvc_row_time, an HDF SDS object stores every data element in the Level 2B Data. An HDF Vdata object stores the wvc_row_time. The number of wvc_row_time entries matches the number of WVC rows in the Level 2B Product.

Except for the element wvc_row, every SDS is an array of at least two dimensions. The first SDS dimension represents the WVC row while the second dimension represents a particular WVC within the row.

The Level 2B Product numbers the wind vector cells from left to right when viewing the orbital swath in the direction of spacecraft flight. Thus, num_ambigs[203,15] lists the number of retrieved ambiguities for the 16th wind vector cell from the left hand side of the swath when facing the spacecraft's forward direction of motion in the 204th wvc_row[203] (Recall that descriptions use zero-based indices.).

Several of the Level 2B SDS objects are three-dimensional arrays. For all of these SDS objects, the third array index represents a potential wind solution.

Each WVC includes up to four potential wind velocity solutions. These potential solutions are called 'ambiguities'.   The SDS objects wind_speed, wind_dir, wind_speed_err, wind_dir_err and

max_likelihood_est list these ambiguities in descending likelihood order. Therefore, the value stored in wind_speed[210,34,0] is the wind speed solution with the greatest likelihood estimator for the wind vector cell stored at array location[210,34]. Likewise, if an entry exists in location wind_speed[210,34,3], its value represents the wind speed solution with the smallest likelihood estimator for the same WVC. The SDS object wvc_selection indicates which of the ambiguities was selected by the median filter ambiguity removal algorithm.

The DIR (Direction Interval Retrieval) algorithm enhances the solution selected by ambiguity removal. When the Level 2B Processor uses DIR, the metadata element l2b_algorithm_descriptor in the Level 2B Product indicates that the wind direction of the selected ambiguity has been enhanced.

When DIR is in use, the SDS objects wind_speed_selection and wind_dir_selection give the output from DIR processing. Users who have interest in the wind solution based on DIR should employ the data that are stored in these SDS objects. Users who are interested in wind solutions that have not been modified by the DIR algorithm should locate the data element that represents the selected ambiguity in the SDS objects wind_speed and wind_dir. For instance, if wvc_selection[204,30] indicates that the second ambiguity was selected, then the solutions that were not enhanced by DIR processing are located in data elements wind_speed[204,30,1] and wind_dir[204,30,1].

When the Level 2B Processor does not use the DIR algorithm, the SDS objects wind_speed_selection and wind_dir_selection list the wind speed vector that was selected by ambiguity removal. Thus, if DIR is not in use, and data element wvc_selection[612,54] indicates that the first ambiguity was selected. wind_speed_selection is then equal to wind_speed[612,54,0], and wind_dir_selection is equal to wind_dir[612,54,0].

6.1.4   Level 2B Data Structure

Figures illustrating the internal structure of the QuikSCAT Level 2B data can be found in Section 3.2 of the Level 2B Data Software Interface Specification (SIS).

Except for the wvc_row_time, each entry in this table represents a unique HDF SDS object. The wvc_row_time is stored in an HDF Vdata object. The name of each Level 2B HDF object is the same as the name of the data element that the HDF object stores.

With the exception of wvc_row, every SDS object is an array of at least two dimensions. In every case, the first array index specifies the wind vector cell row while the second array index specifies a wind vector cell in that row. For all three-dimensional SDS elements in the Level 2B Product, the third dimension represents one of the wind solution ambiguities.

For example, data elements wvc_row[256] and wvc_row_time[256] reference the same wind vector cell row. Data elements wvc_lon[256,12] and num_ambigs[256,12] represent the same wind vector cell. Data elements wind_dir[256,12,1] and wind_speed[256,12,1] represent the same ambiguity in the same wind vector cell.

The following table lists each element in the Level 2B Data. For the 25 km product, [nrow,ncol] = [1624,76], and for the 12.5 km product [nrow,ncol] = [3248,152].

Table 6.2 Data Structure for L2B Product

Element Name	Storage Type	Repetition	Scale	Unit	Minimum	Maximum
wvc_row_time	char	[nrow]	n/a	UTC	1993-001 T00: 00: 00.000	2008-366 T23: 59: 60.999
wvc_row	int16	[nrow]	1	Index	1	1624
wvc_lat	int16	[nrow,ncol]	0.01	Deg	-90.00	90.00
wvc_lon	uint16	[nrow,ncol]	0.01	Deg E	0.00	359.99
wvc_index	uint8	[nrow,ncol]	1	Index	1	76
num_in_fore	int8	[nrow,ncol]	1	Count	0	127
num_in_aft	int8	[nrow,ncol]	1	Count	0	127
num_out_fore	int8	[nrow,ncol]	1	Count	0	127
num_out_aft	int8	[nrow,ncol]	1	Count	0	127
wvc_quality_flag	uint16	[nrow,ncol]	1	Bit Field	0x0000	0x7F83
atten_corr	int16	[nrow,ncol]	0.001	dB	0	32.767
model_speed	int16	[nrow,ncol]	0.01	m/s	0.00	70.00
model_dir	uint16	[nrow,ncol]	0.01	Deg from N	0.00	359.99
num_ambigs	int8	[nrow,ncol]	1	Count	0	4
wind_speed	int16	[nrow,ncol,4]	0.01	m/s	0.00	50.00
wind_dir	uint16	[nrow,ncol,4]	0.01	Deg from N	0.00	359.99
wind_speed_err	int16	[nrow,ncol,4]	0.01	m/s	0.00	50.00
wind_dir_err	int16	[nrow,ncol,4]	0.01	Deg	0.00	180.00
max_likelihood_est	int16	[nrow,ncol]	0.001	N/A	-30.0	0.0
wvc_selection	int8	[nrow,ncol]	1	Index	0	4
wind_speed_selection	int16	[nrow,ncol]	0.01	m/s	0.00	50.0
wind_dir_selection	uint16	[nrow,ncol]	0.01	Deg from N	0.00	359.99
mp_rain_probability	int16	[nrow,ncol]	0.001	Probability	(-3.000flag) 0	1.000
nof_rain_index	uint8	[nrow,ncol]	1	Flag Value	0	250
srad_rain_rate	int16	[nrow,ncol]	0.01	mm/hr	0.00	300.00

6.1.5 Level 2B Bit Flag Convention

At the start of processing, all QuikSCAT bit flag values are initialized. The standard procedure for QuikSCAT initialization of bit flags sets all defined bits to 1 and all undefined bits to 0. If the Level 2B Processor detects an anomalous condition which halts the processing for a particular wind vector cell, the appropriate bit flag which indicates the error condition remains set to 1. 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.

For instance, if wvc_quality_flag indicates that there is poor azimuth diversity among the σ_o values in a wind vector cell, the Level 2B Processor does not retrieve winds for that cell. Since wind retrieval does not take place, the code cannot determine whether wind solutions for that wind vector cell are within or outside of the optimal range. Thus, the bits which represent the presence of either high and low wind speeds in the wind vector cell remain set to 1. These settings indicate neither a high nor a low wind speed. Users should ignore these values. On the other hand, the remaining bits in the wvc_quality_flag do contain valid values. These bits are valid, because they were determined before the Level 2B Processor halted processing for the associated wind vector cell.

The following table lists the wvc_quality_flag bit flag dependencies. The column on the left lists the pivotal Wind Retrieval Flag. The middle column lists the two possible values for that bit. The column on the right indicates which of the remaining bits in the wvc_quality_flag are meaningful under the specified conditions.

Table 6.3 Wvc_Quality_Flag Bit Flag Dependencies

Bit Flag	Value	Other Bits with Meaningful Value
Wind Retrieval Flag (bit 9)	0	Adequate Sigma0 Flag (bit 0)
		Adequate Azimuth Diversity Flag (bit 1)
		Coastal Flag (bit 7)
		Ice Edge Flag (bit 8)
		High Wind Speed Flag (bit 10)
		Low Wind Speed Flag (bit 11)
	1	Adequate Sigma0 Flag (bit 0)
		Adequate Azimuth Diversity Flag (bit 1)
		Coastal Flag (bit 7)
		Ice Edge Flag (bit 8)

6.1.6 Level 2B Null Values

QuikSCAT null values are listed as zeros in the Level 2B Product. The Level 2B Product does, however, contain adequate information so that users can easily distinguish null values from actual zero values. The Level 2B Product contains null values whenever a wind vector cell has fewer than four ambiguities. In those situations, the Level 2B Product lists zeros for all of the data elements associated with each unneeded ambiguity in that wind vector cell. Clearly, these zero values should be interpreted as null values.

For example, if all the wind_dir values for the WVC at array location [210,34] are equal to zero, and num_ambigs is equal to 3, then the wind_dir[210,34,0], wind_dir[210,34,1] and wind_dir[210,34,2] are true zero values. On the other hand, wind_dir[210,34,3] is a null value. The SDS objects for wind_speed, wind_speed_err, wind_dir_err and max_likelihood_est should be interpreted similarly.

The wind retrieval flag in the wvc_quality_flag distinguishes null values from zero values for certain SDS objects. If the wvc_quality_flag indicates that wind retrieval did not take place, then the listed zero values for model_speed, model_dir, num_ambigs, wind_speed, wind_dir, wind_speed_err, wind_dir_err, max_likelihood_est and wvc_selection are null values.

6.1.7 Rain Flagging Techniques

The SeaWinds scatterometer was developed by NASA JPL to accurately measure the normalized radar cross section (σ_o) of the ocean surface. Such measurements are then used to infer the speed and direction of ocean surface winds. When rain is present, measurements of the ocean surface σ_o become contaminated for several reasons. Some of the transmitted energy is scattered back towards the scatterometer by the rain and never reaches the ocean surface. Energy backscattered from rain can constitute a significant but unknown portion of the measured echo energy. Some of the transmitted energy is scattered and/or absorbed by the rain and is never measured by the scatterometer. This has the

effect of attenuating the echo energy from the ocean. Additionally, the rain roughens the ocean surface and changes its radar cross section.

Two rain-flagging scientific data sets, mp_rain_probability and nof_rain_index, are included to indicate the detection of rain contamination in the QuikSCAT Level 2B data. Please note that the nof_rain_index is incorporated as an additional parameter in the IMUDH rain algorithm, but it is not currently being used to compute mp_rain_probability. The GDS software does compute the nof_rain_index, and there is a weighting assigned to it in the IMUDH table, but that weight is now and has always been zero.

6.1.7.1   mp_rain_probability

mp_rain_probability is derived using the Impact-based Multidimensional Histogram (IMUDH) rain-flagging technique developed by James Huddelston and Bryan Stiles at NASA JPL. For a detailed description of the multi-dimensional histogram technique, please refer to the "Multidimensional Histogram (MUDH) Rain Flag Product Description" [Huddleston and Stiles, 2000].

Briefly, mp_rain_probability from the new IMUDH does not flag a specifc rain rate but a likelihood that the wind speed is perturbed by more than 2 m/s or the direction by more than 15 deg. (The previous MUDH gave the probability of encountering a columnar rain rate that is greater than 2 km*mm/hr.) This probability value is read directly from a table based on eight input parameters including nof_rain_index and the average brightness temperature. The space spanned by these parameters can detect whether the set of σ_o used in wind retrieval contain a noteworthy component created by some physical phenomenon other than wind over the ocean's surface.

Values of mp_rain_probability range between 0 and 1. Missing values are indicated by a value of –3.0. Additionally, bit 12 of the wvc_quality_flag indicates whether the MP algorithm computation was valid (0) or invalid (1), and bit 13 indicates whether rain was detected (1) or not detected (0) by the algorithm. Bit 14 of the wvc_quality_flag indicates whether the rain detection is based on data from both beams (0) or from outer-beam measurements only (1).

6.1.7.2   nof_rain_index

nof_rain_index is derived using the Normalized Objective Function (NOF) Rain-Flagging Technique developed by Carl Mears, Frank Wentz and Deborah Smith at Remote Sensing Systems. For a detailed description of the NOF technique, please refer to the "SeaWinds on QuikSCAT Normalized Objective Function Rain Flag Product Description" [Mears et al, 1999].

nof_rain_index is based upon a simplified version of the standard model function to determine a maximum likelihood estimator and a wind speed for each wind vector cell. The maximum likelihood estimator is based upon the sum of the squared differences between the set of σ_o that were used to retrieve winds and the corresponding model function σ_o that would generate the ambiguity with the greatest maximum likelihood estimator. The wind speed is based upon a modified σ_o which is specifically calculated to be less sensitive to rain. The simplified maximum likelihood estimator is normalized by a tabular empirical estimate for the 95th percentile of the squared difference distribution. These tabular values are indexed by beam polarization, cross track location in the measurement swath and wind speed. The normalized maximum likelihood estimator is then divided by the number of σ_o's in the wind vector cell, multiplied by thirty, and rounded to the nearest integer value.

nof_rain_index is most effective for wind speeds under 10 m/s and should not very effective for wind speeds greater than 15 m/s. Users should employ this flag with caution in regions of high wind speed.

Values of nof_rain_index range between 0 and 249. Invalid values are indicated with a nof_rain_index of 250.

6.1.8   Level 2B Data Usage Notes

The L2B data set is the most highly processed standard product and has the simplest flagging.

wvc_qual_flag (See: L2B SIS, Sect. 3.5.68): This flag will be 0 for the best data. The key bit is bit 9 indicating that wind retrieval was performed. A value of 1 for bit 9 indicates that no wind retrieval was performed, and therefore no ambiguities were calculated (variable "num_ambigs"=0) nor was any ambiguity chosen by an ambiguity removal algorithm ("wvc_selection"=0).

The coastal (bit 7) or ice edge (bit 8) flags will be of interest to investigators attempting to work close to land or ice; these advisory bits may be set if any part of the wind vector cell was over land or ice, respectively, even though sufficient good ocean σ_o measurements were available in the WVC to retrieve winds.

While accuracy requirements do not apply outside the 3 to 30 m/s range indicated by the high (bit 10) and low (bit 11) speed flags, and preliminary analysis shows that these winds have larger differences from NWP models, there is nothing inherently wrong with winds with the speed flags set. It is, however, suggested that winds below 1 m/s be used with great caution. In addition, the model function has had less development and correlative validation measurements are rare above about 20 m/s even for QSCAT-1/F13.

Rain flagging bits: Bit 12 indicates whether the rain flag bit 13 is usable. Thus, when bit 12 is set to 0 and bit 13 set to 1, rain is indicated. When both bits 12 and 13 are set to 0, no rain is indicated.

Data availability: Bit 14 indicates whether all four instrument "views" (inner and outer beams looking fore and aft of the spacecraft) were available; this will always be 1 (invalid) in the outer swath as only the outer beam (V-pol) is available.

wvc_selection (L2B SIS 3.5.71): The variables "wind_speed" and "wind_dir" contain speed and direction information for up to four ambiguities for each wind vector cell. As noted in the SIS and Users Guide, the ambiguities are listed in decreasing likelihood order. The variable "wvc_selection," if non-zero, contains a pointer (values 1 to 4) to the ambiguity selected by the ambiguity removal algorithm. *Therefore, the first-listed ambiguity in "wind_speed" and "wind_dir" does not correspond automatically to the chosen ambiguity.* Cells with wvc_selection=0 have no ambiguity selected and should be excluded from comparisons and most statistics.

The L2B data set also contains nudge field wind speed ("model_speed") and wind direction ("model_dir") estimates for each valid wind vector cell.   These speed and direction values are derived from the available operational NCEP global 2.5° resolution, 1000mb analysis closest in time to the QuikSCAT overpass at the geographical location of the WVC. They represent spatially, but not temporally, interpolated winds. Wind speeds are estimates for the 1000 mb level – they are *not* 10 m wind speeds. Comparisons between the QuikSCAT wind velocity estimates and the "model" wind velocity estimates contained in the L2B data provide only an exceptionally crude indication of the accuracy of the QuikSCAT winds.

The "atten_corr" variable in the L2B product contains a single, representative value for the atmospheric attenuation in each WVC. The actual attenuation corrections applied to each backscatter measurement in

a WVC (from a monthly average map) prior to wind retrieval can be different from the single atten_corr value.

Please refer to Section 9.6.1 for a more complete listing of Level 2B flag values.

6.2   QuikSCAT Level 2A Product—Surface Flagged Sigma0s and Attenuations in 25 km Swath Grid

The Level 2A product consists of σ_o values for every radar backscatter measurement acquired during one satellite rev. Each σ_o is based on the sum of the echo energies measured among the eight center high resolution slices in a single scatterometer pulse. The Level 2A Product file also contains ancillary data elements that correspond to each of the σ_o values. Among the ancillary data elements are entries that list the location, the quality and the uncertainty of the σ_o values.

6.2.1   Level 2A Header

The contents of the QuikSCAT Level 2A header are contained in metadata elements which are stored as HDF global attributes. The header data covers the entire contents of the file.

The name of each global attribute used for metadata storage matches the name of a metadata element. Each global attribute consists of ASCII characters and contains at least three lines of data. The information specified in each global attribute indicates the data type, the array size and value of the metadata element.

6.2.2   Level 2A Header Structure

The following table lists all of the elements in the QuikSCAT Level 2A Header. All of the header elements except skip_start_time and skip_stop_time must appear in every Level 2A Product file. These two optional elements delimit data gaps or regions of data that were not processed. These metadata elements appear only when expected sequences of data are missing from the Product file.

Table 6.4 Header Structure for L2A Product

Element Name	Definition	Max Array Size
LongName	"QuikSCAT Level 2A Surface Flagged Sigma0s and Attenuations in 25.0 km Swath Grid"	[1]
ShortName	"QSCATL2A"	[1]
producer_agency	"NASA"	[1]
producer_institution	"JPL"	[1]
InstrumentShortName	"SeaWinds"	[1]
PlatformLongName	"NASA Quick Scatterometer"	[1]
PlatformShortName	"QuikSCAT"	[1]
PlatformType	"spacecraft"	[1]
project_id	"QuikSCAT"	[1]
data_format_type	"NCSA HDF"	[1]
GranulePointer	A pointer to the output data granule	[1]
QAGranulePointer	A pointer to the quality assurance granule.	[1]
InputPointer	A pointer to the major input data granule.	[1]
ancillary_data_descriptors	An array of file names, which specifies all of the ancillary data, files which were used to generate the output product.	[10]
OrbitParametersPointer	A pointer to one data granule or a set of granules that provide the orbit parameters that are used to generate the data in this product.	[5]
sis_id	A character string that specifies which SIS document describes the organization and format of data in the file.	[1]
build_id	A character string that identifies the version of the SeaPAC software that was used to generate this data file.	[1]
HDF_version_id	A character string that identifies the version of the HDF software that was used to	[1]

	generate this data file.	
ParameterName	"sigma0"	[1]
QAPercentOutOfBoundsData	The percent of instances when a particular data element within the data product is out of bounds.	[1]
QAPercentMissingData	The percent of instances when a particular data element within the data product is missing.	[1]
OperationMode	"Wind Observation"	[1]
StartOrbitNumber	The orbit number that corresponds to the data at the beginning of the granule.	[1]
StopOrbitNumber	The orbit number that corresponds to the data at the end of the granule.	[1]
EquatorCrossingLongitude	The interpolated longitude of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingTime	The interpolated time of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingDate	The date of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
rev_orbit_period	The time between two consecutive ascending node crossings in the spacecraft orbital path.	[1]
orbit_inclination	The angle between the plane of the spacecraft's orbital path and the earth's equatorial plane.	[1]
orbit_semi_major_axis	The length of the semi-major axis of the QuikSCAT spacecraft orbit.	[1]
orbit_eccentricity	The eccentricity of the spacecraft orbital path.	[1]
rev_number	The assigned revolution number based on the spacecraft orbital history.	[1]
RangeBeginningDate	The initial date for data coverage within this QuikSCAT data product.	[1]
RangeEndingDate	The final date for data coverage within this QuikSCAT data product.	[1]
RangeBeginningTime	The initial time for data coverage within this QuikSCAT data product	[1]
RangeEndingTime	The final time for data coverage within this QuikSCAT data product.	[1]
ProductionDateTime	Wall clock time when this data file was created.	[1]
skip_start_time	A specific date and time, which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment begins.	[10]
skip_stop_time	A specific date and time, which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment ends.	[10]
maximum_sigma0s_per_row	The maximum number of composite sigma0 measurements among all of the wind vector cell rows in the accompanying QuikSCAT level product file.	[1]
ephemeris_type	"GPS", "EPHD" or "EPHP"	[1]
l2a_algorithm_descriptor	A set of character stings that list important details about the implementation of the L2A Processor algorithm that was used to generate this product.	[8]
l2a_actual_wvc_rows	The number of wind vector cell rows in the Level 2A Product which contain valid sigma0 measurement data.	[1]
l2a_expected_wvc_rows	The expected number of wind vector cell rows.	[1]
sigma0_granularity	"whole pulses", "slice composites", "composites of composites", or "pulse slices"	[1]

6.2.3 Level 2A Data

The standard QuikSCAT Level 2A Product contains whole pulse σ_o's. Each whole pulse σ_o incorporates the measures of the eight center high resolution slices from the same scatterometer pulse. The Level 2A σ_o's are grouped by wind vector cell (WVC) rows. Each WVC row corresponds to a single cross-track cut of the SeaWinds instrument measurement swath. Each Level 2A WVC is a 25 km square. Thus, 1624 WVC rows are required to cover one complete circumference of the earth.

The Level 2A Processor passes the full set of data which lie within the input Level 1B Product into the output Level 2A Product. The Level 1B Product is in temporal order and therefore defined by time boundaries. The Level 2A Product is in spatial order and defined by spatial boundaries. To insure that all data are transferred from the input to the output product, the Level 2A Processor design must consider the data acquisition pattern of the SeaWinds instrument's rotating antenna. As the spacecraft approaches and passes a rev boundary, the SeaWinds instrument acquires data on either side of that boundary. Thus, the Level 2A Product must include wind vector cell rows that extend beyond the 1624, which comprise one complete earth circumference. To cover those σ_o measurements that lie beyond the spatial boundaries of the rev, the Level 2A Product includes 39 additional wind vector cell rows before the start and after the end of each rev. These additional wind vector cell rows cover 975 km at each end of the rev. Thus, the nominal Level 2A Product contains a total of 1702 wind vector cell rows.

The nominal instrument measurement swath extends for 900 km to either side of the satellite nadir track. Thus, a total of 72 WVC values, with 36 on either side of the nadir track, should accommodate nearly every σ_o measurement. The attitude of the QuikSCAT spacecraft and the shape of the earth influence the ultimate location of each backscatter footprint on the earth's surface. Due to these variations, some σ_o cells fall outside of the nominal 900 km SeaWinds instrument measurement swath. Few if any composite σ_o cells, however, should lie further than 950 km from the spacecraft nadir track. Thus, the Level 2A Product design includes four additional cell indices per WVC row. The Level 2A data entry cell_index stores the location indicator for each composite σ_o within the WVC row.

Since the SeaWinds pencil beam antenna rotates as the spacecraft travels, the number of composite σ_o measurements that fall within each particular WVC is highly dependent on the cell's cross-track location. Studies indicate that a few cells located about 700 km from spacecraft nadir track may contain 40 or more scatterometer pulses. Most cells in the swath, however, are likely to contain between 12 and 30 scatterometer pulses. Clearly, a data design that assigns adequate space for the maximum number of expected pulses to every WVC in the grid is wasteful.

Using the spacecraft velocity and the instrument telemetry pulse rate, a simple calculation determines the expected number of measurement pulses which the SeaWinds instrument can acquire over its full swath as it travels between two along-track locations. Nominal instrument specifications indicate that the SeaWinds instrument pulses approximately 709 times, as the spacecraft travels a distance of 25 km. This distance is the width of one Level 2A WVC row.

The Level 2A data design takes advantage of this constant pattern. The Level 2A Product groups composite σ_o cells by WVC row.

To accommodate the highest pulse rate in the Scatterometer Electronic Subsystem (SES) specifications, the product design assumes that space should be available for 810 measurements pulses per wind vector cell row.

Almost all of the elements in the Level 2A Data are stored in HDF SDS data objects. The only exception is the wvc_row_time, which is stored in an HDF Vdata object.

Among the SDS objects in the Level 2A Product, only row_number and num_sigma0 are one-dimensional arrays. Every element in both of these arrays is representative of an entire WVC row.

All of the remaining Level 2A Data entries are two-dimensional SDS objects. In each case, the first array index represents the WVC row. For SDS objects num_sigma0_per_cell, num_wvc_tb_in, num_wvc_tb_out, mean_wvc_tb_in, mean_wvc_tb_out, std_dev_wvc_tb_in and std_dev_wvc_tb_out, the second array index represents one of the wind vector cells within the row. For the remaining two

dimensional SDS objects in the Level 2A Product, the second dimension index represents a specific σ_o within the WVC row.

Figures illustrating the internal structure of the QuikSCAT Level 2A data can be found in Section 3.2 of the Level 2A Data Software Interface Specification (SIS).

6.2.4   Level 2A Data Structure

With the exception of wvc_row_time, every entry in the Level 2A Data is stored in an HDF scientific data set (SDS) object. An HDF Vdata object stores the wvc_row_time. The name of each Level 2A HDF data object matches the name of the data element which it stores. For all Level 2A Data HDF objects, the first array index identifies the wind vector cell row.

Objects wvc_row_time, wvc_row and num_sigma0 are one-dimensional. Each entry of these arrays applies to an entire wind vector cell row.

All of the remaining Level 2A Data elements are two-dimensional SDS objects. The second dimension index of the Level 2A two dimensional SDS objects may represent one of two different counters. Among one set of two dimensional SDS objects, the second dimension index represents a wind vector cell. In the second set of two dimensional SDS objects, the second dimension index represents a particular σ_o measurement.

Data elements num_sigma0_per_cell, num_wvc_tb_in, num_wvc_tb_out, mean_wvc_tb_in, mean_wvc_tb_out, std_dev_wvc_tb_in and std_dev_wvc_tb_out comprise the first set of two dimensional SDS objects. For each of these SDS objects, the second dimension index represents a wind vector cell. Thus, num_sigma0_per_cell[390,70] contains the number of σ_o entries in the 71st wind vector cell of the 391st wind vector cell row. Likewise, sigma0_qual_flag[523,245] contains quality information regarding the 246th σ_o cell in the 524th wind vector cell row.

Cell_index indicates the wind vector cell location of a σ_o measurement within the wind vector cell row. The QuikSCAT standard numbers wind vector cells from left to right when viewing the orbital swath in the direction of spacecraft flight. Thus, if cell_index[502,100] is 14, then the 101st σ_o in the 503rd wind vector cell row lies in the 14th wind vector cell from the left hand side of the orbital swath when facing the spacecraft's forward direction of motion.

The following table lists the data elements in the SeaWinds Level 2A Data. For the 25 km product, [nrow,ncol,nsig] = [1702,76,810], and for the 12.5 km product [nrow,ncol,nsig] = [3404,152,2000].

Table 6.5 Data Structure for L2A Product

Element Name	Storage Type	Repetition	Scale	Unit	Minimum	Maximum
wvc_row_time	char	[nrow]	n/a	UTC	1993-001 T00: 00:00.000	2008-366 T23: 59: 60.999
row_number	int16	[nrow]	1	Index	1	1624
num_sigma0	int16	[nrow]	1	Count	0	810
num_sigma0_per_cell	uint8	[nrow,ncol]	1	Count	0	255
num_wvc_tb_in	uint8	[nrow,ncol]	1	Count	0	120
num_wvc_tb_out	uint8	[nrow,ncol]	1	Count	0	120
mean_wvc_tb_in	uint16	[nrow,ncol]	0.01	K	0	350
mean_wvc_tb_out	uint16	[nrow,ncol]	0.01	K	0	350

std_dev_wvc_tb_in	uint16	[nrow,ncol]	0.01	K	0	350
std_dev_wvc_tb_out	uint16	[nrow,ncol]	0.01	K	0	350
cell_lat	int16	[nrow,nsig]	0.01	Deg	-90.00	90.00
cell_lon	uint16	[nrow,nsig]	0.01	Deg E	0.00	359.99
cell_azimuth	uint16	[nrow,nsig]	0.01	Deg from N	0.00	359.99
cell_incidence	int16	[nrow,nsig]	0.01	Deg	44.00	60.00
sigma0	int16	[nrow,nsig]	0.01	dB	-300.00	20.00
sigma0_attn_amsr	int16	[nrow,nsig]	0.01	dB	-50.00	30.00
sigma0_attn_map	int16	[nrow,nsig]	0.01	dB	-50.00	30.00
kp_alpha	int16	[nrow,nsig]	0.001	N/A	0.100	2.000
kp_beta	uint16	[nrow,nsig]	1.0E-7	N/A	1.0E-6	1.0E-3
kp_gamma	float32	[nrow,nsig]	1.0	N/A	1.0E-10	1.0E-2
sigma0_qual_flag	uint16	[nrow,nsig]	1	Bit Field	0x0000	0x03FF
sigma0_mode_flag	uint16	[nrow,nsig]	1	Bit Field	0x0000	0xFFFE
surface flag	uint16	[nrow,nsig]	1	Bit Field	0x0000	0x0C03
cell_index	uint8	[nrow,nsig]	1	Index	0	76
frame_pulse_index	uint32	[nrow,nsig]	1	Index	0	1300000

6.2.5 Level 2A Bit Flag Convention

At the start of processing, all QuikSCAT bit flag values are initialized. The standard procedure for QuikSCAT initialization of bit flags sets all defined bits to 1 and all undefined bits to 0. If the Level 2A Processor detects an anomalous condition which halts the processing for a particular σ_o, the appropriate bit flag which indicates the error condition remains set to 1. Since the processor may curtail sub-sequent operations for a composite σ_o that fails a test, those bit flag conditions which normally would be tested in the subsequent code could retain their initialized value. Thus, the order in which bit flags are processed often determines whether their values are meaningful.

For instance, if the surface_flag for a particular composite σ_o indicates that land is present, the Level 2A Processor does not test whether ice is present. Since the code does not test for ice, the value of the surface ice flag and ice map available flag remain set to 1. Clearly, these values for the surface ice flag and the ice map available flag are not indicative of the conditions for that σ_o.

On the other hand, the Level 2A Processor does attempt to calculate attenuation for every σ_o regardless of whether the measurement had been flagged for land or for ice. Thus, the value of the attenuation map available flag is always correct, regardless of previously flagged conditions.

The following table describes the bit flag dependencies for the surface_flag in the Level 2A Product. The column on the left lists three pivotal bits in the surface_flag. The middle column lists the possible values for those bits. The column on the right indicates which of the remaining bits in the surface_flag are meaningful under the corresponding conditions.

41

Table 6.6 Surface_Flag Bit Flag Dependencies

Bit Flag	Value	Other Bits with Meaningful Value
Surface land flag (bit 0)	0	Ice map data available flag (bit 10)
		Attenuation map data available flag (bit 11)
	1	Attenuation map data available flag (bit 11)
Surface ice flag determined by map (bit 1)	0	Surface land flag (bit 0)
		Ice map data available flag (bit 10)
		Attenuation map data available flag (bit 11)
	1	Surface land flag (bit 0)
		Attenuation map data available flag (bit 11)
Ice map data available flag (bit 10)	0	Surface land flag (bit 0)
		Surface ice flag determined by map (bit 1)
		Attenuation map data available flag (bit 11)
	1	Surface land flag (bit 0)
		Attenuation map data available flag (bit 11)

6.2.6   Level 2A Null Values

QuikSCAT null values are listed as zeros in the Level 2A Product. The Level 2A Product does, however, contain adequate information so that users can easily distinguish null values from actual zeros.

The Level 2A Product lists null values whenever the maximum number of σ_o values in a wind vector cell row is less than the maximum 810. As an example, assume the SDS num_sigma0 indicates that there are 700 σ_o records in a particular wind vector cell row. For that wind vector cell row, each SDS contains exactly 700 valid second dimension entries. The Level 2A Product lists zeros for every data element that represents a composite σ_o with a second dimension index which is greater than or equal to 700 for that wind vector cell row.   Clearly, all of those zeros should be interpreted as null values.

Based on this example, assume that num_sigma0[400] is 700. If cell_lat[400,699] and cell_lat[400,700] are both equal to zero, cell_lat[400,699] is a true zero value. The associated σ_o is located on the equator. On the other hand, cell_lat[400,700] is a null value. This data interpretation method applies to all of the data objects in the Level 2A Product where the second dimension index represents a σ_o.

The data element cell_index verifies the existence of null entries. Every composite σ_o must lie within a wind vector cell. Thus, if the cell_index for a particular pair of indices is zero, no associated σ_o exists. All data associated with that pair of indices are null. For example, if cell_index[400,700]=0, then the index pair [400,700] references null values for all Level 2A Product SDS objects.

The attenuation map available bit in the surface_flag also distinguishes zero from null values in the Level 2A Product. If the surface_flag indicates that the attenuation data are not available, then the sigma0_attn_map data element with matching array indices is zero. That zero represents a null value.

6.2.7   Level 2A Data Usage Notes

sigma0_qual_flag (See: L2A SIS, Sect. 3.5.60): This is the key flag for σ_o quality.   Note the dependencies table in the SIS. For good data it will = 0, except, perhaps, for the negative σ_o flag in bit 2. Because of the noise subtraction process, it is possible to obtain an estimate of signal power that is < 0 giving a negative σ_o. Since most σ_o 's are fractional, they are represented as negative in dB. Thus to indicate an estimate of negative signal power, bit 2 is set. These are valid measurements from very low

backscatter areas (low wind speed, land, etc.) Data with low SNR (third bit) may also be valid, but are of lesser quality.

slice_qual_flag (See: L1B SIS, Sect. 3.5.81): Four bits give information about each of the 8 slices in a pulse. Except for the second of each set of bits—the negative σ_o flag—the bits should all be 0 for good data. Data with low SNR (third bit) may also be valid, but are of lesser quality. Note the dependencies table in the SIS.

Please refer to Section 9.6.2 for a more complete listing of Level 2A flag values.

6.3   QuikSCAT Level 1B Product—Time-Ordered Earth-Located Sigma0s

Each Level 1B file represents one satellite rev. The Level 1B Product lists the σ_o and the σ_o slice values for each radar backscatter measurement within the rev. In addition, the Level 1B Product includes elements which specify the location and the quality of each backscatter measurement. The product contains a few additional parameters that indicate particular conditions and uncertainties that the higher level QuikSCAT Processors require.

6.3.1   Level 1B Header

The contents of the SeaWinds Level 1B header are contained in metadata elements which are stored as HDF global attributes. Each header data set applies to the entire contents of the file.

The name of each global attribute used for metadata storage matches the name of a metadata element. Each global attribute consists of ASCII characters and contains at least three lines of data. The information specified in each global attribute indicates the data type, the array size and contents of the metadata element.

6.3.2   Level 1B Header Structure

The following table lists all of the elements in the QuikSCAT Level 1B header. All of the header elements except skip_start_time, skip_stop_time, skip_start_frame and skip_stop frame must appear in every Level 1B Product file. These four optional elements delimit data gaps of regions of data that were not processed. These metadata elements appear only when expected sequences of data are missing from the Product file.

Table 6.7 Header Structure for L1B Product

Element Name	Definition	Max Array Size
LongName	"QuikSCAT Level 1B Time-Ordered Earth-Located Sigma0s"	[1]
ShortName	"QSCATL1B"	[1]
producer_agency	"NASA"	[1]
producer_institution	"JPL"	[1]
InstrumentShortName	"SeaWinds"	[1]
PlatformLongName	"NASA Quick Scatterometer"	[1]
PlatformShortName	"QuikSCAT"	[1]
PlatformType	"spacecraft"	[1]
project_id	"QuikSCAT"	[1]
data_format_type	"NCSA HDF"	[1]
GranulePointer	A pointer to the output data granule	[1]
QAGranulePointer	A pointer to the quality assurance granule.	[1]
InputPointer	A pointer to the major input data granule.	[1]
ancillary_data_descriptors	An array of file names that specifies all of the ancillary data files which were used to generate the output product.	[32]
OrbitParametersPointer	A pointer to one data granule or a set of granules that provide the orbit parameters that are used to generate the data in this product.	[5]
sis_id	A character string that specifies which SIS document describes the organization and format of data in the file.	[1]
build_id	A character string that identifies the version of the SeaPAC software that was used to generate this data file.	[1]
HDF_version_id	A character string that identifies the version of the HDF software that was used to generate this data file.	[1]
ParameterName	"slice_sigma0"	[1]
QAPercentOutOfBoundsData	The percent of instances when a particular data element within the data product is out of bounds.	[1]
QAPercentMissingData	The percent of instances when a particular data element within the data product is missing.	[1]
OperationMode	"Wind Observation"	[1]
StartOrbitNumber	The orbit number that corresponds to the data at the beginning of the granule.	[1]
StopOrbitNumber	The orbit number that corresponds to the data at the end of the granule.	[1]
EquatorCrossingLongitude	The interpolated longitude of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingTime	The interpolated time of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
EquatorCrossingDate	The date of the equator crossing of the spacecraft nadir track in the ascending direction.	[1]
rev_orbit_period	The time between two consecutive ascending node crossings in the spacecraft orbital path.	[1]
orbit_inclination	The angle between the plane of the spacecraft's orbital path and the earth's equatorial plane.	[1]
orbit_semi_major_axis	The length of the semi-major axis of the QuikSCAT spacecraft orbit.	[1]
orbit_eccentricity	The eccentricity of the spacecraft orbital path.	[1]
rev_number	The assigned revolution number based on the spacecraft orbital history.	[1]
RangeBeginningDate	The initial date for data coverage within this QuikSCAT data product.	[1]
RangeEndingDate	The final date for data coverage within this QuikSCAT data product.	[1]
RangeBeginningTime	The initial time for data coverage within this QuikSCAT data product	[1]

45

RangeEndingTime	The final time for data coverage within this QuikSCAT data product.	[1]
ProductionDateTime	Wall clock time when this data file was created.	[1]
skip_start_time	A specific date and time, which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment begins.	[10]
skip_stop_time	A specific date and time, which indicates where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment ends.	[10]
l1b_expected_frames	The expected number of telemetry frames in the Level 1B Product file.	[1]
l1b_actual_frames	The number of telemetry frames which are listed in the Level 1B Product.	[1]
l1b_algorithm_descriptor	A set of character strings which list important details about the implementation of the Level 1B Processor algorithm.	[8]
ephemeris_type	"GPS", "EPHD", or "EPHP"	[1]
attitude_type	"Star Tracker"	[1]
maximum_pulses_per_frame	The maximum number of scatterometer pulses among all of the telemetry frames in this SeaWinds level product file.	[1]
cell_kpc_b	A two dimensional array which contains the first order coefficient of an inverse second order polynomial in the signal to noise ratio.	[8,2]
slice_kpc_b	A two dimensional array which contains the first order coefficient of an inverse second order polynomial in the signal to noise ratio.	[8,2]
cell_kpc_c	A two dimensional array which contains the second order coefficient of an inverse second order polynomial in the signal to noise ratio.	[8,2]
slice_kpc_c	A two dimensional array which contains the second order coefficient of an inverse second order polynomial in the signal to noise ratio.	[8,2]
num_slices_per_cell_sigma0	The number of high resolution slices which combine to determine a representative measurement for each complete scatterometer pulse.	[1]
receiver_gain_ratio	The gain ratio of the echo filter frequency response function to the noise filter frequency response function. Nominally, "4.65".	[1]
skip_start_frame	The array index of a telemetry frame that specifies where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment begins.	[10]
skip_stop_frame	The array index of a telemetry frame that specifies where a nonexistent, unnecessary, spurious, questionable, or erroneous data segment ends.	[10]

6.3.3   Level 1B Data

The QuikSCAT Level 1B data are grouped by telemetry frames. Within these telemetry frames, the Level 1B data are divided into three major subsets. These subsets are the Telemetry Frame Header, the Pulse Data and the Slice Data.

The Telemetry Frame Header data report the state of the SeaWinds instrument as well as indicate the spacecraft position, velocity, and attitude. The Telemetry Frame Header data also include algorithmic and instrument parameters which are common to all σ_o cells within the same telemetry frame. All of the Telemetry Frame Header data correspond to the time listed in data element frame_time.

The Pulse Data list the outcome of the QuikSCAT implementation of the radar equation for each entire scatterometer pulse. This data set includes parameters that locate each pulse's footprint on the earth's surface, as well as indicators of each measurement's quality and uncertainty.

Most of the Slice Data parameters are analogous to those found in the Pulse Data. The Slice Data elements, however, reference the individual σ_o slices that are generated by the SeaWinds instrument's high resolution Linear Frequency Modulation Chirp (LFMC) function. The QuikSCAT Level 1B Product

lists measurements for the eight innermost slices of each σ_o. The two slices at either end of the σ_o pulse do not appear in the Level 1B Product.

An HDF Vdata object stores the frame_time data element. An HDF SDS object stores all other data element in the Level 1B Product. The first dimension index of every data object within the Level 1B Data references the telemetry frame. Thus, every data element with the same first dimension index relates to the same telemetry frame. Data element sc_lat[6212] specifies the spacecraft latitude at frame_time[6212].

The elements in the Pulse and Slice Data contain a second data index. The second index in these arrays references on of the 100 scatterometer pulses in each telemetry frame. Thus, data element cell_azimuth[6212,41] represents the azimuth of the σ_o cell for the forty second scatterometer pulse in the telemetry frame which begins at frame_time[6212].

Except for the slice_qual_flag, the data elements in the Slice Data contain a third data index. The third index in these arrays represents one of the slices in each pulse. By convention, slices are numbered from the one nearest the spacecraft to the one farthest away. Thus, data element slice_sigma0[6212,41,3] contains the normalized radar cross section measurement for the fourth nearest slice of the forty second scatterometer pulse in the telemetry frame which begins at frame_time[6212]. Data element slice_qual_flag folds all of the information about each slice into a single element. Thus, slice_qual_flag does not require the third dimension index.

For more information about the QuikSCAT scatterometer slice and pulse geometry, refer to Section 5.2.2.

Figures illustrating the internal structure of the QuikSCAT Level 1B data can be found in Section 3.2 of the Level 1B Data Software Interface Specification (SIS).

6.3.4 Level 1B Data Structure

6.3.4.1 Telemetry Frame Header

These entries pertain to an entire telemetry frame within the Level 1B data. Data element frame_time is stored in an HDF Vdata object. All of the other data elements are stored in one-dimensional HDF SDS objects. The array index for these SDS objects specifies the telemetry frame. The table below lists the HDF objects in the Level 1B frame header.

Table 6.8 Telemetry Frame Header Structure for L1B Product

Element Name	Storage Type	Repetition	Scale	Unit	Minimum	Maximum
frame_time	char	[13000]	n/a	UTC	1993-001 T00: 00:00.000	2008-366 T23: 59: 60.999
orbit_time	uint32	[13000]	1	Sec	0	4294967295
frame_inst_status	uint32	[13000]	1	Bit Field	0x00000000	0x3FFFFFFF
frame_err_status	uint32	[13000]	1	Bit Field	0x00000000	0x01FFFFFF
frame_qual_flag	uint16	[13000]	1	Bit Field	0x0000	0x001F
num_pulses	int8	[13000]	1	Count	0	100
sc_lat	float32	[13000]	1	Deg	-90.000	90.000
sc_lon	float32	[13000]	1	Deg E	0.000	359.999
sc_alt	float32	[13000]	1	m	700000	900000
x_pos	float32	[13000]	1	m	-9999999	9999999

y_pos	float32	[13000]	1	m	-9999999	9999999
z_pos	float32	[13000]	1	m	-9999999	9999999
x_vel	float32	[13000]	1	m/s	-8000.00	8000.00
y_vel	float32	[13000]	1	m/s	-8000.00	8000.00
z_vel	float32	[13000]	1	m/s	-8000.00	8000.00
roll	int16	[13000]	0.001	Deg	-3.000	3.000
pitch	int16	[13000]	0.001	Deg	-3.000	3.000
yaw	int16	[13000]	0.001	Deg	-3.000	3.000
bandwidth_ratio	int16	[13000]	0.001	N/A	0	32.767
x_cal_A	int16	[13000]	0.01	N/A	-300.00	300.00
x_cal_B	int16	[13000]	0.01	N/A	-300.00	300.00

6.3.4.2 Pulse Data

The Pulse Data list individual values for each radar backscatter measurement. In some instances, the Pulse Data list instrument calibrations instead of measurements. The Calibration/ Measurement Pulse bit flag in data element sigma0_mode_flag specifies whether the corresponding pulse is a calibration or a measurement.

A distinct SDS object stores each data element in the Pulse Data. The name of each SDS object matches the data element that it stores. All of the data elements in the Pulse Data are two-dimensional arrays. The first dimension index specifies the telemetry frame. The second dimension index represents a particular σ_o measurement. Data elements cell_lon[4367,15] is the cell longitude and snr[4367,15] is the signal to noise ratio for the 16th σ_o measurement in the 4368th telemetry frame. The table below lists all of the elements within the Pulse Data.

Table 6.9 Pulse Data Structure for L1B Product

Element Name	Storage Type	Repetition	Scale	Unit	Minimum	Maximum
cell_lat	float32	[13000,100]	1	Deg	-90.00	90.00
cell_lon	float32	[13000,100]	1	Deg E	0.00	359.99
sigma0_mode_flag	uint16	[13000,100]	1	Bit Field	0x0000	0x1FFE
sigma0_qual_flag	uint16	[13000,100]	1	Bit Field	0x0000	0x03FF
cell_sigma0	int16	[13000,100]	0.01	dB	-300.00	20.00
frequency_shift	int16	[13000,100]	1	Hz	-25000	25000
cell_azimuth	uint16	[13000,100]	0.01	Deg from N	0.00	359.99
cell_incidence	int16	[13000,100]	0.01	Deg	44.00	60.00
antenna_azimuth	uint16	[13000,100]	0.01	Deg	0.00	359.99
cell_snr	int16	[13000,100]	0.01	dB	-30.00	300.00
cell_kpc_a	int16	[13000,100]	0.0001	N/A	0.01	0.1
qscat_app_tb	int16	[13000,100]	0.1	K	0.0	350.0

6.3.4.3 Slice Data

The Slice Data reference each of the slices that are generated by the SeaWinds instrument's high-resolution mode Linear Frequency Modulation Chirp (LFMC) function. In some instances, the Slice Data

list instrument calibrations instead of measurements. The Calibration/ Measurement Pulse bit flag in data element sigma0_mode_flag specifies whether the corresponding pulse is a calibration or a measurement.

A distinct SDS stores each data element in the Slice Data. Except for the slice_qual_flag, all of these data elements are three-dimensional arrays. The first dimension index specifies the telemetry frame. The second dimension index represents the σ_o measurement. The third dimension index represents each of the slices of the σ_o measurement. Thus, slice_sigma0[2304,31,4] is the normalized backscatter measure and slice_incidence[2304,31,4] is the beam incidence angle for the 5th slice of the 32nd pulse in the 2305th telemetry frame.

The slice_qual_flag is a two dimensional array. The first dimension index represents the telemetry frame. The second dimension index represents a scatterometer the slices within the scatterometer pulse.

The table below lists all of the elements within the Slice Data.

Table 6.10 Slice Data Structure for L1B Product

Element Name	Storage Type	Repetition	Scale	Unit	Minimum	Maximum
slice_qual_flag	uint32	[13000,100]	1	Bit Field	0x00000000	0xFFFFFFFF
slice_lat	int16	[13000,100,8]	0.0001	Deg	-3.2768	3.2767
slice_lon	int16	[13000,100,8]	0.0001	Deg E	-3.2768	3.2767
slice_sigma0	int16	[13000,100,8]	0.01	dB	-300.00	20.00
x_factor	int16	[13000,100,8]	0.01	N/A	-300.00	300.00
slice_azimuth	uint16	[13000,100,8]	0.01	Deg from N	0.00	359.99
slice_incidence	int16	[13000,100,8]	0.01	Deg	44.00	60.00
slice_snr	int16	[13000,100,8]	0.01	dB	-30.00	300.00
slice_kpc_a	int16	[13000,100,8]	0.0001	N/A	0.01	0.1

6.3.5   Level 1B Bit Flag Convention

The Level 1B Product includes two critical bit flags that identify the data elements that have acceptable quality. The two bit flags are the Data Quality Flag (bit 4) in the frame_qual_flag and the Sigma0 Usability Flag (bit 0) in the sigma0_qual_flag. If the Data Quality Flag in the frame_qual_flag is 0, then most, if not all of the data in the corresponding telemetry frame are valid. If the value of the Data Quality Flag in the frame_qual_flag is 1, then all of the data in the corresponding telemetry frame are suspect. If the Sigma0 Usability Flag in the sigma0_qual_flag is 0, then the data which pertain to the corresponding whole scatterometer pulse are valid. The bit flags in the slice_qual_flag indicate whether the data that pertain to each individual slice are valid as well. If the Sigma0 Usability Flag in the sigma0_qual_flag is set to 1, then most, if not all of the data associated with the corresponding telemetry pulses are suspect.

At the start of processing, all QuikSCAT bit flag values are initialized. The standard procedure for QuikSCAT initialization of bit flags sets all defined bits to 1 and all undefined bits to 0. If the Level 1B Processor detects an anomalous condition which halts the processing for a particular σ_o, or σ_o slice, the appropriate bit flag which indicates the error condition remains set to 1. Since the processor curtails subsequent operations for the σ_o or the slice 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.

For example, if the sigma0_qual_flag for a particular σ_o indicates an error in the determination of the cell location, the Level 1B Processor curtails all further processing for that σ_o and its component slices. Since

49

further processing does not take place, most of the remaining bits in the sigma0_qual_flag and the slice_qual_flag associated with that pulse do not list valid values. Only four bits in the sigma0_qual_flag contain valid values. One valid bit indicates the quality of the scatterometer pulse which is used to calculate the σ_o. Two other valid bits indicate the quality of the ephemeris and attitude data which are used to locate the σ_o. Finally; the bit that specifies σ_o usability indicates that this σ_o is not usable for wind retrieval purposes. This bit flag value is valid.

The following table describes the bit flag dependencies for the sigma0_qual_flag and the slice_qual_flag in the Level 1B Product. The column on the left lists the pivotal bits in the sigma0_qual_flag and the slice_qual_flag. The column on the right indicates which of the remaining bits in the sigma0_qual_flag and slice_qual_flag are meaningful when the bit in the corresponding left hand column has a value of 0.

The order of the bit flags listed in the left hand column parallels the processing order in the Level 1B Processor. Thus, the order of the blocks provides additional information. If a pivotal bit flag has a value of 0, then all of the bit flags listed in the right hand column of the same table block have meaningful values. If a pivotal bit flag has a value of 1, then all of the bit flags listed in both the left and the right hand columns of the previous table block have meaningful values.

For example, assume that data analysis is based on the value of the cell location flag. If the cell location flag for a particular pulse σ_o is 0, then the eight bit flags in the same table block are valid. These include the σ_o measurement usable flag, the low SNR flag, the pulse quality flag, the frequency shift flag, the attitude data flag, the ephemeris data flag, the center location flags for each slice and the low SNR flags for each slice. On the other hand, if the cell location flag for a particular pulse is 1, then the five bit flags listed in both columns of the preceding table block are valid. These include the σ_o measurement usable flag, the pulse quality flag, the cell location flag, the attitude data flag, and the ephemeris data flag.

Table 6.11 Bit Flag Dependencies

Pivotal Bit Flag	Other Bit Flags With Meaningful Value when Pivotal Flag is 0
Pulse quality flag (sigma0_qual_flag bit 4)	Sigma0 measurement usable flag (sigma0_qual_flag bit 0)
	Ephemeris data flag (sigma0_qual_flag bit 9)
Ephemeris data flag (sigma0_qual_flag bit 9)	Sigma0 measurement usable flag (sigma0_qual_flag bit 0)
	Pulse quality flag (sigma0_qual_flag bit 4)
	Cell location flag (sigma0_qual_flag bit 5)
	Attitude data flag (sigma0_qual_flag bit 8)
Cell location flag (sigma0_qual_flag bit 5)	Sigma0 measurement usable flag (sigma0_qual_flag bit 0)
	Low SNR flag (sigma0_qual_flag bit 1)
	Pulse quality flag (sigma0_qual_flag bit 4)
	Frequency shift flag (sigma0_qual_flag bit 6)
	Attitude data flag (sigma0_qual_flag bit 8)
	Ephemeris data flag (sigma0_qual_flag bit 9)
	Center location flag for each slice (slice_qual_flag bits 3, 7, 11, 15, 19, 23, 27, 31)
	Low SNR flag for each slice (slice_qual_flag bits 2, 6, 10, 14, 18, 22, 26, 30)
Frequency shift flag	Sigma0 measurement usable flag (sigma0_qual_flag bit 0)

(sigma0_qual_flag bit 6)	Low SNR flag (sigma0_qual_flag bit 1)
	Negative sigma0 flag (sigma0_qual flag bit 2)
	Sigma0 out of range flag (sigma0_qual_flag bit 3)
	Pulse quality flag (sigma0_qual_flag bit 4)
	Cell location flag (sigma0_qual_flag bit 5)
	Temperature range flag (sigma0_qual_flag bit 7)
	Attitude data flag (sigma0_qual_flag bit 8)
	Ephemeris data flag (sigma0_qual_flag bit 9)
	Center location flag for each slice (slice_qual_flag bits 3, 7, 11, 15, 19, 23, 27, 31)
	Low SNR flag for each slice (slice_qual_flag bits 2, 6, 10, 14, 18, 22, 26, 30)
	Peak gain flag for each slice (slice_qual_flag bits 0, 4, 8, 12, 16, 20, 24, 28)
Center location flag for slice (slice_qual_flag bits 3, 7, 11, 15, 19, 23, 27, 31)	Negative sigma0 flag for corresponding slice (slice_qual_flag bits 1, 5, 9, 13, 17, 21, 25, 29)

The Level 1B Processor sets the values of the sigma0_mode_flag before algorithmic processing begins. Thus, the values of the sigma0_mode_flag are valid for all σ_o in the Level 1B Product.

6.3.6 Level 1B Null Values

QuikSCAT null values are listed as zeroes in the Level 1B Product. The Level 1B Product does, however, contain adequate information so that users can distinguish null values from actual zeroes.

Data element num_pulses in the Level 1B Product specifies the number of pulses in each telemetry frame. Under normal circumstances, this number should always be 100. When the Level 1B Processor does not process a telemetry frame, the value of num_pulses is zero. Thus, when num_pulses is zero, virtually all of the other elements in the telemetry frame are zero as well. These zeros represent null values.

If data values associated with a pulse create untenable algorithmic conditions, the Level 1B Processor may curtail processing for that pulse. When these conditions take place, the Level 1B Product displays whatever values the Processor was able to calculate.

The Sigma0 Measurement Usable Flag in the sigma0_qual_flag indicates whether the algorithmic process was successful for each pulse. Whenever the Sigma0 Measurement Usable Flag is set, some or all of the values associated with that pulse may be bad or unreliable. When zeros appear in the data elements which represent a pulse where the Sigma0 Measurement Usable Flag is set, the Level 1B Processor most likely did not reach the point in the algorithm where that particular element is calculated. Thus, users should interpret zeros associated with "unusable" σ_o values as null values.

6.3.7 Level 1B Data Usage Notes

The Level 1B Processor sets the values of the sigma0_mode_flag before algorithmic processing begins. Thus, the values of the sigma0_mode_flag are valid for all σ_o values in the Level 1B product.

frame_err_status (See: L1B SIS, Sect. 3.5.20): It is recommended that only frames with this flag=0 be used. Other settings indicate unusual instrument conditions, or bad attitude (bit 23), or bad ephemeris (bit 24).

frame_inst_status (See: L1B SIS, Sect. 3.5.21): This flag gives information on the instrument state. Many of these bits will normally be non-zero. Normal wind observation mode data will have bits 0-3 = 0000, bits 4-6= 5 (011, resolution = 6 km, effective gate width 0.5 msec), bit 7 = 0, and bit 8 = variable, bits 9-31 = 0 for the initial configuration and no unusual events in the frame.

frame_qual_flag (See: L1B SIS, Sect. 3.5.22): For good telemetry this flag will be 0. If bit 0 or 1 are set the pulses up to the point of filler are probably valid if no other flags indicate otherwise. It is recommended that frames with bit 4 = 1 (bad data found in frame) not be used.

sigma0_mode_flag (See L1B SIS, Sect. 3.5.67): This flag gives information on each σ_o. It propagates some of the information from frame_inst_status to individual σ_o values. Many of the bits will normally be non-zero.

sigma0_qual_flag (See: L1B SIS, Sect. 3.5.68): This is the key flag for σ_o quality. Note the dependencies table in the SIS. For good data it will =0, except, perhaps, for the negative σ_o flag in bit 2. Because of the noise subtraction process, it is possible to obtain an estimate of signal power which is < 0 giving a negative σ_o. Since most σ_o values are fractional, they are represented as negative in dB. Thus to indicate an estimate of negative signal power, bit 2 is set. These are valid measurements from very low backscatter areas (low wind speed, land, etc.) Data with low SNR (third bit) may also be valid, but are of lesser quality.

slice_qual_flag (See: L1B SIS, Sect. 3.5.81): Four bits give information about each of the 8 slices in a pulse. Except for the second of each set of bits—the negative σ_o flag—the bits should all be 0 for good data. Data with low SNR (third bit) may also be valid, but are of lesser quality. Note the dependencies table in the SIS.

Please refer to Section 9.6.3 for a more complete listing of Level 1B flag values.

7　Software and Data Conventions

7.1　File Names

QuikSCAT data file names are 23 characters in length. The file naming convention is as follows:

>   Level 1B: QS_S1Bnnnnn.yyyydddhhmm
>   Level 2A, 25 km Pulse : QS_S2Annnnn.yyyydddhhmm
>   Level 2A, 12.5 km Composite : QS_S2Annnnn.yyyydddhhmm.CP12
>   Level 2B, 25 km Pulse: QS_S2Bnnnnn.yyyydddhhmm
>   Level 2B, 12.5 km Composite: QS_S2Bnnnnn.yyyydddhhmm.CP12

where:

nnnnn:	The QuikSCAT satellite orbital rev number
yyyy:	The calendar year when this product was generated
ddd:	The day of the year when this product was generated
hh:	The hour in twenty-four hour time when this product was generated
mm:	The minute when this product was generated

7.2　File Organization

All QuikSCAT standard products are in Hierarchical Data Format (HDF version 4). 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 QuikSCAT data products using either C or FORTRAN should utilize the NCSA HDF interface library routines (see Section 7.2.1).

All QuikSCAT files are created under the UNIX™ operating system. Since these files are in HDF format, however, these data should be portable to most major computing devices, provided the requisite HDF software tools are available.

Each of the QuikSCAT Level 1B, 2A and 2B 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 QuikSCAT revolutions begin and end at the southernmost orbital latitude.

Each QuikSCAT data product file includes a header. The product header contains multiple metadata elements. The conditions specified by the QuikSCAT 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 QuikSCAT software.

7.3　HDF Data Notation

HDF classifies data elements into one of four distinct data classes. These classes include unsigned integers, signed integers, floating point numbers and characters.

53

HDF class declarations employ the following symbols:

HDF Class	Class Definition
uint	unsigned integer
int	signed integer
float	floating point number
char	character variable

Individual data element class declarations take the form:

    class#

where a legal class is one of the symbols in the above table. The subsequent number, represented by the # sign, indicates the number of bits required to store each instance of the data element. Thus, uint16 designates an unsigned integer data element that requires 16 bits of storage space. Valid HDF classes include 8, 16 and 32 bit signed and unsigned integers, 32 and 64 bit floating point numbers, and character strings of variable length.

The HDF library supports six data models and their accompanying interfaces. The NCSA HDF objects, which the QuikSCAT Level Processors employ, include Scientific Data Sets (SDS), Vdata, and Global Attributes.

An HDF SDS is a fixed dimensional array. An HDF SDS may contain as many as 32,768 dimensions. All of the elements within an SDS must belong to the same data class, and must require the same amount of storage space. Permissible element classes of an SDS include 8, 16 or 32 bit signed or unsigned integers, and 32 or 64 bit floating point numbers. The HDF SDS model incorporates a set of attributes that describe the data object. Standard attributes specify labels, units, plot scales, display formats, maxima, and minima for each data dimension within the SDS. Attributes can contain any descriptive information, including comments. One set of attributes is associated with each dimension of the SDS. An additional set of attributes describes the entire SDS object.

SDS array notation is similar to the standards of the C programming language where indices are zero based. Thus, the first index in each dimension is zero. This convention is unlike Fortran, where the initial index in each dimension is one. In multidimensional SDS arrays, the rightmost subscript index changes most rapidly. Thus, elements ARRAY[15,0,5] and ARRAY[15,0,6] are stored contiguously.

The Vdata model provides a framework to store customized data records. A Vdata object is a one-dimensional array of records. Each record in a Vdata object contains a set of elements that adhere to a specifically defined template. The template may contain any number of data elements, so long as each element belongs to a standard HDF data class. Thus, every array member within the same Vdata object conforms to exactly the same structural definition. A unique character string can serve as an identifier for a specific Vdata structural template.

HDF Global Attributes function identically to the attributes associated with individual SDS objects. Global Attributes, however, specify characteristics of the full set of data within the entire file instead of a single SDS object in the file.

7.4   Data Definition Standards

Below are explanations for the data attributes used in sections 6.2 to 6.4. In most cases, these explanations include all of the potential values for each attribute. In some situations, a particular attribute may not apply to a data element. In those cases, the attribute field does not appear, or the listing contains the character string 'n/a'. Hexadecimal representation sometimes indicates data content more clearly. Numbers represented in hexadecimal begin with the character string '0x'.

HDF_model: The HDF model that stores the data element. QuikSCAT level data products use "scientific data sets", "Vdata" elements, and "global attributes". Most QuikSCAT data are stored in scientific data sets. Global attributes are descriptive entries which are used to store the QuikSCAT metadata.

repetition: Repetition count of the data element, when applicable. Array subscript expressions specify the element's dimension. The number of subscripts indicates the number of dimensions. The value of each subscript represents the maximum number of members in the corresponding dimension.

conceptual_type: The type identifier which reflects the data element in concept. This entry is critical, since QuikSCAT data are often not stored in the form which matches the concept. Acceptable type values include "string", "time", "boolean", "real", "integer" and "enum".

storage_type: The data representation of the element within the storage medium. The storage class specification must conform to a valid HDF type. The valid HDF class strings are "int8", "int16", "int32", "uint8", "uint16", "uint32", "float32", "float64", and "char".

number_of_bytes: HDF classes indicate the storage space required to store integers and floating point numbers. They do not indicate, however, the storage space required for character strings. This entry lists the number of bytes allocated to store data elements as character strings. This attribute does not appear under floating point number and integer listings.

units: Units of measure. Typical values include "deg", "C", "K", "deg/sec", "Watts", "dB", "m", "m**2", "m/sec", "sec", "DN", "frames", "pulses" and "counts".

minimum_value: The appropriate minimum value for a data element in its conceptual type.

maximum_value: The appropriate maximum value for a data element in its conceptual type.

scale_factor: The factor used to convert the value of a non-string element from its conceptual type to its storage type. By convention, the conversion operation from conceptual type to storage type is always division. Users should remember to include the value of the high order bit when interpreting data elements that are stored as unsigned integers.

offset: The component used to convert the value of a non-string element from its conceptual type to its storage type. By convention, the conversion operation from conceptual type to storage type is always subtraction.

valid_values: Some data elements may store a restricted set of values. In these instances, this attribute appears in the data element entry. This attribute lists those values that the data element may store.

nominal_value: The expected or typical value for a data element in its conceptual type.

QuikSCAT time measurements are either character strings or double precision real values. QuikSCAT character string time variables are in Coordinated Universal Time (UTC) format. Strings, which specify both the date and the time, contain 21 ASCII characters. The date/time format conforms to the ASCII Day Segmented Time Code B recommended by the Consultative Committee for Space Data Systems (CCSDS). The string format is yyyydddThh:mm:ss.sss. Time accuracy is to the nearest thousandth of a second. To accommodate leap years, the maximum value in the day of the year field is 366. A maximum value in the seconds field of 60.999 permits leap second addition.

QuikSCAT double precision time variables contain measurements in International Atomic Time (TAI). TAI measurements represent the real number of Standard International (SI) compatible seconds since 12:00 AM January 1, 1993 UTC. This initial time is an Earth Observing System Data and Information System (EOSDIS) Core System (ECS) standard. Although the QuikSCAT Project does not work directly with the ECS, the QuikSCAT Project uses this initial time to generate data that are compatible with data stored in the ECS.

7.5 Coordinate Systems

QuikSCAT level data products employ the Earth Centered Rotating (ECR) Coordinate System to specify the location and velocity of the QuikSCAT spacecraft. The ECR coordinate system is right handed. The origin is at the earth's center. The positive x-axis extends from the origin through the intersection of the equator and the prime (Greenwich) meridian. The positive y-axis runs from the origin through the equator at 90 degrees East longitude. The z-axis extends from the origin through the North Pole.

The spacecraft fixed coordinate system is also right handed. The origin is the center of mass of the spacecraft. The y-axis points in the direction of flight, while the z-axis points in the nadir direction. Spacecraft attitude measurements employ a roll-pitch-yaw system relative to these axes. Positive rotations of attitude conform to the right hand rule.

7.6 Metadata

All of the entries in the QuikSCAT level product header are metadata. Each header data set encompasses the entire contents of the file.

A set of HDF global attributes stores the metadata. The name of each global attribute that is used for metadata storage matches the name of the metadata element. The contents of each global attribute are ASCII characters. Global attributes that list QuikSCAT metadata elements must contain at least three lines. Lines are delimited by the ASCII new-line character.

The first line indicates the metadata type. This entry may contain one of three possible strings:

Metadata Type	Type Definition
int	integer
char	character or character string
float	floating point

The second line indicates the array size. QuikSCAT metadata must be single values, one-dimensional arrays, or two-dimensional arrays. For single valued metadata elements, this line lists the integer 1. For one-dimensional arrays, this line contains a single integer that specifies the number of elements in the array. For two-dimensional arrays, this entry contains two integers that represent the extent of the array's dimensions. The two-dimension specifiers are delimited by a comma.

The third line and all of the lines thereafter list the metadata contents. If the second line indicates that the metadata element is a two-dimensional array, the contents of the array are listed in row major order. In other words, entries with matching first dimension indices and consecutive second dimension indices are listed on consecutive lines.

Metadata elements are character strings that can easily vary in size. Any change in product specification can modify the total number of bytes that are needed to store all of the characters in a metadata element. The number of bytes that are listed for metadata elements are estimates of the maximum number of characters required to store that data element. Software that reads QuikSCAT product metadata may use these byte estimates to insure that the complete content of the metadata element is extracted from the QuikSCAT data product.

7.7   Data Representation

Unless stated otherwise, all data are in binary format. The term byte is synonymous with the ISO term "octet".

7.7.1   Bit and Byte Format

The basic addressable unit is the 8-bit byte. Multi-byte quantities are addressed by the most significant byte, and hence bytes are stored in order of decreasing significance. A byte is 8 contiguous bits starting on an addressable byte boundary. The bits are numbered 0 through 7 starting from right to left.

Example:

Byte n	Byte n+1	Byte n+2	Byte n+3
31 ... 24	23 ... 16	15 ... 08	07 ... 00

The twos complement system is used for negative numbers. The twos complement representation of a negative number is formed by performing binary subtraction of each digit from 1 and then adding 1 to the least significant digit. For example, the twos complement of 11010011 is 00101101.

8   Acquiring and Extracting the QuikSCAT Science Data

8.1   Obtaining the Data

After QuikSCAT data processing, the Level 1B and Level 2A data are distributed by PO.DAAC to approved researchers via a password-protected FTP site. Level 2B data are distributed by PO.DAAC without restriction on the PO.DAAC FTP site:

ftp://podaac.jpl.nasa.gov/pub/ocean_wind/quikscat

Higher-level QuikSCAT data products may also be accessed through the World Wide Web:

http://podaac.jpl.nasa.gov/quikscat

8.1.1   Network Access

Supporting software, documentation and higher-level data products (Level 2B and above) will be available on the PO.DAAC FTP site: ftp://podaac.jpl.nasa.gov. These files are located in the FTP directory **/pub/ocean_wind/quikscat** in the following subdirectories:

Level 2B data, 25 km	data/L2B/
Level 2B data, 12.5 km	data/L2B12/
QA report	mission_status_report/
Rev vs Time	rev_time/REV_TIME.DAT
Software	L2B/sw/, L2B12/sw
Documentation	doc/, L2B/doc, L2B12/doc

8.2   Reading the QuikSCAT Data

Sample read software for the QuikSCAT data are available in C, FORTRAN and Interactive Data Language (IDL). These programs can be easily modified to meet the requirements of individual users. Please contact the PO.DAAC QuikSCAT Data Team (**qscat@podaac.jpl.nasa.gov**) if you encounter any difficulty while using this software.

Program Name	Description	Notes
read_qscat_info.c	C program to read the attributes in Levels 1B, 2A and 2B	1
read_qscat_data1b.c	C program to read the Level 1B data	1
read_qscat_data2a.c	C program to read the Level 2A data	1
read_qscat_data2b.c	C program to read the Level 2B data	1
read_qscat_info.f	FORTRAN program to read the attributes in Levels 1B, 2A and 2B	1
read_qscat_data1b.f	FORTRAN program to read the Level 1B data	1
read_qscat_data2a.f	FORTRAN program to read the Level 2A data	1
read_qscat_data2b.f	FORTRAN program to read the Level 2B data	1
read_qscat_data2a_12.f	FORTRAN program to read the 12.5 km Level 2A data	3
read_qscat_data2b_12.f	FORTRAN program to read the 12.5 km Level 2B data	3
read_qscat_info.pro	IDL program to read the attributes in Levels 1B, 2A and 2B	2
read_qscat_data1b.pro	IDL program to read the Level 1B data	2
read_qscat_data2a.pro	IDL program to read the Level 2A data	2
read_qscat_data2b.pro	IDL program to read the Level 2B data	2

Notes:

(1)   The HDF library must be installed locally before the read software in C or FORTRAN will work properly. The HDF library and further information about HDF may be obtained from the NCSA HDF web site at http://hdf.ncsa.uiuc.edu.

(2)   IDL is a software tool used for the analysis and display of scientific data. It is a registered trademark of Research Systems, Inc. The installation of the HDF library is not necessary in order to use the IDL read software, because IDL already contains the HDF library.

(3)   Separate readers for the 12.5km L2A and L2B are required for Fortran, due to static memory allocation in F77. The IDL and C readers are capable of handling either resolution, because those readers inherently use dynamic memory allocation for the data arrays.

9   Appendices

9.1   PO.DAAC Points of Contact

Questions and comments concerning the QuikSCAT Science Data Products should be directed to PO.DAAC. Please note that e-mail is always the preferred method of communication.

```
E-mail:            podaac@podaac.jpl.nasa.gov
Home Page:         http://podaac.jpl.nasa.gov/quikscat
FTP:               ftp://podaac.jpl.nasa.gov
```

```
       By mail:            JPL PO.DAAC User Services Office
                           Jet Propulsion Laboratory
                           Mail Stop Raytheon-299
                           4800 Oak Grove Drive
                           Pasadena, CA  91109 U.S.A.
```

9.2   Definitions of Commonly-Used Terms

Ambiguity Removal   Also called the ambiguity selection process. This is the process of selecting the best wind vector field from the wind solutions retrieved from the scatterometer measurements within each wind vector cell. The QuikSCAT level processing software performs ambiguity removal using a median filter.

Doppler Binning   A technique used on QuikSCAT to adjust the σ_o cell bandpass frequencies as a function of orbit location in order to maintain accurate beam-to-beam cell co-registration and constant swath location. The processing of return signals is controlled by a binning parameter table, which is used by the on-board processor to divide the received power into cells in the frequency domain, and is used in the ground processing to perform Earth location of the σ_o cells. The binning parameter table for a given swath layout and cell resolution depends mainly on the spacecraft orbit.

Model Function   The relationship between normalized radar backscatter cross-section (σ_o) and wind velocity. The model function is known to be a function of wind speed, wind direction relative to the look angle, incidence angle, and radar polarization. Other, possibly significant, uncalibrated parameters include sea surface temperature, sea state, and salinity. For QuikSCAT, the model function is cast in a tabular form.

Wind Retrieval   The process of finding the set of wind vector solutions representing the best fit of the σ_o measurements to the model function. Since the model function gives σ_o as a function of wind velocity, the wind retrieval process attempts to invert the model function to derive the wind solutions. The QuikSCAT algorithm is a non-linear search for extrema of a maximum-likelihood objective function.

NWP "Nudging"   The median filter ambiguity removal algorithm requires an initial field of wind vector solutions in order to begin the selection process.   The NWP "nudging" technique, first developed for ERS-1 and NSCAT processing by Dunbar and Freilich, uses a Numerical Weather Prediction (NWP) model to assist the initialization of the ambiguity removal algorithm. Originally, either the first or the second ranked QuikSCAT wind vector, whichever is closer to the direction of NWP wind vector, was chosen as the initial guess used by the ambiguity removal algorithm. With Threshold Nudging now in use, any ambiguity with probability above a threshold is considered for closeness to the NWP vector. When no suitable NWP field is available, the processing reverts to using the first-ranked wind vector solutions to initialize the algorithm.

9.3   Abbreviations and Acronyms

This is the standard SeaWinds Processing and Analysis System (SeaPAC) list of acronyms and abbreviations. Not all of these acronyms and abbreviations appear in every SeaWinds/ QuikSCAT document.

ADEOS	Advanced Earth Observing Satellite (Japan)
AMSR	Advanced Microwave Scanning Radiometer
ANSI	American National Standards Institute
APC	Antenna Pattern Correction
ASA	Antenna Switching Assembly
BPF	Band Pass Filter
C	degrees Celsius
CCB	Configuration Control Board

CCSDS	Consultative Committee on Space Data Systems
CDE	Cognizant Development Engineer
CDR	Critical Design Review
CDS	Command and Data Subsystem
CR	Change Request
CRC	Cyclic Redundancy Code
dB	decibels
dBi	decibels isotropic
dBm	decibels relative to 1 milliwatt
DBW	decibels relative to 1 watt
DDE	Data Dictionary Entry
deg	degrees (angle)
deg/sec	degrees per second
DIRTH	Direction Interval Retrieval with Threshold Nudging
DIU	Digital Interface Unit
DN	Data Number
DSS	Digital Subsystem
EA	SeaPAC Engineering Analysis program set
ECI	Earth Centered Inertial Coordinate System
ECR	Earth Centered Rotating Coordinate System
ECS	EOSDIS Core System
EOC	Earth Observation Center (Japan)
EOSDIS	Earth Observing System Data and Information System
EPHD	Determined Ephemeris
EPHP	Predicted Ephemeris
ESDIS	Earth Science Data and Information System Project
ESDT	Earth Science Data Type
EU	Engineering Unit
FRB	Functional Requirements Baseline
FTP	File Transfer Protocol
FTS	File Transfer Server
FX	SeaPAC File Transfer program set
GPS	Global Positioning System
GHA	Greenwich Hour Angle
GMST	Greenwich Mean Sidereal Time
HDF	Hierarchical Data Format
HK1	QuikSCAT Playback Spacecraft Housekeeping Data
HK2	SeaWinds on QuikSCAT Playback Instrument Housekeeping Data
HVPS	High Voltage Power Supply
Hz	Hertz
ICD	Interface Control Document

IDP	Instrument Data Processor
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IF	Intermediate Frequency
IMUDH	Impact-based Multidimensional Histogram [technique]
ISO	International Organization for Standardization
JPL	Jet Propulsion Laboratory
K	Kelvin (degrees of absolute temperature)
LAD	Latest-available-data
LAN	Local Area Network
LMDR	Low Mission Data-rate Recorder
LOE	Level Of Effort
LFMC	Linear Frequency Modulation Chirp
LP	SeaPAC Level Processor program set
MLE	Maximum Likelihood Estimator
m	meters
m/sec	meters per second (also m/s)
msec	milliseconds
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCEP	National Center for Environmental Prediction
NCSA	National Center for Supercomputing Applications
NERT	Near Real Time
NFS	Network File System/Server
NIC	National Ice Center
NOAA	National Oceanic and Atmospheric Administration
NOP	No Operation
NORDA	Naval Ocean Research Development Activity
NSCAT	NASA Scatterometer
NWP	Numerical Weather Prediction
n/a	not applicable
OCL	Operations Coordination Letter
ODL	Object Description Language
OIS	Operational Interface Specification
PBI	Payload Bus Interface
PCD	Payload Correction Data
PCU	Power Converter Unit
PEC	Precision External Clock
PM	SeaPAC Process Management program set
PO.DAAC	Physical Oceanography Distributed Active Archive Center
PP	SeaPAC Preprocessor program set

PR	Problem Report
PRF	Pulse Repetition Frequency
PROM	Programmable Read Only Memory
PSU	Power Switching Unit
PVL	Parameter Value Language
QuikSCAT	NASA Quick Scatterometer
RAM	Random Access Memory
RDD	Release Description Document
RF	Radio Frequency
RFA	Request For Action
RFS	Radio Frequency Subsystem
RIU	Remote Interface Unit
rms	Root Mean Square
ROM	Read Only Memory
S/C	Spacecraft
SA	SeaPAC Science Analysis program set
SAA	Spin Actuator Assembly
SAS	SeaWinds Antenna Subsystem
SCCLK	Spacecraft Clock
SCF	Science Computing Facility
SDS	Scientific Data Set
SE	System Engineer
SeaPAC	SeaWinds Processing and Analysis Center
SES	Scatterometer Electronic Subsystem
SI	Standard International
sigma0	Normalized radar cross section (σ_o)
SIS	Software Interface Specification
SITP	System Integration and Test Plan
snr	signal to noise ratio
SOM	Software Operators Manual
SPARC™	Sun™ Scalable Processor Architecture
SRB	Software Requirements Baseline
SRD	Software Requirements Document
SRM	System for Resource Management
SSD	Software Specifications Document
SSM/I	Special Sensor Microwave/Imager
STALO	Stable Local Oscillator
STP	Software Test Plan
SWT	Science Working Team
sec	seconds
TAI	International Atomic Time

TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Internet Protocol
TRS	Transmit Receive Switch
TSR	Technical Status Review
TWT	Traveling Wave Tube
TWTA	Traveling Wave Tube Amplifier
UTC	Coordinated Universal Time
VTCW	Vehicle Time Code Word
WTS	Waveguide Transfer Switch
WVC	Wind Vector Cell

9.4   Scatterometry References and Bibliography

Dunbar, R. S., S. V. Hsiao, and B. H. Lambrigtsen, "Science Algorithm Specifications for the NASA Scatterometer Project," JPL D-5610 (597-521), Vol. 1 (Sensor Algorithms) and Vol. 2 (Geophysical Algorithms). Issued May 1988, last updated November 1991.

Freilich, M. H., and R. S. Dunbar, "A Preliminary C-Band Scatterometer Model Function for the ERS-1 AMI Instrument," *Proceedings of the First ERS-1 Symposium: Space at the Service of our Environment,* Cannes, 4-6 November 1992, ESA SP-359, European Space Agency, Paris.

Huddleston, J.N. and B.W. Stiles, "Multidimensional Histogram (MUDH) Rain Flag Product Description, Version 2.1," Jet Propulsion Laboratory, Pasadena, CA, 2000.

Naderi, F. M., M. H. Freilich, and D. G. Long, "Spaceborne Radar Measurement of Wind Velocity Over the Ocean—An Overview of the NSCAT Scatterometer System," *Proc. IEEE, 79*, 6, June 1991.

Shaffer, S., R. S. Dunbar, S. V. Hsiao, and D. G. Long, "A Median-Filter-Based Ambiguity Removal Algorithm for NSCAT," *IEEE Trans. Geosci. Remote Sens., 29,* 1991.

Stiles, B.W., "Special Wind Vector Data Product: Direction Interval Retrieval with Threshold Nudging (DIRTH) Product Description, Version 1.1," Jet Propulsion Laboratory, Pasadena, CA, 1999.

Tsai, W., J. E. Graf, C. Winn, J. N. Huddleston, R. S. Dunbar, M. H. Freilich, F. J. Wentz, D. G. Long, and W. L. Jones, "Postlaunch Sensor Verification and Calibration of the NASA Scatteromoter," *IEEE Trans. Geosci. Remote Sens.,* vol. 37, pp. 1517-1542, May 1999.

Wentz, F. J., "Climatology of 14 GHz Atmospheric Attenuation," Remote Sensing Systems Tech. Memo 052096, May 1996.

Zhang, A, R. S. Dunbar, S. V. Hsiao, K. Pak, Y. Kim, "Science Algorithm Specifications for SeaWinds," Internal JPL SeaWinds project document, 1996, 1999.

Collections:
"NSCAT: Scientific Applications," American Geophysical Union collection of NSCAT papers reprinted from *J. Geophys. Res, Geophys. Res Letters, Eos, Transactions*, AGU, 1999.

9.5   Data Correspondence between the Level 2A and Level 2B Products

The Level 2B Processor uses the σ_o values in the Level 2A Product to generate winds over the ocean's surface. Since the organization of the Level 2A and Level 2B Products are considerably different, the correspondence between the σ_o values in the Level 2A Product and the winds generated from those σ_o values in the Level 2B Product is not straightforward.

Two data elements in the Level 2A Product specify the Level 2B wind vector cell where each σ_o lies. These elements are the row_number and the cell_index.

To demonstrate the use of these two data elements, assume a data element sigma0[i,j] that is located within the spacecraft rev which is designated in the name of a Level 2A Product file. Sigma0[i,j] is the (j-1)th sigma0 in the (i-1)th row of the Level 2A Product. Element row_number[i] specifies the wind vector cell row where sigma0[i,j] is located. Element cell_index[i,j] specifies the wind vector cell where sigma0[i,j] is located.

In other words, if

m = row_number[i] - 1

and

n = cell_index[i,j] - 1,

then the ordered pair [m,n] specifies the location of the elements in the Level 2B Product which were generated using sigma0[i,j]. Thus, wind_speed[m,n,0] and wind_dir[m,n,0] in the Level 2B Product are the wind speed and wind direction of the ambiguity with the highest max_likelihood_est for the wind vector cell where sigma0[i,j] is located in the Level 2A Product. Users should note that sigma0[i,j] represents just one of several scatterometer measurements which contribute to the same wind vector solution.

This reasoning applies only for those σ_o values which lie within the rev that is designated in the name of the Level 2A Product file. The first 39 wind vector cell rows in each Level 2A file represent measurements which are located in the spacecraft rev that precedes the one specified in the file name. The final 39 wind vector cell rows in each Level 2A file represent measurements which are located in the spacecraft rev that follows the one specified in file name. Thus, the Level 2B Processor does not use any of the σ_o values in the first 39 or last 39 wind vector cell rows of the input Level 2A Product for wind retrieval.

9.6   Selected Element Definitions

9.6.1   Selected Level 2B Definitions

9.6.1.1   wvc_quality_flag

This flag indicates the quality of wind retrieval within a given wind vector cell. 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 is as follows:

Bit	Definition	Bit Significance
0	Adequate Sigma0 Flag	0 - Adequate good sigma0s available for wind retrieval.
		1 - Not enough good sigma0s available for wind retrieval.
1	Adequate Azimuth Diversity Flag	0 - Good azimuth diversity among sigma0s for wind retrieval.
		1 - Poor azimuth diversity among sigma0s for wind retrieval.
2-6	Reserved for future use	Always clear (0)
7	Coastal Flag	0 - No land mass was detected within the wind vector cell.
		1 - Some portion of the wind vector cell is over land.
8	Ice Edge Flag	0 - No ice was detected within the wind vector cell.
		1 - Some portion of the wind vector cell is over ice.
9	Wind Retrieval Flag	0 - Wind retrieval performed for wind vector cell.
		1 - Wind retrieval not performed for wind vector cell.
10	High Wind Speed Flag	0 - Reported wind speed is less than or equal to 30 m/sec.
		1 - Reported wind speed is greater than 30 m/sec.
11	Low Wind Speed Flag	0 - Reported wind speed is greater than or equal to 3 m/sec.
		1 - Reported wind speed is less than 3 m/sec.
12	Rain Flag Usable	0 – Rain flag for the wind vector cell is usable.
		1 – Rain flag for the wind vector cell is not usable.
13	Rain Flag	0 – Rain flag algorithm does not detect rain.
		1 – Rain flag algorithm detects rain.
14	Available Data Flag	0 – Inner beam data with QuikSCAT view forward and aft and outer beam data with QuikSCAT view forward and aft are available.
		1 – Data from at least one of the four possible beam and view combinations are not available.
15	Spare	Always clear (0)

9.6.2   Selected Level 2A Definitions

9.6.2.1   sigma0_mode_flag

These bit flags indicate the SeaWinds instrument mode and status at the time the σ_o measurement was acquired.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0-1	Calibration/Measurement Pulse Flag	0 - Measurement pulse
		1 - Loop back calibration pulse
		2 - Cold load calibration pulse
		3 - N/A
2	Antenna Beam Flag	0 - Inner antenna beam
		1 - Outer antenna beam
3	Sigma0 Location Flag	0 - Sigma0 cell is forward of spacecraft
		1 - Sigma0 cell is aft of spacecraft
4-5	Current Mode	0 - Wind Observation Mode
		1 - Calibration Mode
		2 - Standby Mode
		3 - Receive Only Mode
6-8	Effective Gate Width - Slice Resolution	0 - 0.0 milliseconds
		1 - 0.1 milliseconds
		2 - 0.2 milliseconds
		3 - 0.3 milliseconds
		4 - 0.4 milliseconds
		5 - 0.5 milliseconds
		6 - 0.6 milliseconds
		7 - none - chirp modulation off
9	Data Acquisition Mode Flag	0 - High resolution mode - slice data
		1 - Low resolution mode - whole pulse data
10	Scatterometer Electronic Subsystem (SES) A/B Flag	0 - SES A
		1 - SES B
11	Antenna Spin Rate	0 - Nominal rate - 18 rpm
		1 - Alternate rate - 19.8 rpm
12	Receive Protect On/Off	0 - Receiver not protected
		1 - Receiver protected
13-15	Slices Per Composite Flag	0 - One pulse slice contributes to this composite
		1 - Two pulse slices contribute to this composite
		2 - Three pulse slices contribute to this composite
		3 - Four pulse slices contribute to this composite

		4 - Five pulse slices contribute to this composite
		5 - Six pulse slices contribute to this composite
		6 - Seven pulse slices contribute to this composite
		7 - Eight pulse slices contribute to this composite

9.6.2.2 sigma0_qual_flag

These bit flags indicate the quality of the data used to generate the σ_o measurement.   The significance of each bit is as follows:

Bit	Definition	Bit Significance
0	Sigma0 Measurement Usable Flag	0 - Measurement is usable
		1 - Measurement is not usable
1	Low SNR Flag	0 – SNR level is acceptable (SNR $\geq$ TBD)
		1 – SNR level is low (SNR < TBD)
2	Negative Sigma0 Flag	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
3	Sigma0 Out of Range Flag	0 - Sigma0 is in acceptable range
		1 - Sigma0 is outside of acceptable range
4	Pulse Quality Flag	0 - Scatterometer pulse quality is acceptable
		1 - Scatterometer pulse quality is not acceptable
5	Cell Location Flag	0 - Sigma0 cell location algorithm converges
		1 - Sigma0 cell location algorithm does not converge
6	Frequency Shift Flag	0 - Frequency shift is within the range of the x factor table
		1 - Frequency shift lies beyond the range of the x factor table
7	Temperature Range Flag	0 - Spacecraft temperature is within calibration coefficient range
		1 - Spacecraft temperature is beyond calibration coefficient range
8	Attitude Data Flag	0 - An applicable attitude record was found for this sigma0
		1 - No applicable attitude records were found for this sigma0
9	Ephemeris Data Flag	0 - Interpolated ephemeris data are acceptable for this sigma0
		1 - Interpolated ephemeris data are not acceptable for this sigma0
10-15	Spare	Always clear (0)

9.6.2.3   surface_flag

These bit flags indicate the effect of surface conditions upon the σ_o data. The significance of each bit is as follows:

Bit	Definition	Bit Significance
0	Surface land flag	0 - No land is present
		1 - Land is present
1	Surface ice flag determined by map	0 - Map indicates no ice is present
		1 - Map indicates ice is present
2-9	Reserved for future use	Always clear (0)
10	Ice map data available flag	0 - Ice map data available for this sigma0
		1 - Ice map data not available for this sigma0
11	Attenuation map data available flag	0 - Attenuation map data available for this sigma0
		1 - Attenuation map data not available for this sigma0
12-15	Spare	Always clear (0)

9.6.3   Selected Level 1B Definitions

9.6.3.1   cell_kpc_b

A two-dimensional array which contains the first order coefficient of an inverse second order polynomial in the signal to noise ratio. Evaluation of the polynomial yields Kpc for whole pulse σ_o measurements. Kpc is the normalized standard deviation of σ_o measure due to statistical fluctuations in the echo signal.

The first dimension index represents the slice resolution mode. For all elements in the cell_kpc_b array, the significance of the first dimension index is as follows:

First Dimension Index	Slice Resolution
0	0.0 msec
1	0.1 msec
2	0.2 msec
3	0.3 msec
4	0.4 msec
5	0.5 msec
6	0.6 msec
7	none - modulation off

The second dimension index represents the scatterometer beam. For all elements in the cell_kpc_b array, the significance of the second dimension index is as follows:

Second Dimension Index	Definition
0	Scatterometer Inner Beam
1	Scatterometer Outer Beam

9.6.3.2 cell_kpc_c

A two-dimensional array which contains the second order coefficient of an inverse second order polynomial in the signal to noise ratio. Evaluation of the polynomial yields Kpc for whole pulse σ_o measurements. Kpc is the normalized standard deviation of σ_o measure due to statistical fluctuations in the echo signal.

The first dimension index represents the slice resolution mode. For all elements in the cell_kpc_c array, the significance of the first dimension index is as follows:

First Dimension Index	Slice Resolution
0	0.0 msec
1	0.1 msec
2	0.2 msec
3	0.3 msec
4	0.4 msec
5	0.5 msec
6	0.6 msec
7	none - modulation off

The second dimension index represents the scatterometer beam. For all elements in the cell_kpc_c array, the significance of the second dimension index is as follows:

Second Dimension Index	Definition
0	Scatterometer Inner Beam
1	Scatterometer Outer Beam

74

9.6.3.3   frame_err_status

These bit flags indicate potential problems due to instrument error or poor communication with the spacecraft.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0	Current Error Message Flag	0 - Current error message in telemetry indicates no errors
		1 - Current error message in telemetry indicates errors
1	Equator Crossing Missed	0 - No miss of equator crossing reported
		1 - Miss of equator crossing was reported
2	Misaligned Calibration Pulse Flag	0 - Most recent calibration pulse was where it was expected
		1 - Most recent calibration pulse was not where it was expected
3	Power On Reset	0 - Normal operations, no reset
		1 - Reset event noted
4	CDS Watchdog Timeout Reset	0 - Watchdog resets operating normally
		1 - Watchdog timeout
5	SES Watchdog Timer Event	0 - No watchdog timer event noted
		1 - Watchdog timer event took place
6	Fault Protection Event	0 - Normal operations
		1 - Fault protection event noted
7	Mission Telemetry or Serial Telemetry Error	0 - Normal operations
		1 - Telemetry error noted
8	Missing Spacecraft Time	0 - Normal operations, all spacecraft times available
		1 - Spacecraft time missing event noted
9	Reset Event	0 - No reset event noted
		1 - Reset took place
10	CDS System Reset	0 - Normal operations, no CDS reset
		1 - CDS reset event noted
11	TWTA Malfunction Flag	0 - The active TWTA unit reports no malfunctions
		1 - The active TWTA unit reports a malfunction
12	SES Data Overrun Flag	0 - No SES data overrun detected
		1 - SES data overrun detected
13	SES Data Underrun Flag	0 - No SES data underrun detected
		1 - SES data underrun detected
14	Payload Bus Interface (PBI) Flag	0 - Payload Bus Interface is in expected state
		1 - Payload Bus Interface is in bad or unexpected state
15	Payload Bus Interface (PBI) Watchdog Timer Event Flag	0 - No watchdog timer event noted
		1 - Watchdog timer event noted

16	A to D Transformer Couple Flag	0 - A to D transformer couple voltage is in range
		1 - A to D transformer couple voltage is out of range
17	Excessive Interpolation of Antenna Position Flag	0 - Fewer than 50 consecutive antenna positions were interpolated
		1 - 50 or more consecutive antenna positions were interpolated
18	Ignored Orbit Step Change Flag	0 - Orbit step change is normal
		1 - Step change denoted, but orbit step is same as previous frame
19	Spontaneous Orbit Step Change Flag	0 - Orbit step change is normal
		1 - Orbit step incremented, but step change was not denoted
20	Inconsistent Resolution Mode Flag	0 - Resolution mode is consistent for both scatterometer beams
		1 - Scatterometer beam resolution modes are inconsistent
21	Unexpected Grid Inhibit Condition	0 - Grid inhibit is in expected state
		1 - Grid inhibit is in unexpected state
22	Unexpected Receive Protect Condition	0 - Receive protect is in expected state
		1 - Receive protect is in unexpected state
23	Attitude Data Flag	0 - An applicable attitude record was found for this telemetry frame
		1 - No applicable attitude record was found for this telemetry frame
24	Ephemeris Data Flag	0 - Interpolated ephemeris data are acceptable
		1 - Interpolated ephemeris data are unacceptable
25	Telemetry Time Tag Flag	0 – Telemetry packet time tag is acceptable
		1 – Telemetry packet time tag in unreadable or out of range
26	Telemetry Error Message History Flag	0 – Error message history and error count are consistent
		1 – Error message history and error count are inconsistent
27	Valid Operational Mode Flag	0 - Operational mode is valid
		1 – Operational mode in telemetry is not valid
28-31	Spare	Always clear (0)

9.6.3.4   frame_inst_status

These bit flags indicate the status of spacecraft instruments and ground communication over the time span of a single telemetry frame.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0-1	Current Mode	0 - Wind observation mode
		1 - Calibration mode
		2 - Standby mode
		3 - Receive only mode
2	First Pulse Count in Frame	0 - Pulse A first
		1 - Pulse B first
3	Antenna Spin Rate	0 - Nominal rate - 18 rpm
		1 - Alternate rate - 19.8 rpm
4-6	Slice Resolution Mode - Effective Gate Width	0 - 0.0 milliseconds
		1 - 0.1 milliseconds
		2 - 0.2 milliseconds
		3 - 0.3 milliseconds
		4 - 0.4 milliseconds
		5 - 0.5 milliseconds
		6 - 0.6 milliseconds
		7 - none - modulation off
7	Data Acquisition Mode Flag	0 - High resolution mode - slice data
		1 - Low resolution mode - whole pulse data
8	Cal Pulse Sequence Flag	0 - A calibration pulse sequence begins in this telemetry frame
		1 - No calibration pulse sequence begins in this telemetry frame
9	Scatterometer Electronic Subsystem (SES) A/B Flag	0 - SES A
		1 - SES B
10	SeaWinds Antenna Subsystem (SAS) A/B Flag	0 - SAS A
		1 - SAS B
11	Travelling Wave Tube Amplifier (TWTA) 1/2 Flag	0 – TWTA #1
		1 - TWTA #2
12	Travelling Wave Tube Amplifier (TWTA) Power Flag	0 - TWTA Power On
		1 - TWTA Power Off
13	Grid Enable/Disable Flag	0 - Grid normal for RF transmission
		1 - Grid disable, no RF transmission
14	Receive Protect On/Normal	0 - Receive protect normal

77

		1 - Receive protect on
15	TWT Trip Override	0 - TWT trip override off
		1 - TWT trip override on
16	TWT Body Overcurrent Trip Control	0 - TWT body overcurrent trip enabled
		1 - TWT body overcurrent trip disabled
17	Receive Protect On/Off	0 - Receiver not protected
		1 - Receiver protected
18	Instrument Mode Change	0 - Instrument operations mode did not change
		1 - Instrument operations mode did change
19	Soft Reset Commanded	0 - No flight software soft reset commanded
		1 - Flight software soft reset commanded
20	Relay Set/Reset Started	0 - No change reported
		1 - Change from last packet
21	Internal PRF Clock	0 - Internal PRF clock measure received from SES
		1 - CDS hardware generated PRF clock
22	Hard Reset Commanded	0 - No hard reset commanded
		1 - Hard reset commanded
23	TWTA Monitor Enable/Disable	0 - No change in state of TWTA monitor
		1 - Change in state of TWTA monitor
24	SES Parameter Table Change	0 - No change in the SES parameter tables
		1 - Change in the SES parameter tables
25	Range Gate Table Change	0 - No change in the Range Gate tables
		1 - Change in the Range Gate tables
26	Doppler Table Change	0 - No change in the Doppler tables
		1 - Change in the Doppler tables
27	Serial Telemetry Table Change	0 - No change in the Serial Telemetry tables
		1 - Change in the Serial Telemetry tables
28	Mission Telemetry Table Change	0 - No change in the Mission Telemetry tables
		1 - Change in the Mission Telemetry tables
29	Resolution Mode Change	0 - No change in the slice resolution mode
		1 - Change in the slice resolution mode
30-31	Spare	Always clear (0)

78

9.6.3.5   frame_qual_flag

These bit flags indicate the character and the quality of the data acquired within a particular telemetry frame.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0-1	Frame filler flag	0 - No filler in telemetry frame
		1 - Filler only in packet 2
		2 - Filler only in packet 3
		3 - Filler in both packets 2 and 3
2-3	Frame CRC flag	0 - No CRC errors in telemetry frame
		1 - CRC errors only in packet 2
		2 - CRC errors only in packet 3
		3 - CRC errors in both packets 2 and 3
4	Data quality flag	0 - Good data found in telemetry frame
		1 - Questionable or bad data found in telemetry frame
5-15	Spare	Always clear (0)

79

9.6.3.6   sigma0_mode_flag

These bit flags indicate the SeaWinds instrument mode and status at the time the σ_o measurement was acquired.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0-1	Calibration/Measurement Pulse Flag	0 - Measurement pulse
		1 - Loop back calibration pulse
		2 - Cold load calibration pulse
		3 - N/A
2	Antenna Beam Flag	0 - Inner antenna beam
		1 - Outer antenna beam
3	Sigma0 Location Flag	0 - Sigma0 cell is forward of spacecraft
		1 - Sigma0 cell is aft of spacecraft
4-5	Current Mode	0 - Wind Observation Mode
		1 - Calibration Mode
		2 - Standby Mode
		3 - Receive Only Mode
6-8	Effective Gate Width - Slice Resolution	0 - 0.0 milliseconds
		1 - 0.1 milliseconds
		2 - 0.2 milliseconds
		3 - 0.3 milliseconds
		4 - 0.4 milliseconds
		5 - 0.5 milliseconds
		6 - 0.6 milliseconds
		7 - none - chirp modulation off
9	Data Acquisition Mode Flag	0 - High resolution mode - slice data
		1 - Low resolution mode - whole pulse data
10	Scatterometer Electronic Subsystem (SES) A/B Flag	0 - SES A
		1 - SES B
11	Antenna Spin Rate	0 - Nominal rate - 18 rpm
		1 - Alternate rate - 19.8 rpm
12	Receive Protect On/Off	0 - Receiver not protected
		1 - Receiver protected
13-15	Spare	Always clear (0)

80

9.6.3.7   sigma0_qual_flag

These bit flags indicate the quality of the data that generate the σ_o measurement.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0	Sigma0 Measurement Usable Flag	0 - Measurement is usable
		1 - Measurement is not usable
1	Low SNR Flag	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
2	Negative Sigma0 Flag	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
3	Sigma0 Out of Range Flag	0 - Sigma0 is in acceptable range
		1 - Sigma0 is outside of acceptable range
4	Pulse Quality Flag	0 - Scatterometer pulse quality is acceptable
		1 - Scatterometer pulse quality is not acceptable
5	Cell Location Flag	0 - Sigma0 cell location algorithm converges
		1 - Sigma0 cell location algorithm does not converge
6	Frequency Shift Flag	0 - Frequency shift is within the range of the x factor table
		1 - Frequency shift lies beyond the range of the x factor table
7	Temperature Range Flag	0 - Spacecraft temperature is within calibration coefficient range
		1 - Spacecraft temperature is beyond calibration coefficient range
8	Attitude Data Flag	0 - An applicable attitude record was found for this sigma0
		1 - No applicable attitude records were found for this sigma0
9	Ephemeris Data Flag	0 - Interpolated ephemeris data are acceptable for this sigma0
		1 - Interpolated ephemeris data are not acceptable for this sigma0
10-15	Spare	Always clear (0)

9.6.3.8   slice_kpc_b

A two-dimensional array which contains the first order coefficient of an inverse second order polynomial in the signal to noise ratio. Evaluation of the polynomial yields Kpc for slice σ_o measurements. Kpc is the normalized standard deviation of σ_o measure due to statistical fluctuations in the echo signal.

The first dimension index represents the slice resolution mode. For all elements in the slice_kpc_b array, the significance of the first dimension index is as follows:

First Dimension Index	Slice Resolution
0	0.0 msec
1	0.1 msec
2	0.2 msec
3	0.3 msec
4	0.4 msec
5	0.5 msec
6	0.6 msec
7	none - modulation off

The second dimension index represents the scatterometer beam. For all elements in the slice_kpc_b array, the significance of the second dimension index is as follows:

Second Dimension Index	Definition
0	Scatterometer Inner Beam
1	Scatterometer Outer Beam

9.6.3.9   slice_kpc_c

A two-dimensional array which contains the second order coefficient of an inverse second order polynomial in the signal to noise ratio.   Evaluation of the polynomial yields Kpc for slice σ_o measurements. Kpc is the normalized standard deviation of σ_o measure due to statistical fluctuations in the echo signal.

The first dimension index represents the slice resolution mode. For all elements in the slice_kpc_c array, the significance of the first dimension index is as follows:

First Dimension Index	Slice Resolution
0	0.0 msec
1	0.1 msec
2	0.2 msec
3	0.3 msec
4	0.4 msec
5	0.5 msec
6	0.6 msec
7	none - modulation off

The second dimension index represents the scatterometer beam. For all elements in the slice_kpc_c array, the significance of the second dimension index is as follows:

Second Dimension Index	Definition
0	Scatterometer Inner Beam
1	Scatterometer Outer Beam

83

9.6.3.10 slice_qual_flag

These bit flags indicate the quality of the data, which generate the σ_o measurements for each of the slices of the scatterometer pulse.

The significance of each bit is as follows:

Bit	Definition	Bit Significance
0	Peak Gain Flag for slice 1	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
1	Negative Sigma0 Flag for slice 1	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
2	Low SNR Flag for slice 1	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
3	Center Location Flag for slice 1	0 - Slice center located
		1 - Slice center not located
4	Peak Gain Flag for slice 2	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
5	Negative Sigma0 Flag for slice 2	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
6	Low SNR Flag for slice 2	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
7	Center Location Flag for slice 2	0 - Slice center located
		1 - Slice center not located
8	Peak Gain Flag for slice 3	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
9	Negative Sigma0 Flag for slice 3	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
10	Low SNR Flag for slice 3	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
11	Center Location Flag for slice 3	0 - Slice center located
		1 - Slice center not located
12	Peak Gain Flag for slice 4	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
13	Negative Sigma0 Flag for slice 4	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
14	Low SNR Flag for slice 4	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
15	Center Location Flag for slice 4	0 - Slice center located
		1 - Slice center not located
16	Peak Gain Flag for slice 5	0 - Gain exceeds peak gain threshold

		1 - Gain does not exceed peak gain threshold
17	Negative Sigma0 Flag for slice 5	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
18	Low SNR Flag for slice 5	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
19	Center Location Flag for slice 5	0 - Slice center located
		1 - Slice center not located
20	Peak Gain Flag for slice 6	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
21	Negative Sigma0 Flag for slice 6	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
22	Low SNR Flag for slice 6	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
23	Center Location Flag for slice 6	0 - Slice center located
		1 - Slice center not located
24	Peak Gain Flag for slice 7	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
25	Negative Sigma0 Flag for slice 7	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
26	Low SNR Flag for slice 7	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
27	Center Location Flag for slice 7	0 - Slice center located
		1 - Slice center not located
28	Peak Gain Flag for slice 8	0 - Gain exceeds peak gain threshold
		1 - Gain does not exceed peak gain threshold
29	Negative Sigma0 Flag for slice 8	0 - Sigma0 $\geq$ 0
		1 - Sigma0 < 0
30	Low SNR Flag for slice 8	0 - SNR level is acceptable (SNR $\geq$ TBD)
		1 - SNR level is low (SNR < TBD)
31	Center Location Flag for slice 8	0 - Slice center located
		1 - Slice center not located