NASA Scatterometer

Science Data Product

User's Manual

Overview & Geophysical Data Products

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1. Introduction

It is the goal of this User's Guide to provide assistance to investigators so they can make effective use of the NASA Scatterometer (NSCAT) Science Products (NSP, also referred to as the NSCAT Standard Data Products), which are produced by the NASA Scatterometer Project and distributed by the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the Jet Propulsion Laboratory. This User's Guide gives investigators a comprehensive description of the content and format of the NSP. In addition, it provides users with a discussion of the NSCAT geophysical processing algorithms and how they relate to the NSP. An overview of the NSCAT mission, and an introduction to the operation of the instrument and ground data systems are provided for new investigators. The algorithm and data descriptions presented in this Guide are limited to the geophysical data products (Levels 1.7, 2, and 3).

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 5 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. Section 3 should be reviewed as it provides an introduction to the design and operating characteristics of the NSCAT scatterometer, including key engineering parameters required to understand the data. A practical guide to the use of the NSCAT science data is given in Section 7. This includes how to obtain and read the data, usage of data flags for editing, typical coverage and limitations, other HDF utilities, Bulletin Board Service (BBS) access for mission and processing status news, and points of contact. Section 6 provides a more in-depth summary of the geophysical processing algorithms, with specific references to the data elements in the NSP.

Less experienced or new 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 ADvanced Earth Observing System (ADEOS) spacecraft and the other sensors on the satellite, and a brief description of the overall ADEOS/NSCAT ground system segment. Section 4 describes the NSCAT Data Processing and Instrument Operations (DP&IO) 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 NSCAT data.

Ancillary information, of potential interest to all users, is given in Sections 8 and 9. 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 NSP data are given 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). Beam 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).

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. The approximate resolution for σ_o measurements for NSCAT is 25 km.

The wind retrieval resolution is defined as the dimension of a wind vector cell in which s_o measurements have been grouped. For NSCAT, the wind vector cell grid has a resolution cell size of 50 km x 50 km, along- and cross-track.

1.2.3 Wind direction convention

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

1.2.4 Reference height for surface winds

The adopted reference height for all wind vectors is 19.5 meters above the surface.

1.2.5 Data Flagging and Editing

The policy adopted within the processing algorithms and software design is to flag values which are out of range.

1.3 Applicable documents

Requirements:

NASA Scatterometer Mission Requirements, JPL D-2676, Rev. A (July 1988).

NASA Scatterometer Instrument Systems Functional and Design Requirements, JPL D-2679, Rev. A (March 1989).

Algorithms:

Science Algorithm Specifications for the NASA Scatterometer Project, Volumes 1 and 2, JPL D-5610, R. S. Dunbar, S. V. Hsiao, and B. H. Lambrigtsen, July 1988.

Software Interface Specifications (native format):

NSCAT Science Data Processing System, Level 1.7 Data Software Interface Specification (SIS-2), JPL D-11789, Rev. B (July 1996).

NSCAT Science Data Processing System, Level 2 Data Software Interface Specification (SIS-2), JPL D-11038, Rev. B (July 1996).

NSCAT Science Data Processing System, Level 3 Data Software Interface Specification (SIS-2), JPL D-11791, Rev. B (July 1996).

Software Interface Specifications (HDF format):

Physical Oceanography Distributed Active Archive Center, NSCAT Level 1.7 Data Software Interface Specification (SIS-2), JPL D-12059.

Physical Oceanography Distributed Active Archive Center, NSCAT Level 2 Data Software Interface Specification (SIS-2), JPL D-12060.

Physical Oceanography Distributed Active Archive Center, NSCAT Level 3 Data Software Interface Specification (SIS-2), JPL D-12061.

1.4 Changes to This Document

This document will be kept current to reflect changes in algorithms and NSP content. All requests for other changes, additions, or corrections to this document should be submitted to the PO.DAAC (see Sec. 9.1 for contact information). All significant revisions to this document will be approved by the NSCAT Project.

New features in the user's manual

1. Added one more column of 'SDS order', which describes the order of the data set in the HDF file, to Table 5.3, 5.5 and 5.8.

2. Added description of the straight readers in section 7.2.

3. Deleted description of the shell readers in section 7.1.

4. Added version and date header on the right upper corner of every page.

5. Added storage type and dimension to Vdata (Table 5.2, 5.6, 5.9).

6. Artifact SDS's for each data level are listed (Table 5.3, 5.5, 5.8).

7. Changed the data type of Coeff A, B and C from int16 to uint16 (Table 5.8).

8. Clarification of Level 1.7 Sigma0_Quality_Flag, bit 10 (Table 5.8) and negative Sigma0 values (sections 5.3 and 8.2).

9. Updated the information on how WVC_Quality_Flag are assigned after launch in section 8.2.

10. Added section 8.3, Frequently Asked Questions.

New features in the data

1. Changed the scale factors of Coeff A, B and C for Level 1.7 in the user's manual (Table 5.8). The Coeff A, B and C in the distributed data are correct.

2. NSCAT Mission Overview

2.1 Mission Description

The primary mission of NSCAT is to acquire all-weather high-resolution measurements of near-surface winds over the global oceans. These measurements will help to determine atmospheric forcing, ocean response and air-sea interaction mechanisms on various spatial and temporal scales. Operational users will seek to develop improved methods of assimilating wind data into numerical weather and wave-prediction models. NSCAT wind data, combined with measurements from various scientific disciplines, will help to understand mechanisms of global weather, energy fluxes, and, ultimately, climatic change.

Satellite scatterometers are microwave radar instruments designed specifically to measure near-surface wind velocity (both speed and direction) over the global oceans under all weather conditions. 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 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 a highly 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 s_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-1 and ERS-2) mission. NSCAT will be the first dual-swath, Ku-band, spaceborne scatterometer to fly since Seasat. Additional discussion of the NSCAT mission can be found in Naderi et al. (1991) and Graf et al. (1996).

2.2 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 in 1978, NASA established the interdisciplinary Satellite Surface Stress Working Group to define the scientific requirements for the next NASA spaceborne 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^{o} 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 two weeks after data are received at JPL; 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 1. Major NSCAT 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^{o} (rms)	3-30 m/s
	(closest ambiguity)	
Spatial resolution	25 km	σ_o cells
	50 km	Wind vector cells
Location accuracy	25 km (rms)	Absolute
	10 km (rms)	Relative
Coverage	90% Ice-free ocean	
	Every 2 days	
Mission duration	36 months	

2.3 Satellite Description

ADEOS is the largest satellite Japan has ever developed having dimensions of 4x4x5m (see Figure 1). When the NSCAT antenna and the solar array paddle (approx. 3 x 24m) are deployed, it has a span of 11m in the flight direction and 29m in the perpendicular direction. The spacecraft consists of a mission module which carries mission instruments and a bus module

which carries bus subsystems. Attached to the top panel of the mission module are the NSCAT antenna and the antenna tower. Other mission instruments are located on the earth viewing panel. The satellite has a launch mass of approximately 3500 kg and an in orbit power generation capability of approximately 4500w.

The satellite has several systems which are critical to its operation. The Communications and Data Handling Subsystem (C&DH) enables automatic, autonomous operation of mission instruments by storing weekly mission operation plans and checking the status of mission instruments. The Inter-Orbital Communications Subsystem (IOCS) transmits observation data via the COMmunications and broadcast Engineering Test Satellite (COMETS). The Attitude and Orbital Control Subsystem (AOCS) employs a three-axis attitude detection system and a zero-momentum attitude control system to achieve an attitude error of less than 0.3 degree (3-s) and an attitude stability of less than 0.003 deg/sec (3-s). The Reaction Control Subsystem (RCS) generates the thrust necessary for orbital maneuvers. ADEOS carries Technical Engineering Data Acquisition Equipment (TEDA) to measure the environment the spacecraft travels through. The TEDA monitors radiation absorption, memory malfunction, static charge voltage, and contamination, and analyzes heavy ions.

2.4 Other ADEOS Sensors

In addition to NSCAT, the ADEOS payload includes the following scientific sensors.

o Ocean Color and Temperature Scanner (OCTS)

OCTS will measure the ocean chromaticity to determine the amount of fixed carbon in the oceans. It has twelve observation bands from visible to thermal infrared and scans the Earth's surface using a mirror that scans perpendicular to the satellite's motion.

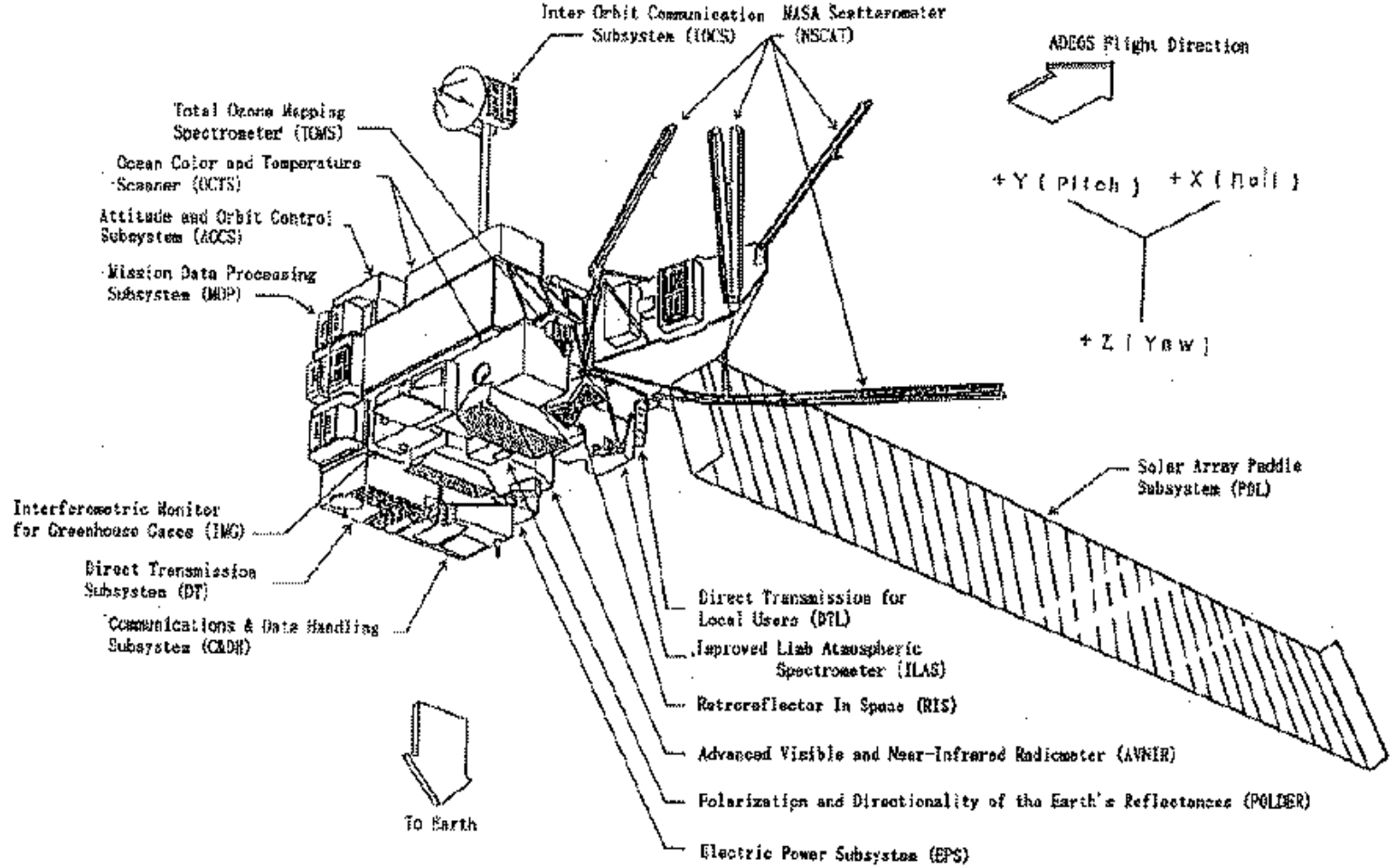
o Advanced Visible and Near Infrared Radiometer (AVNIR)

AVNIR is a scanning radiometer that observes reflected solar light from the Earth's surface. The observing path can be selected arbitrarily in the cross-track direction. AVNIR has four bands with 16 m resolution along the 80 km swath width. In addition, the panchromatic band system has a resolution of 8 m.

o Total Ozone Mapping Spectrometer (TOMS)

TOMS is the other US supplied sensor on ADEOS. TOMS is a mapping ultraviolet polychromator which measures the albedo at six wavelengths absorbed by ozone and sulfur dioxide, and reflected by the clouds and the Earth's surface. The albedos are converted to total ozone and column sulfur dioxide amounts.

o Polarization and Directionality of the Earth's Reflectances (POLDER)


Inter Orbit Communication Subsystem (IOCS)
NASA Scatterometer (NSCAT)
ADEOS Flight Direction
+Y (Pitch)
+X (Roll)
+Z (Yaw)
Total Ozone Mapping Spectrometer (TOMS)
Ocean Color and Temperature Scanner (OCTS)
Attitude and Orbit Control Subsystem (AOCS)
Mission Data Processing Subsystem (MDP)
Interferometric Monitor for Greenhouse Gases (IMG)
Direct Transmission Subsystem (DT)
Communications & Data Handling Subsystem (C&DH)
Solar Array Paddle Subsystem (PDL)
Direct Transmission for Local Users (DTL)
Improved Limb Atmospheric Spectrometer (ILAS)
Retroreflector In Space (RIS)
Advanced Visible and Near-Infrared Radiometer (AVNIR)
Polarization and Directionality of the Earth's Reflectances (POLDER)
Electric Power Subsystem (EPS)
To Earth

POLDER is a French instrument that observes the polarization and directionality of reflected solar radiation. It uses eight spectral bands of which three are used for polarization.

o Interferometric Monitor for Greenhouse Gases (IMG)

IMG is a Michelson interferometer which measures carbon dioxide, methane, nitrogen dioxide and other greenhouse gases in the atmosphere.

o Improved Limb Atmospheric Sounder (ILAS)

ILAS observes atmospheric micro-ingredients on the limb at high latitudes. ILAS has a two-axis gimbal mirror for the observation of sunrise and sunset. Two sensors are included in this instrument. One sensor monitors two infrared bands and the other a third infrared band.

o Retroreflector In Space (RIS)

RIS reflects a laser beam transmitted from a ground station in order to measure ozone, fluorocarbon, carbon dioxide, and other gases using a laser beam absorption technique.

2.5 Nominal Orbit Parameters

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

Recurrent Period:	41 days
Orbits Per Day:	14.26829
Local Sun Time at Descending Node:	10:15-10:45 AM
Altitude Above Equator:	796.75 km
Period:	100.92 minutes
Inclination:	98.59^{o}

3. NSCAT Sensor Overview

3.1 Introduction to NSCAT

NSCAT has two major systems, the spaceborne instrument system and the ground data processing system. The flight instrument is a specialized microwave radar designed to measure winds over the oceans. It was launched into a near-polar Sun-synchronous orbit on ADEOS. Like its predecessor on the Seasat satellite, NSCAT will use an array of antennas that radiate microwave pulses at a frequency of 14 GHz across broad regions of the Earth's surface. This array of six, 3-meter-long antennas will scan two 600 km bands of ocean one band on each side of the instrument's orbital path, separated by a gap of approximately 400 km . Obtaining backscatter and wind vector information nearly continuously, NSCAT makes 190,000 wind measurements per day, more than 100 times the amount of ocean wind information presently available from ships.

The ground system computers produces wind measurements within 2 weeks of receiving raw NSCAT data at JPL, with no backlog (except when the data products are reprocessed), throughout the 3-year mission. NSCAT science data products include global backscatter data; 50 km resolution ocean wind vectors in the measurement swaths, and spatially and temporally averaged, gridded, wind field maps.

As part of the NSCAT project, NASA is also sponsoring a team of scientific investigators who will conduct research based on NSCAT data. Their studies are expected to lead to improved methods of global weather forecasting and modeling and possibly to a better understanding of environmental phenomena (such as El Niño) that greatly affect world economies.

3.2 Principles of Operation

Spaceborne scatterometers transmit microwave pulses to the ocean surface and measure the backscattered power received at the instrument. Since the atmospheric motions themselves do not substantially affect the radiation emitted and received by the radar, scatterometers use an indirect technique to measure wind velocity over the ocean. Wind stress over the ocean generates waves which roughen the sea surface. Changes in wind velocity cause changes in surface roughness, which in turn modify the radar cross section (σ_o) of the ocean and hence the magnitude of backscattered power. In order to extract wind velocity from these measurements, the relationship between σ_o and near-surface winds, known as the geophysical model function, must be known.

The NSCAT scatterometer was designed to be an advanced version of the Seasat SASS. Both are Ku-band Doppler radars using a stick-type antenna design. However, there are three key design differences between the SASS and NSCAT instruments. First, NSCAT is designed to measure backscatter at 25 km resolution, and retrieve wind vectors at 50 km resolution; SASS resolutions were 50 km and 100 km, respectively. Second, the addition of a dual-polarized mid-beam antenna provides an additional azimuth look that is expected to improve the wind retrieval and ambiguity selection (see definition in Sec. 9.2) skill. The third difference is the use of digital Doppler filtering

of the return signal, in which the cell power binning is a function of orbit position. The Doppler binning algorithm used by the on-board processor computes the frequency shifts for each cell as a function of time from the equator crossing, maintaining the cross-track locations and co-registration of the cells from the four antenna beams at all orbit latitudes.

NSCAT has six stick-type antennas generating fan beam footprints on the ground (see Figure 2), oriented to make observations at three independent azimuths on each side of the satellite subtrack. With the dual-polarized mid-beams, there are a total of eight independent antenna/polarization combinations. In order to achieve 25 km resolution in the along-track direction, the instrument must cycle through all eight beams in 3.74 seconds (the *antenna cycle* period), giving 468 msec per beam in which to obtain σ_o measurements. The radar return signal is received in four bandpass filter "channels", and divided by the on-board digital Doppler processor into 25 σ_o "cells" (24 science + 1 monitor) with cross-track resolution of 25 km. Each beam measurement period consists of a sequence of 29 *pulse cycles* 16 msec long, of which the first 25 cycles are transmit/receive cycles (5 msec transmit pulse length, 11 msec receive interval) and the last 4 are receive-only cycles, providing signal+noise and noise-only received power measurements respectively. Superimposed on these cycles is the *measurement cycle* sequence, consisting of 128 antenna cycles (about 8 minutes long), of which the first cycle is a calibration cycle. NSCAT carries a calibrated noise source which is used during the calibration cycles to update the receiver gain. This is needed to convert the received power data numbers into engineering units (watts). During a calibration cycle, the receiver looks only at the noise source through the sequence of antenna ports, so no ocean σ_o data can be obtained.

NSCAT "programmability" includes commanding of mode selection and beam sequences, and the ability to uplink new Doppler binning tables to track changes in the orbit or to conduct special engineering tests. Mode changes will be made periodically to obtain additional calibration data, and special beam sequences will be used during the Calibration and Validation campaign during overflights of the NSCAT ground calibration station.

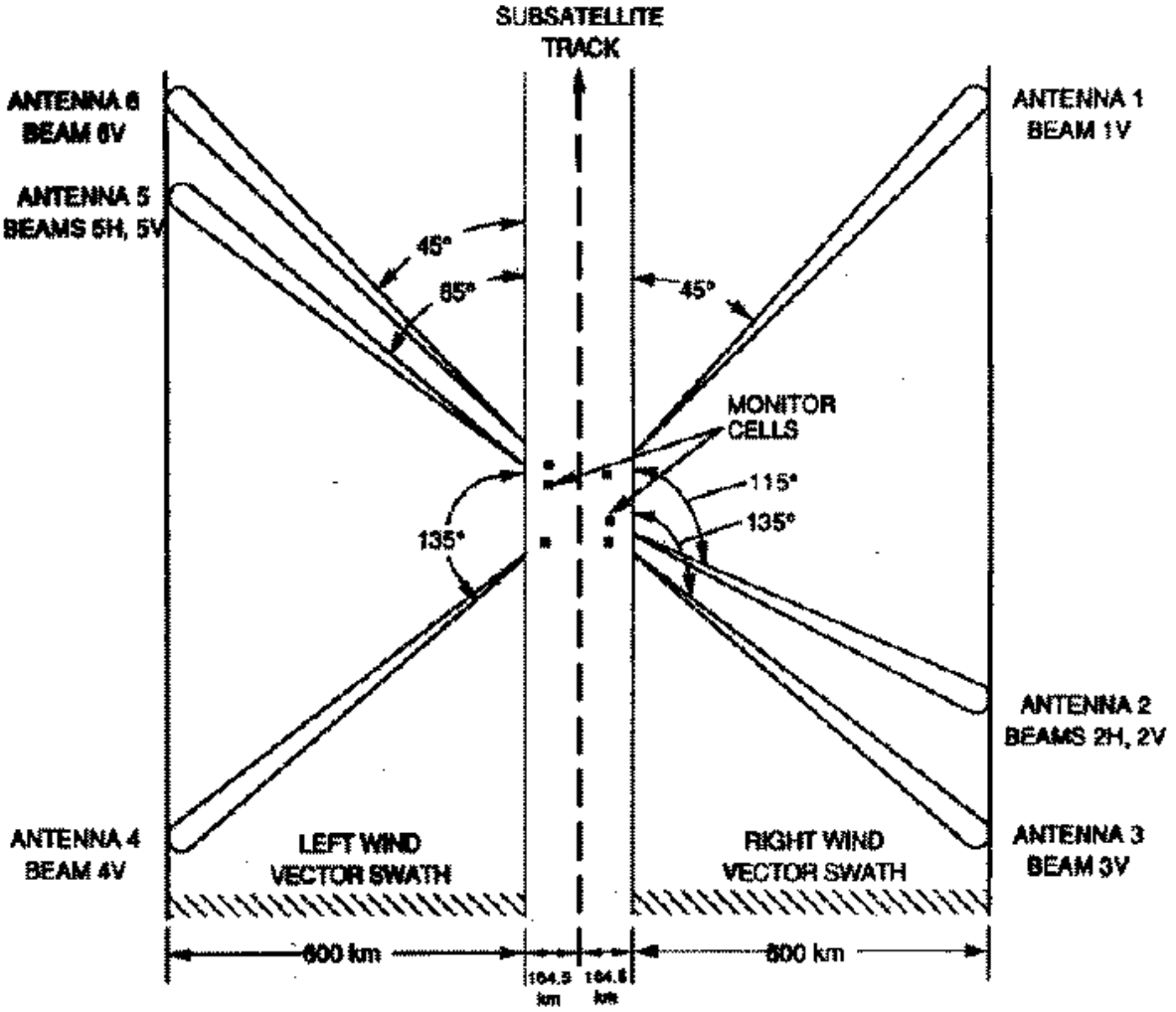
3.3 Operating Modes

Mode 0: Standby mode

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

Mode 1: Debug mode

NSCAT ANTENNA ILLUMINATION PATTERN



The purpose of Debug mode is to obtain data on the status of the digital signal processor (DSP). During this mode, an internal signal is substituted for the data from the receiver, except during calibration cycles. No science data are returned.

Mode 2: Continuous Calibration mode

In Continuous Calibration mode, NSCAT performs only calibration cycles in place of normal (science) antenna cycles. This mode provides the most accurate receiver calibration data, and will be used periodically throughout the mission. No science data are returned.

Mode 3: Receive-only mode

In Receive-only mode the transmitter is turned off while the receiver collects data at the antenna ports. This mode will be used during Cal/Val to assess radio frequency interference and antenna switch matrix biases. No science data are returned.

Mode 4: Wind Observation mode

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

4. Data Processing Overview

The NSCAT Ground System includes components provided by Japan (NASDA) and by the US (NASA). For the NSCAT data used for processing the science products the ADEOS Low Mission Data-Rate Recorders (LMDR) are played back to the Earth Observation Center (EOC) at Hatoyama. Data are collected for one week and organized into a time-ordered Level 0 file. This file also contains definitive ADEOS ephemeris data, attitude data and information to correlate the spacecraft clock with UTC. A weekly data tape is shipped by EOC to JPL for processing by the NSCAT Science Processing Operations Team (SPOT) using the NSCAT Science Data Processing System (SDPS) software. The Science Algorithm Performance and Instrument Engineering Team (SAPIENT) performs quality assurance tests to the standard science products, in addition to calibration and validation analyses. After the data quality has been verified, the SPOT sends the data to PO.DAAC, which is also located at JPL. The data formats provided by SDPS software are specific to NSCAT. PO.DAAC converts the SDPS formats to Hierarchical Data Format (HDF) for distribution. The level products in HDF are Level 1.7 (Grouped Sigma-0), Level 2 (Wind Vectors), and Level 3 (Averaged Daily Map). The NSCAT products available for distribution to the NSCAT Science Working Team (SWT) and to the general science community are the HDF formatted products. PO.DAAC will send a weekly tape of the NSCAT Standard Products to EOC for distribution to Japan Science Team members. Anyone interested in the data will be able to retrieve the NSCAT Science Products electronically from the PO.DAAC file server or may request distribution by tape. PO.DAAC maintains a Bulletin Board Service (BBS) and World Wide Web site to inform the community of NSCAT instrument and processing status. The Project requirement for distribution of standard NSCAT Science Data Products is that they be distributed within two weeks of receipt of the Level 0 NSCAT data at JPL.

In addition to the standard data processing of science products, two additional processing tracks have been implemented for operational data and engineering evaluation. The LMDR's are played back, orbit-by-orbit, to tracking stations especially built for supporting ADEOS at the University of Alaska, Alaska SAR Facility (ASF), and the NASA Wallops Flight Facility (WFF), Virginia. The orbit-by-orbit LMDR data are electronically transferred to the NOAA processing facility in Suitland, MD, where wind products are generated for inclusion in (real-time) weather forecasting models and other operational uses. These wind products are also sent, by NOAA, electronically to the Japan Meteorological Agency (JMA) for JMA's operational use. The distinct differences between the data acquired for science processing and the data acquired for operational processing are that the latter must use predict ephemerides and may be less complete. Scientific quality assurance is not applied to the operational data.

The second processing track uses the "near real-time" or Level 0 data. These data are the same as the standard Level 0 data, but with the predict, not final, orbit ephemerides. Level 0 data are also obtained electronically from Japan by JPL and are used to evaluate the engineering performance of the instrument. These data are obtained daily, typically 24 hours or more after the data are taken. After processing to Level 1 and for limited, selected files to higher levels, the data are made available to the Instrument Operations Team (IOT) and the SAPIENT at JPL. The IOT analyzes the

engineering data from the NSCAT telemetry to monitor the health and safety of the instrument. IOT also uses housekeeping engineering data that are sent electronically to JPL on a daily basis. It should be emphasised that the Level 0 data are not used to produce the science products because only the predict orbit ephemerides are available at that time.

4.1 DP&IO Organization

4.1.1 Instrument Operations Team

The NSCAT IOT is responsible for instrument commanding and monitoring the health and safety of the instrument. The NSCAT IOT does not have direct control of the instrument. Instead it must depend on the ADEOS mission operations team at EOC and the Tracking And Control Center (TACC, at Tsukuba, Japan) to perform requested command and data uplinks to NSCAT on orbit. The health and status of the instrument is monitored chiefly through analysis of two main data streams, the housekeeping data (HKDT) and the Level 0 (or near-real-time) mission data. Both data streams are made available to IOT within 24 hours or less of the data reception at TACC and forwarded through EOC via a network link with Japan.

Instrument status information is shared with the SDPS/SPOT and SAPIENT teams, to be considered at the time that the main Level 0 science data is processed when it arrives. Command requests originated by SAPIENT are processed by IOT and forwarded to EOC which integrates them into the total spacecraft command sequence that is executed through TACC. The results of IOT analyses are combined with QA and data verification analyses by SAPIENT to provide a broad picture of the state of the NSCAT instrument at every stage throughout the mission.

4.1.2 Science Processing Operations Team

During mission operations, SPOT is responsible for producing the science data level products using the SDPS software. SPOT is required to process ADEOS Level 0 data, consisting of spacecraft frames with embedded NSCAT telemetry, delivered by ADEOS to JPL on 8mm tape. The tape includes approximately one data-week of data, a "determined" spacecraft ephemeris (i.e. the ephemeris derived from tracking data), and ancillary metadata supplied by ADEOS. The data is extracted from the tape and staged for processing through five successive level processor stages, producing the six major data level products defined in section 4.2.

In addition to the main tape processing string, SPOT is responsible for retrieving and processing ADEOS Level 0 data to Level 1 for IOT instrument health analysis. Furthermore, at some later stage of the mission, after the calibration of the instrument and the geophysical model function have been definitively determined, the SPOT will be responsible for reprocessing the previous science data to conform with the new calibrations, thus maintaining uniform quality of the data throughout the mission.

4.1.3 Science Algorithm Processing and Instrument Engineering Team

SAPIENT is a multi-function analysis team responsible for NSCAT data quality. SAPIENT maintains and operates the Algorithm Testbed (ATB), to be used during mission operations for small-scale data reprocessing, algorithm refinement and testing, and SDPS troubleshooting. SAPIENT includes the Sensor Verification Team (Project Engineering), which is responsible for validation of the instrument calibration. The SVT will occasionally generate command requests to be sent to the instrument in order to obtain special calibration data and to monitor the stability of the instrument. The Data Product Verification, or QA, task is responsible for checking the data produced by SPOT before it is delivered to PO.DAAC for distribution. SAPIENT will also participate in the calibration/validation activities early in the mission.

Another responsibility of SAPIENT is the maintenance and update of processing tables which define the instrument and the processing algorithms. As the calibration of the instrument is refined after launch, SAPIENT will deliver the required processing table updates to the SDPS. Included in this task is a limited mission planning role, primarily to initiate mode, beam sequence, and binning parameter table changes as they are required for calibration experiments or to improve the instrument performance. The latest calibration information and processing tables are forwarded to NOAA for incorporation in the NOAA operational processing.

4.1.4 Physical Oceanography Distributed Active Archive Center

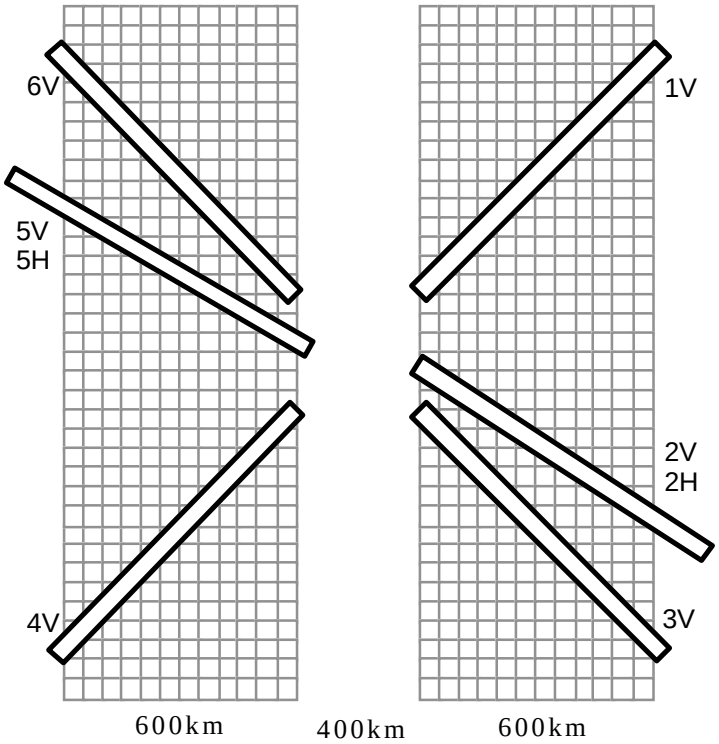
PO.DAAC is responsible for the final formatting, packaging, distribution, and archiving of the NSCAT science data. PO.DAAC receives the processed data from SPOT after the SAPIENT QA has certified the data quality. The Level 1.7, 2, and 3 data, constituting the NSCAT Science Product, are converted to Hierarchical Data Format (HDF) and copied to distribution media (8mm Exabyte tape). Information from the Data Management database is loaded into the archive catalog. The data tapes are packaged and distributed to the NSCAT science users, including the ADEOS project in Japan. Data at all levels from Level 0 to 3 are retained by PO.DAAC for permanent archive. However, only the Levels 1.5 - 3 data are available for general distribution. The Level 1.5 data are distributed to Japan and to individuals only upon special request (which needs to be approved by the NSCAT Project).

4.2 Data Flow

The NSCAT science processing proceeds through a well-defined series of level conversion stages, producing more refined products at each stage. Each product has its own utility for certain applications. Starting from raw telemetry (the Level 0 product), the data is processed first to engineering units (Level 1) and then to the main Sensor Data product (Level 1.5), which is available as a special request product. The Science Data Products, which are to be distributed to the SWT and investigators world-wide, are the Level 1.7 (collocated σ_o), Level 2.0 (wind vector), and Level 3.0 (average wind map) geophysical products.

The data products for each level are defined as follows:

NSCAT Products



Level 0 Data Files

- LMDR frame-synchronized, time ordered and non-redundant data with all available supplemental information.

- Organized by beams (.468 sec/beam; 1V 6V 2V 5V 2H 5H 3V 4V)

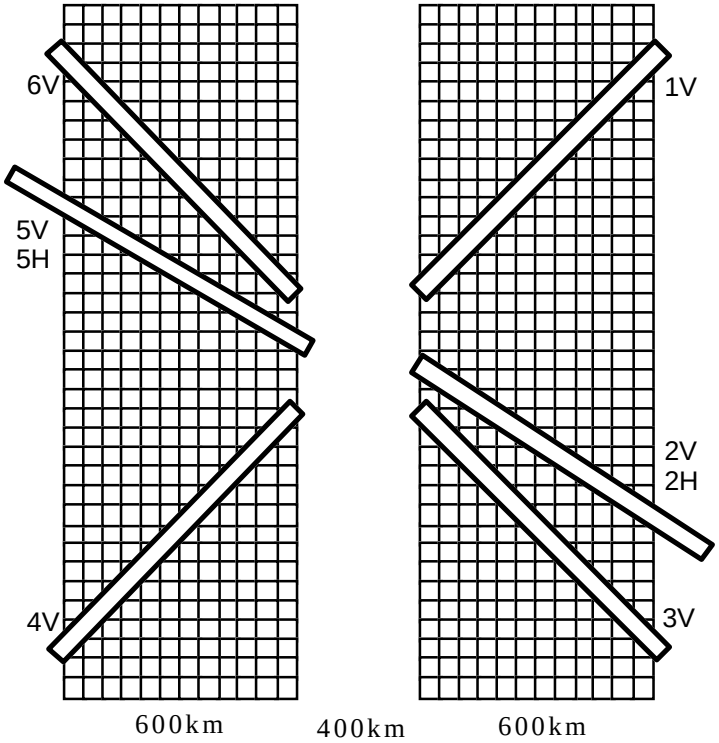
- Each beam data frame contains 25 signal + noise measurements, 25 noise measurements, 4 channel noise measurements, time, attitude, and engineering data

Level 1 Data Files

- Organized by beams (.468 sec/beam; 1V 6V 2V 5V 2H 5H 3V 4V)

- Contains Level 0 data plus converted engineering units

NSCAT Products



† Special Request Product
* NSCAT Standard Product for PO.DAAC Distribution

Level 1.5 Sigma-0 Beam Product †

- Earth located 25km sigma-0 cell data organized by beam with quality and surface flags.

- Power values converted to sigma-0 cell data, using sensor calibration data.

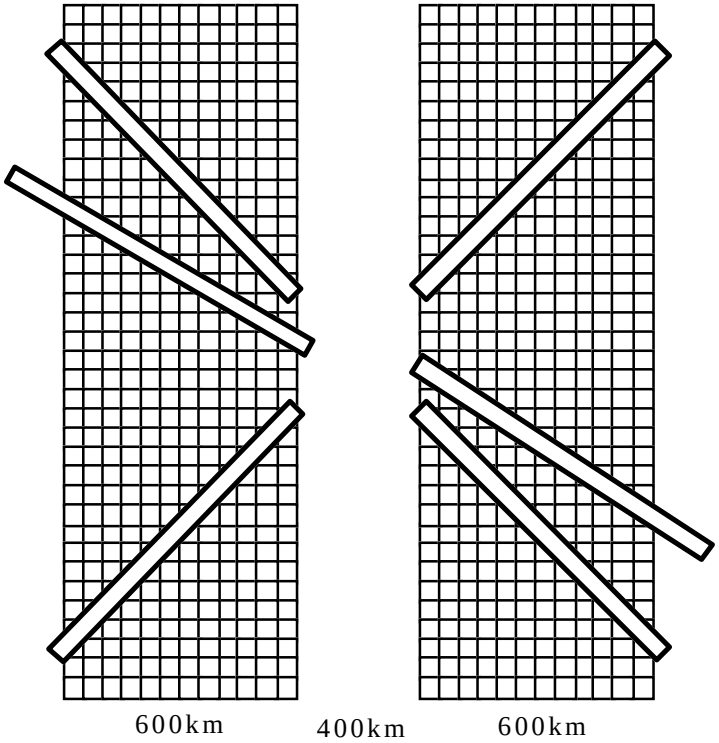
- Organized by beam frame and contain selected engineering data and all science data from Level 1.

Level 1.7 Sigma-0 Wind Vector Cell Product *

- Up to 24 (typically ~16) earth-located, 25km sigma-0s per cell in subtrack 50km wind vector cells with quality flags.

- Each record contains only data fields for wind retrieval. Records organized by NSCAT swath and contain ocean-only data.

NSCAT Products



Level 2 Vector Wind Product *

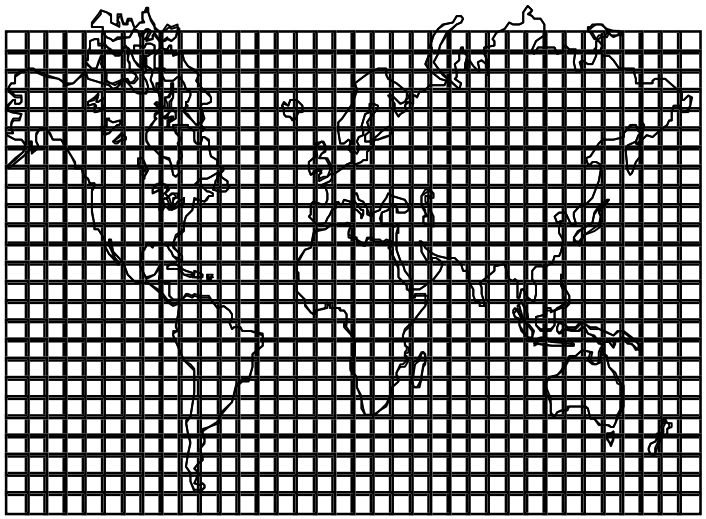
- Up to 4 wind vector solutions in 50 km Wind Vector Cells (in likelihood order) as selected by the Geophysical Model Function.

- Wind vector selected by ambiguity removal also flagged.

- Records contain the number of sigma-0's used for wind retrieval and sigma-0 quality flags.

* NSCAT Standard Products for Distribution

NSCAT Products



Level 3 Wind Map Product *

- One day average, oceans-only, global map gridded at .5 degree resolution from +75 to -75 latitude (720 cells by 300 cells)

- Each cell contains ten averaged parameters (e.g., avg wind vectors, avg speed, rms speed, wind vector std dev, map day fractions)

* NSCAT Standard Products for Distribution

Between these data levels are the following conversion stages, corresponding to major programs in the SDPS software, and the general algorithm tasks to be accomplished:

Level 0 — Stage ADEOS Level 0 data from tape to disk. Extract NSCAT telemetry portion of ADEOS frames into individual NSCAT L0 frames, and assign UTC time tags and attitude data.

L0-L1.0 — Decommutate and convert telemetry to engineering units, divide data into orbit (rev) files, assign spacecraft orbit state vectors, perform receiver gain calibrations. NSCAT orbit or rev files contain a single orbit of data starting and ending at the most southerly nadir latitude (~-81 ^{o}) of the spacecraft's orbit.

L1.0-L1.5 — Perform sensor data processing, which includes: σ_o cell location and geometry, land and ice surface flags, data quality flags, estimation of σ_o and associated factors, estimation of uncertainties.

L1.5-L2.0 — Perform geophysical data processing, which includes: colloc ation of σ_o measurements in wind vector cells, composite data quality checks and flags, wind retrieval, and ambiguity removal.

L2.0-L3.0 — Obtain an average wind map by binning wind vector data on a global map grid, and averaging at the required spatial and temporal resolution.

The next three sub-sections describe these algorithm tasks in further detail.

4.2.1 ADEOS Data Package Processing (Level 0)

The ADEOS data package includes a number of ke y items for the NSCAT data processing. These are the Platform Position Record, Time Difference (TMDF) file, and the Signal Data Records. The Platform Position Record contains the spacecraft ephemeris data. These data are reformatted for later use in the Level 1 processing. The TMDF has the time correlation constants that relate the spacecraft and NSCAT instrument timer clock counts to UTC, and is used to assign time tags to the NSCAT Level 0 frames. The Signal Data Records are the ADEOS LMDR frames containing the NSCAT telemetry and attitude data. Due to the asynchronicity between the NSCAT frames and the ADEOS LMDR frames, the NSCAT data stream must be extracted and frame-synchronized to obtain the individual NSCAT mission telemetry frames. The LMDR frames also contain attitude data (roll, pitch, yaw angles and rates) at 2 second intervals. The attitude data are assigned to the NSCAT Level 0 frames on a latest-available-data (LAD) basis.

4.2.2 Level 1 Processing

Telemetry Conversion: The NSCAT telemetry, received as a continuous time-ordered series of data frames, must be converted from the instrument data numbers (DN) into engineering units (EU) via known calibration formulas. Also, there is engineering data which is subcommutated over several

frames which must be tracked and inserted into each Level 1 data record. The algorithms for this processing have been inherited from the instrument test team.

Rev splitting: The received data batch, spanning a time period of a few hours up to a week of data, is to be split into rev files at the Level 1 stage. The NSCAT rev boundary has been defined to begin at the southernmost ascending point of the orbit and end at the southernmost descending point of the orbit. This unconventional choice is driven by the need to provide continuity of the science data over the oceans. Using the spacecraft ephemeris, the rev start times can be derived. The converted telemetry data are then written to individual Level 1.0 rev files. A rev is the minimum NSCAT granule that can be separately identified and requested.

Ephemeris and Attitude Interpolation: The spacecraft ephemeris and attitude data accompany the NSCAT telemetry. The Level 1 data have been defined to contain both the spacecraft state vector (position and velocity coordinates) and the attitude (roll, pitch, yaw) at the times of the instrument data frames. These are interpolated from the auxiliary ephemeris and attitude files.

Receiver gain: Every 128 antenna cycles, NSCAT performs a self-calibration step to provide receiver gain data necessary in computing the radar backscatter. The calibration cycle data are processed to produce receiver channel and cell gains and are then entered into a gain table used by the sensor processing. In addition, data are gathered to produce a profile of the bandpass filter response for each of the four receiver channels. These profiles, stored in a separate processing table, are used to correct the cell gains for filter ripple and spurious noise.

4.2.3 Level 1.5 Processing

The main purpose of the NSCAT sensor algorithms is to compute the various geometric and power terms of the radar equation so that the normalized radar cross-section, or σ_o, can be estimated from the received instrument power measurements. The radar equation is given by:

$$P_r = \frac{P_t L \lambda^2}{(4\pi)^2} \int \sigma_0 \frac{G_a{}^2 G_r{}^2}{R^4} dA$$

where

P_t = transmit power
G_a = antenna gain at the cell
G_r = receiver gain
P_r = received power
R = slant range (distance between the spacecraft and the cell)
A = cell area
L = system losses
λ = wavelength of the radar (Ku band, 13.995 Ghz = ~2.3 cm)

σ_o = radar backscatter coefficient

Making suitable approximations to this integral, the radar equation can be inverted to yield the backscatter cross section σ_o as a function of the transmitted and received radar powers and parameters.

Cell Location and Geometry

The processing begins with the spacecraft orbit and attitude data that are contained in the Level 1.0 record. From this information plus the knowledge of the antenna deployment angles and the Doppler binning table, all of the necessary geometric information can be derived. The Doppler filtering and cell power binning done on-board the instrument is governed by the "Doppler binning" algorithm. As the spacecraft orbits the rotating Earth, the relative velocity between the antenna beam and the ground location of a given measurement cell changes continuously as a function of latitude. By adjusting the receiver filter frequencies to compensate for this change, the cells can be maintained at fixed cross-track locations all around the orbit. The benefit of this technique is that σ_o cells from different beams can be accurately coregistered on the same geographical location, improving the accuracy of the subsequent wind vector estimate.

From the spacecraft location and Doppler binning information, the locations of the corners of the measurement cells is derived. The centroid of these locations is computed, and yields the slant range, antenna angle (which corresponds to a value of the broad-beam antenna gain), and the cell azimuth and incidence angles (which are required later for wind retrieval). From the cell corners, the cell area is computed. The along-track and cross-track locations of the cells are computed and stored for later use in collocating the measurements into wind vector cells. The formal uncertainties in the geometric parameters are assigned to each cell.

Land and Ice Flags

Radar returns from land and ice correspond to different scattering processes than those over open ocean, and can contaminate wind vector estimates. Knowing the location and extent of each cell, the cell can be checked against maps of land locations and sea ice maps derived from operational products to set surface flags. These flags are checked prior to wind retrieval to determine whether or not to use a given σ_o measurement.

Radar Backscatter (σ_o)

Having computed the main geometrical terms of the radar equation, it remains to compute the received power P_r from the instrumental measurements of received signal+noise and noise-only power in the Level 1.0 record. The instrumental data numbers are converted to powers using the receiver gains (G_r) derived from calibration frame processing and stored in the Receiver Gain table.

The noise power is estimated and subtracted from the signal+noise power to derive the estimate of P_r. At this point, all of the information required to compute σ_o is available.

The normalized standard d eviation of σ_o, known as K_p, is computed to give an estimate of the measurement uncertainty of the backscatter. There are three major sources of K_p in the scatterometer system:

1) the uncertainty in the receiver noise, known as communication K_p or K_{pc}; in the case of NSCAT with its digital Doppler receiver, the calculation of K_{pc} is given by a complex formula known as the digital K_p equation;

2) the uncertainties in the geometric and gain parameters, known as retrieval K_p or K_{pr}, contribute uncertainty in the derived estimate of σ_o;

3) the uncertainty associated with the geophysical model function; since K_p is defined relative to the true σ_o for the true wind, the lack of knowledge of the relation between σ_o and vector wind contributes the model function K_p term, or K_{pm}.

The total K_p of the measured σ_o is used in the wind retrieval algorithm to weight the individual measurements used to estimate the wind vector.

Mean Atmospheric Attenuation

The radar signal will be attenuated as it passes through the Earth's atmosphere. To correct for this effect, a mean atmospheric attenuation correction, based on the climatology provided by Wentz (1996), is applied to the σ_o values. In the NSCAT processing, the monthly 1x1 degree mean two -way nadir attenuation is spatially interpolated to the σ_o location and coverted to a line -of-sight attenuation.

The Wentz climatology is based on eight years of SSM/I data (over the ocean). 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 mean atmospheric attenuation, in dB, used to correct the σ_o values is a parameter in the Level 1.7 data product (see Table 5.8). It should also be noted that this correction has already been applied to the σ_o values in the Level 1.7 data product.

4.2.4 Level 1.7 and level 2.0 Processing

The NSCAT geophysical algorithms produce the main science data products to be distributed to the science team. These consist of the Level 1.7, Level 2.0, and Level 3.0 products, providing collocated ocean σ_o data, vector wind data, and averaged global wind maps, respectively. The principal algorithm functions performed at this stage are:

Sigma-0 Grouping: Before the wind vector at a given location is computed, the σ_o measurements, stored in time-ordered beam-frames in Level 1.5, are grouped or collocated in wind vector cells (WVC). The σ_o data from all four beams, taken at 25-km average resolution, are grouped into 50-km wind vector cells prior to wind retrieval. Thus, an average of 16 measurements are used to estimate the wind vector at each location.

Wind Retrieval: The process of wind retrieval depends on knowledge of the relationship between radar backscatter from the ocean surface and the local wind conditions at the location of the backscatter measurements. The objective of the wind retrieval algorithm is to invert this relationship to yield the wind speed and direction by fitting a set of σ_o measurements taken at a number of different look angles to the model function. Because of the nature of the scattering, this process yields a set of possible wind vector solutions, known as wind vector ambiguities, which have similar wind speeds at different directions.

Ambiguity Removal: The NSCAT wind retrieval algorithm derives wind vectors on a cell-by-cell, or point-wise, basis, without considering data in adjacent WVC. It is the job of the ambiguity removal algorithm to examine the retrieved wind vector field as a whole to ensure that it is geophysically consistent. The NSCAT algorithm uses a vector median filter as described in Shaffer et al (1991).

The level 1.7 processing produces the σ_o grouping while the level 2.0 processing gives the retrieved winds. The geophysical processing algorithms are described in further detail in Section 6.

4.2.5 Level 3.0 Processing

The Level 3.0 Average Wind Map is a high-resolution, daily global synopsis of the selected NSCAT wind vector data. It is intended to be used to create long-term average maps of various geophysical quantities, while it retains sufficient time resolution to be useful in investigating higher-frequency variations. The map algorithm bins the Level 2.0 wind vector data on a rectangular 0.5° x 0.5° latitude-longitude grid covering latitudes from -75° to $+75^\circ$, then averages the data in each map cell. A series of statistics (see Section 5.1) are also created for each grid cell. These are designed so the investigator can evaluate the average wind vectors.

4.3 Data Quality Assurance

In essence, quality assurance (QA) is the continuing task of checking the reasonableness of the data values contained within each data level science product. This process includes the production of a "Reasonable Value Report" which summarizes statistics on each parameter and flag included in each data product. Among the statistics are "out-of-range" occurrences for each parameter. Flags and

out-of-range occurrences are also summarized on global plots so patterns can be detected. Long-term QA includes the monitoring of key parameters using time series and histograms. A short summary of the QA analyses will be provided to PO.DAAC for inclusion in their data shipments to investigators.

If something unusual is detected during the QA analysis, every effort will be made to resolve the problem without impacting the data release schedule. Possible data release scenarios include:

- Releasing all available data

- Releasing all the data with an appropriate warning

  If a general QA problem is detected, but is found to have only minor impact, the data products may be released to PO.DAAC with a warning to users. This release option would be used only for interim data releases (not final or reprocessed data) and would be considered when the delay in releasing the data, in order to fix the problem, is not warranted.

- Releasing only the good files

  If a problem is detected that only affects a limited number or percentage o f the files, the remaining data may be processed and distributed.

- Not releasing the data

  If a serious problem is detected that affects most or all of the data files, the data level products will not be released until the problem is corrected.

5. Geophysical Data Product Content & Format

The NSCAT Geophysical Data Products (Levels 1.7, 2 and 3) are distributed to the science community in HDF format. The HDF file structure consists of four main types of data structures:

SDS An array of a data item of a given type, with fixed dimensionality (rank); permitted to have one "unlimited" dimension along which the array can grow indefinitely.

Vdata A record-based structure wherein record fields may be defined, named, and typed individually. Vdatas are one-dimensional arrays of records.

Vgroup A structure for associating sets of data objects. Vgroups may "contain" any HDF objects, including other Vgroups.

Attribute A named value or list of values, all of the same data type. An attribute can be global (pertaining to the entire file) or local (associated with an individual data object).

The contents of the data products are classified by HDF structure type as they are described. Other features of the HDF file structure as it relates to the use of the NSCAT data products are described in Chapter 7 of this volume.

The NSCAT parameters, given in HDF context are described in the sections and tables below. They are discussed in reverse order, Level 3 to Level 1.7, because that is the order they appear on the NSP tapes.

5.1 Level 3 -- Average Wind Vector Map Product

The Level 3 data are a set of global averaged maps of wind vector solutions, various secondary variables and statistical descriptors. The averaging interval is one day, spanning complete revs beginning and ending nearest to 0h UTC and 24h UTC, respectively. Each map contains one averaged parameter. The map projection used is a simple linear latitude/longitude projection. The map grid is in half degree resolution defined within latitude limits of -75° to $+75^{\circ}$ and longitude limits of 0° to 360°. The horizontal and vertical map grid dimensions are 720 and 300, respectively. One horizontal map grid row is considered one record. The starting grid row corresponds to the southernmost latitude and the starting grid column corresponds to the westernmost longitude within the map region. To find out whether data are missing values, check WVC_count (defined in Table 5.3). If WVC_count is greater than 0 then there is data and is 0 if there is no data. Note that there are artifact SDS's in the Level 3 HDF data file, namely, row and column.

The HDF version of the Level 3 data consists of a "header", containing the HDF Global Attributes, and a PlanetaryGrid Vgroup structure containing the data. The Planetary Grid Vgroup includes a Geometry Vgroup containing map projection information, and the set of map data SDS arrays. The individual parameters are specified in Tables 5-1, 5-2, and 5-3.

Table 5.1 HDF Global Attributes for NSCAT Level 3 Product

Attribute	Definition
ADEOS_Data_Package_ID	ADEOS data package identifier. "S#", where # ranges from 1-2147483647.
ADEOS_Data_Package_Type	Always "S", indicating science data.
Build_ID	Version ID of SDPS software used.
Data_Format_Type	Always "HDF"
Data_Status	Status of data file: Should always be "COMPLETE" - no errors or warnings.
Data_Type	Always "L3"
First_Data_Time	UTC start time of the data. Format: yyyy-doyThh:mm:ss.sss where yyyy is the year, doy is day of year, hh is hour, mm is minutes, and ss.sss is seconds.
First_Rev_Eq_Crossing_Lon	Equator crossing longitude for the first rev.
First_Rev_Eq_Crossing_Time	Equator crossing time for the first rev. Same format as First_Data_Time.
First_Rev_Number	First rev number in the data file.
HDF_Build_ID	PO.DAAC HDF software identifier. Format is "JPL PO.DAAC 4.0r2 10/24/96" which specifies the number and date of JPL release description document.
HDF_Conversion_Organization	Always "JPL PO.DAAC"
HDF_Conversion_Time	Local time HDF conversion was performed by PO.DAAC.
HDF_SIS_ID	HDF Software Interface Specification identifier. Same format as HDF_Build_ID.
Last_Data_Time	UTC end time of the data. Same format as First_Data_Time.
Last_Rev_Number	Last rev number in the data file.
Producer_Agency	Always "NASA"
Producer_Agency	Always "NASA"

Table 5.1 HDF Global Attributes for NSCAT Level 3 Product (continued)

Attribute	Definition
Product_Creation_Time	Local time when data file was created
Project_ID	Always "NSCAT"
Sensor_Name	Always "NSCAT"
SIS_ID	Original (native) Software Interface Specification identifier. Same format as HDF_Build_ID.
Skip_Start_Time	Start UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator. Skipped data are data received, but not processed due to some problem.
Skip_Stop_Time	End (stop) UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator.

Table 5.2 Geometry Vdata for NSCAT Level 3 Product

Element	Definition	Storage type
bin_meth	Binning methodology used. Always "ARITHMEAN" indicating arithmetic mean.	9*char8
grid_origin	Location of the origin of the grid. Always "SOUTHWEST" indicating that the cell of the first row and column in a grid corresponds to the southwest corner of the map region, and the grid's column direction corresponds to the maps' longitude direction.	9*char8
hsize	Horizontal size (degrees longitude) of grid cell. Always "0.5" degrees.	float32
max_east	Eastern most longitude covered by grid. Always "360" degrees.	int16
max_north	Northern most longitude covered by grid. Always "75" degrees.	int16
max_south	Southern most longitude covered by grid. Always "-75" degrees.	int16
max_west	Western most longitude covered by grid. Always "0" degrees.	int16
registration	Relationship between the first grid cell and the geographic location of the cell. Always "SOUTHWEST" indicating that the first grid cell's geographical coordinate of 0 degrees longitude and -75 degrees latitude corresponds to the southwest corner of the grid cell.	9*char8
vsize	Vertical size (degrees longitude) of grid cell. Always "0.5" degrees.	9*char8

Table 5.3 Map Data SDS's for NSCAT Level 3 Product

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Avg_Sigma0_Count	4	Average Number of σ_0 measurements per WVC in map grid cell.	uint16	0.1	300x720	n/a
Avg_Wind_Speed	7	Average wind speed in cell.	uint16	0.01	300x720	m/s
Avg_Wind_Vel_U	5	Average east-west component of the wind velocity vector. Positive eastward.	int16	0.01	300x720	m/s
Avg_Wind_Vel_V	6	Average north-south component of the wind velocity vector. Positive northward.	int16	0.01	300x720	m/s
Map_Day_Fraction	3	Average value of time tags of WVC's within a map grid cell, expressed as a fraction of the map interval (1 day).	uint16	0.001	300x720	n/a
Map_Day_Fraction_StdDev	9	Standard deviation of Map_Day_Fraction	uint16	0.001	300x720	n/a
RMS_Wind_Speed	8	RMS difference from the wind speed calculated for each grid cell.	uint16	0.01	300x720	m/s
Wind_Vel_U_StdDev	10	Standard deviation of the average east-west component of the wind velocity vector.	uint16	0.01	300x720	m/s
Wind_Vel_V_StdDev	11	Standard deviation of the average north-south component of the wind velocity vector.	uint16	0.01	300x720	m/s
WVC_Count	0	Number of WVC's in grid cell.	uint16	1	300x720	counts

5.2 Level 2 -- Ocean Wind Vector Product

The NSCAT Level 2 data product consists of ocean wind vector solutions, derived from σ_o measurements grouped by geographic location into wind vector cells (WVC). Each data record is a cross-track row of WVC's. The maximum number of data records is estimated at 820, while the nominal number of records is approximately 70% of this, due to the presence of land or ice. A record is written to the file if at least one WVC contains data from which ocean winds were retrieved.

The HDF version of the Level 2 data file consists of "header" information stored as HDF global attributes, and a Swath Data Vgroup. The Swath Data Vgroup contains three major parts: the swath data itself (stored as a set of SDSs), a Swath Index Vdata of WVC row number versus record number (-1 indicates no record for a given row), and a Swath Metadata Vdata containing flag fields and record time tags.

Within each WVC, there are up to four possible sets of values for wind speed, direction, speed and direction uncertainties, and the MLE likelihood. Each of these are in SDS arrays with dimensions 820 (max) x 24 x 4, with the last index representing the ambiguity position. The wind vector solution selected by the ambiguity removal algorithm is placed in the first position, with the remaining ambiguities in decreasing order of MLE likelihood.

To find out whether data are missing values, check Num_Ambigs (defined in Table 5.5). If Num_Ambigs is greater than 0 then there is data and is 0 if there is no data. Note that row, WVC and position are artifact SDS's.

Tables 5-4, 5-5, and 5-6 specify the Level 2 parameters.

Table 5.4 HDF Global Attributes for NSCAT Level 2 Products

Attribute	Definition
ADEOS_Data_Package_ID	ADEOS data package identifier. "S#", where # ranges from 1-2147483647.
ADEOS_Data_Package_Type	Always "S", indicating science data.
Ambig_Removal_Method	Method used for ambiguity removal. "0" = baseline used.
Build_ID	Version ID of SDPS software used.
Data_Format_Type	Always "HDF"
Data_Status	Status of data file: Should always be "COMPLETE" - no errors or warnings.
Data_Type	Always "L2"
First_Data_Time	UTC start time of the data. Format: yyyy-doyThh:mm:ss.sss where yyyy is the year, doy is day of year, hh is hour, mm is minutes, and ss.sss is seconds.
First_Rev_Eq_Crossing_Lon	Equator crossing longitude for the first rev.
First_Rev_Eq_Crossing_Time	Equator crossing time for the first rev. Same format as First_Data_Time.
First_Rev_Number	First (and only) rev number in the data file.
HDF_Build_ID	PO.DAAC HDF software identifier. Format is "JPL PO.DAAC 4.0r2 10/24/96" which specifies the number and date of JPL release description document.
HDF_Conversion_Organization	Always "JPL PO.DAAC"
HDF_Conversion_Time	Local time HDF conversion was performed by PO.DAAC.
HDF_SIS_ID	HDF Software Interface Specification identifier. Same format as HDF_Build_ID.
Last_Data_Time	UTC end time of the data. Same format as First_Data_Time.
Number_Actual_Output_Records	Number of data records in the data file.
Number_Expected_Output_Records	Expected number of output records based on the time interval of the data.

Table 5.4 HDF Global Attributes for NSCAT Level 2 Products (continued)

Attribute	Definition
Producer_Agency	Always "NASA"
Producer_Institution	Always "JPL"
Product_Creation_Time	Local time when data file was created.
Project_ID	Always "NSCAT"
Sensor_Name	Always "NSCAT"
SIS_ID	Original (native) Software Interface Specification identifier. Same format as HDF_Build_ID.
Skip_Start_Time	Start UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator. Skipped data are data received, but not processed due to some problem.
Skip_Stop_Time	End (stop) UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator.

Table 5.5 Swath Data SDS's for NSCAT Level 2 Product

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Error_Dir	13	Uncertainty estimated for a given wind direction value. The dimensions represent along track cell rows (820 max) x cross track cells (24) x wind vector ambiguities (up to 4). Selected ambiguity is always given first.	uint16	0.01	820 (max) x24x4	degrees
Error_Speed	14	Uncertainty estimated for a given wind speed value. See definition of Error_Dir.	uint16	0.01	820 (max) x24x4	m/s
Mean_Wind	10	Mean wind speed of all ambiguities for the given WVC, excluding out-of-range values. No solution --> 0.0.	uint16	0.01	820 (max) x24	m/s
MLE_Likelihood	16	Relative likelihood that a given wind vector solution is correct. Raw value of the MLE objective function; the highest rank is given to the maximum value of this function. See definition of Error_Dir.	int16	0.1	820 (max) x24x4	n/a
Num_Ambigs	17	The number of wind vector ambiguities reported for a given WVC and stored in the data record.	uint8	1	820 (max) x24	counts
Num_Beam_Fore	5	Total number of σ_0 measurements received from the fore beam (1 or 2)	uint8	1	820 (max) x24	counts
Num_Beam_MidV	6	Total number of σ_0 measurements received from the mid-V beam (3 or 4)	uint8	1	820 (max) x24	counts
Num_Beam_MidH	7	Total number of σ_0 measurements received from the mid-H beam (5 or 6)	uint8	1	820 (max) x24	counts

Table 5.5 Swath Data SDS's for NSCAT Level 2 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Num_Beam_Aft	8	Total number of σ_0 measurements received from the aft beam (7 or 8)	uint8	1	820 (max) x24	counts
Num_Sigma0	4	Total number of σ_0 measurements present in the WVC. Sum of Num_Beam_Fore, Num_Beam_MidV, Num_Beam_MidH, and Num_Beam_Aft.	uint8	1	820 (max) x24	counts
Wind_Dir	13	Wind direction solutions for a given WVC. See definition of Error_Dir.	uint16	0.01	820 (max) x24x4	degrees
Wind_Speed	11	Wind speed solutions for a given WVC. See definition of Error_Dir.	uint16	0.01	820 (max) x24x4	m/s
WVC_Lat	0	Geodetic latitude of the center of the WVC.	int16	0.01	820 (max) x24	degrees
WVC_Lon	3	Geodetic longitude of the center of the WVC.	uint16	0.01	820 (max) x24	degrees
WVC_Quality_Flag	9	Wind retrieval quality flag: 0 = All σ_0's used in wind retrieval. 1 = Minimum of 6 σ_0's used. Some σ_0's flagged (and not used) because of land/ice contamination. 2 = Minimum of 6 σ_0's used. Some σ_0's flagged for absorption (and not used). 3 = Less than 6 σ_0's used in wind retrieval. 4 = Insufficient data for wind retrieval. Other fields have **NO VALID DATA**.	uint8	1	820 (max) x24	

Table 5.6 Swath Vdatas for NSCAT Level 2 Product

Vdata/Element	Definition	Storage type
SwathIndex Vdata		
begin	Number denoting the along-track location of a WVC in a rev. Nominally there are 812 WVC rows in one rev. This field is used to reassemble a swath, including the missing WVC rows. The name "begin" is from the standard EOSDIS V0 index structure.	int16
SwathMeta Vdata	All the variables below are dimensioned 820 - one for each possible WVC row.	
High_Wind_Speed_Flags	Caution flags for high wind speeds based on the Mean_Wind value for each WVC. Possible values: 0 = wind speed ≤ 30 m/s. 1 = wind speed > 30 m/s. Flags for a given row of WVC cells are specified such that bit 0 corresponds to WVC1 and bit 23 to WVC24.	uint32
Low_Wind_Speed_Flags	Caution flag for low wind speeds based on the Mean_Wind value for each WVC. Possible values: 0 = wind speed ≥ 3 m/s. 1 = wind speed < 3 m/s. Flags for a given row of WVC cells are specified such that bit 0 corresponds to WVC1 and bit 23 to WVC24.	uint32
Mean_Time	The average time tag for a row of WVCs. Format: yyyy-doyThh:mm:ss.sss where yyyy is the year, doy is day of year, hh is hour, mm is minutes, and ss.sss is seconds.	24*char8

5.3 Level 1.7 -- Grouped σ_o Product

The NSCAT Level 1.7 data product consists of ocean-only backscatter (s_o) measurements, grouped by geographic location into wind vector cells (WVC). Each data record is a cross-track row of WVC's. Included with the σ_o measurements are ancillary geometric and beam membership information needed to process the data into vector winds. The maximum number of data records is estimated at 820, while the nominal number of records is approximately 70% of this, due to the presence of land or ice. A record is written to the file if at least one WVC contains data from which ocean winds may be retrieved, and for which a corresponding WVC of wind vector data is present in the Level 2 data product.

The HDF version of the Level 1.7 data file consists of "header" information stored as HDF global attributes, and a Swath Data Vgroup. The Swath Data Vgroup contains three major parts: the swath data itself (stored as a set of SDSs), a Swath Index Vdata of WVC row number versus record number (-1 indicates no record for a given row), and a Swath Metadata Vdata containing flag fields and record time tags.

The values for s_o and associated data are placed in specific sections of the WVC array based on beam number. Each WVC can have up to six actual σ_o measurements from each of the four antenna beams, for a maximum of 24 measurements per WVC. Each record holds data for 24 WVC's in a cross-track row. There are three indices: WVC row index x WVC index (within a row) x σ_o position index (within a WVC), which correspond to the array dimensions of 820 (max) x 24 x 24.

For each WVC (1-24) there is space reserved for up to 24 sigma0 data values, with a maximum of 6 measurements from each of the four beams (fore, mid-V, mid-H, aft). The data in these arrays have been rearranged so that the first six positions contain fore beam measurements, positions 7-12 contain the mid-V beam measurements, 13-18 contain the mid-H beam measurements, and 19-24 contain the aft beam measurements. In each case where there are fewer than 6 measurements from a given beam (nominally there are 4 measurements from each beam), the unfilled positions are occupied by flag values. Note that row, WVC and Sigma0_Dimension are artifact SDS's.

Negative sigma0 values can be found in Level 1.7 data. The Sigma0_Quality_Flag has 11 different (bits 0-10) quality indicators. Information of negative σ_0 is given in bit 10, which denotes the sign of the normal (ratio) space σ_0. Any use of the σ_0's must take into account this bit flag. The σ_o measurements are provided in dB, so to properly use the data the following conversion must be used:

$$\sigma_o\,[\text{ratio}] = (-1)^{(\text{bit } 10)}\ 10^{(0.1\sigma o[\text{dB}])}$$

Tables 5-7, 5-8, and 5-9 specify the NSCAT Level 1.7 parameters.

Table 5.7 HDF Global Attributes for NSCAT Level 1.7 Products

Attribute	Definition
ADEOS_Data_Package_ID	ADEOS data package identifier. "S#", where # ranges from 1-2147483647.
ADEOS_Data_Package_Type	Always "S", indicating science data.
Build_ID	Version ID of SDPS software used.
Data_Format_Type	Always "HDF"
Data_Status	Status of data file: Should always be "COMPLETE" - no errors or warnings.
Data_Type	Always "L17"
First_Data_Time	UTC start time of the data. Format: yyyy-doyThh:mm:ss.sss where yyyy is the year, doy is day of year, hh is hour, mm is minutes, and ss.sss is seconds.
First_Rev_Eq_Crossing_Lon	Equator crossing longitude for the first rev.
First_Rev_Eq_Crossing_Time	Equator crossing time for the first rev. Same format as First_Data_Time.
First_Rev_Number	First (and only) rev number in the data file.
HDF_Build_ID	PO.DAAC HDF software identifier. Format is "JPL PO.DAAC 4.0r2 10/24/96" which specifies the number and date of JPL release description document.
HDF_Conversion_Organization	Always "JPL PO.DAAC"
HDF_Conversion_Time	Local time HDF conversion was performed by PO.DAAC.
HDF_SIS_ID	HDF Software Interface Specification identifier. Same format as HDF_Build_ID.
Last_Data_Time	UTC end time of the data. Same format as First_Data_Time.
Number_Actual_Output_Records	Number of data records in the data file.
Number_Expected_Output_Records	Expected number of output records based on the time interval of the data.
Producer_Agency	Always "NASA"
Producer_Institution	Always "JPL"

Table 5.7 HDF Global Attributes for NSCAT Level 1.7 Products (continued)

Attribute	Definition
Product_Creation_Time	Local time when data file was created.
Project_ID	Always "NSCAT"
Sensor_Name	Always "NSCAT"
SIS_ID	Original (native) Software Interface Specification identifier. Same format as HDF_Build_ID.
Skip_Start_Time	Start UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator. Skipped data are data received, but not processed due to some problem.
Skip_Stop_Time	End (stop) UTC date and time for data skipped during level processing. Same format as First_Data_Time. For multiple skips, times are appended together using ";" as a separator.

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Cell_Azimuth	14	The azimuth angle of the instantaneous σ_0 cell, measured clockwise from north to the local direction of the antenna beam, subtended at the satellite nadir. The dimensions represent along track cell rows (820 max) x cross track cells (24) x σ_0 measurements (up to 24).	uint16	0.01	820 (max) x24x24	degrees
Cen_Lat	11	Geodetic latitude of center of the σ_0 cell.	int32	0.001	820 (max) x24x24	degrees
Cen_Lon	13	Geodetic longitude of center of the σ_0 cell.	int32	0.001	820 (max) x24x24	degrees
Coeff_A	17	Coefficient α in the σ_0 variance (k_p) equation.	uint16	1.0e-6	820 (max) x24x24	n/a
Coeff_B	18	Coefficient β in the σ_0 variance (K_p) equation.	uint16	1.0e-7	820 (max) x24x24	n/a
Coeff_C	19	Coefficient γ in the σ_0 variance (K_p) equation.	uint16	1.0e-9	820 (max) x24x24	n/a
Incidence_Angle	15	Angle between the local (cell center) normal vector at the Earth's surface and the spacecraft to cell center vector.	uint16	0.01	820 (max) x24x24	degrees

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
K_Polar	21	Polarization index used by the model function table. Possible values: 0 = no measurement 1 = vertical polarization 2 = horizontal polarization	uint8	1	820 (max) x24x24	n/a
Mean_Atmos_Attenuation	26	The average two-way value of the radar signal attenuation in dB due to atmospheric water vapor, oxygen and clouds. Attenuation due to rain is not included. See discussion in Sec. 4.2.3	uint8	0.004	820 (max) x24	dB
Num_Beam_Fore	6	Total number of σ_0 measurements received from the fore beams (1&2)	uint8	1	820 (max) x24	counts
Num_Beam_MidV	7	Total number of σ_0 measurements received from the mid-V beams (3&4)	uint8	1	820 (max) x24	counts
Num_Beam_MidH	8	Total number of σ_0 measurements received from the mid-H beams (5&6)	uint8	1	820 (max) x24	counts
Num_Beam_Aft	9	Total number of σ_0 measurements received from the aft beams (7&8)	uint8	1	820 (max) x24	counts
Num_Good_Sigma0	5	Total number of σ_0 measurements present in the WVC usable for wind retrieval.	uint8	1	820 (max) x24	counts
Num_Sigma0	4	Total number of σ_0 measurements present in the WVC. Sum of Num_Beam_Fore, Num_Beam_MidV, Num_Beam_MidH, and Num_Beam_Aft.	uint8	1	820 (max) x24	counts

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Sigma0	16	σ_0 value given in dB. Calculated from the absolute value of σ_0 in normal space. Prior to using Sigma0, the sign bit defined in Sigma0_Quality_Flag (bit 10) must be checked to insure that the value of σ_0 in normal space is positive.	int16	0.01	820 (max) x24x24	dB
Sigma0_Quality_Flag	20	Bit flags indicating the quality of the value of the each σ_0 measurement. Definition of the bits is given below: Bit Definition 0 Cell location failed to converge 0 - No 1 - Yes 1 Subtrack location out of range 0 - No 1 - Yes 2 Antenna angle out of range 0 - No 1 - Yes 3 Transmit power flag 0 - Transmit power available 1 - Transmit power not available 4 Receiver gain flag 0 - Interpolated 1 - LAD/NAD value	uint16	1	820 (max) x24x24	n/a

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Sigma0_Quality_Flag (cont.)		Bit Definition 5 BPF ripple flag 0 - Computed 1 - Fixed table 6 BPF ripple table correction flag 0 - Correction applied 1 - No Correction 7 Spurious noise flag 0 - Computed 1 - Fixed 8 Spurious Noise in Cell 0 - No 1 -Yes 9 Signal and noise are zeros 0 - No 1 - Yes 10 Negative σ_0 bit = 0 if $\sigma_0 \geq 0$ bit = 1 if $\sigma_0 < 0$ 11-15 Spares -- always 0				
Sigma0_Usable_Flag_1	22	Eight bit (0-7) flags indicating whether or not the first eight σ_0 measurements are usable for wind retrieval. Each bit is defined as follows: 0 - Usable 1 - Not usable	uint8	n/a	820 (max) x24	n/a

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
Sigma0_Usable_Flag_2	23	Eight bit (0-7) flags indicating whether or not the second eight σ_0 measurements are usable for wind retrieval. Each bit is defined as follows: 0 - Usable 1 - Not usable	uint8	n/a	820 (max) x24	n/a
Sigma0_Usable_Flag_3	24	Eight bit (0-7) flags indicating whether or not the third eight σ_0 measurements are usable for wind retrieval. Each bit is defined as follows: 0 - Usable 1 - Not usable	uint8	n/a	820 (max) x24	n/a
Surface_Flag	25	Bit flags indicating land and ice contamination. Bits are defined as follows: Bit — Definition 0 — Surface land flag 0 - Data not over land 1 - Data over land 1 — Ice flag data 0 - Ice data available 1 - Ice data not available 2 — Surface ice flag 0 - Data not over sea ice 1 - Data over sea ice 3-7 — Spares - always 0	uint8	1	820 (max) x24x24	n/a

Table 5.8 Swath Data SDS's for NSCAT Level 1.7 Product (continued)

Element	SDS order	Definition	Storage Type	Scale Factor	Dimension	Units
WVC_Lat	0	Geodetic latitude of the center of the WVC.	int16	0.01	820 (max) x24	degrees
WVC_Lon	3	Geodetic longitude of the center of the WVC.	uint16	0.01	820 (max) x24	degrees
WVC_Quality_Flag	10	Wind retrieval quality flag: 0 = All σ_0's used in wind retrieval. 1 = Minimum of 6 σ_0's used. Some σ_0's flagged (and not used) because of land/ice contamination. 2 = Minimum of 6 σ_0's used. Some σ_0's flagged for absorption (and not used). 3 = Less than 6 σ_0's used in wind retrieval. 4 = Insufficient data for wind retrieval. Other fields have **NO VALID DATA**.	uint8	1	820 (max) x24	n/a

Table 5.9 Swath Vdatas for NSCAT Level 1.7 Product

Vdata/Element	Definition	Storage type
SwathIndex Vdata		
begin	Number denoting the along-track location of a WVC in a rev. Nominally, there are 812 WVC rows in one rev. This field is used to reassemble a swath, including the missing WVC rows. The name "begin" is from the standard EOSDIS V0 index structure.	int16
SwathMeta Vdata	All the variables below are dimensioned 820 - one for each possible WVC row.	
L17_Quality_Flags	A set of flags [TBD] indicating the Level 1.7 WVC row quality conditions. [Not currently used. Treated as a spare.]	uint32
Mean_Time	The average time tag for a row of WVCs. Format: yyyy-doyThh:mm:ss.sss where yyyy is the year, doy is day of year, hh is hour, mm is minutes, and ss.sss is seconds.	24*char8

6. Geophysical Algorithm Summary

6.1 Sigma-0 Grouping

The Sigma-0 Grouping algorithm prepares the NSCAT σ_o data for wind retrieval processing. The data contained in the Level 1.5 product is grouped by geographic location into wind vector cells (WVC). Each WVC contains all the data required to perform the wind retrieval computation, as well as data for the Level 2 wind vector product. The grouped σ_o data are saved as WVC records in the Level 1.7 product.

The main function of the Sigma-0 Grouping algorithm is to re-order the Level 1.5 sensor data from time-ordered, beam-oriented data frames into a primarily spatially-ordered (also time-ordered, but in an average sense) data set. It makes use of the subtrack bin coordinates WVC_I and WVC_J assigned to each sigma-0 cell in the L15 processing. These coordinates describe the location of each sigma-0 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 sigma-0 data to particular buffer locations on a 50 km wind vector cell grid in preparation for wind retrieval. The data are buffered in arrays called "span" buffers, because the size of the buffers is determined by the area "spanned" by the scatterometer antenna beams in both the along- and cross-track dimensions. These buffers reserve space for data until the wind vector cell row is out of range to receive new data, at which point the entire row of WVC's (nominally 24) is passed to the Wind Vector Cell Preparation algorithm and to the wind retrieval algorithm. Once a row has been passed on to subsequent processing, the space can be re-used for new data.

The principal advantage of this algorithm is that the Level 1.5 data may be read, sequentially, only once to perform all of the processing in the Level 1.5-2.0 conversion. It avoids complex file search and data sorting algorithms while achieving the required data grouping. The technique is conceptually simple, direct, and efficient.

The Wind Vector Cell Preparation algorithm operates on a row of WVC's, passed from the Grouping algorithm, one WVC at a time. It then must determine if there is sufficient data of sufficient quality to perform wind retrieval. This algorithm checks each WVC to determine the data counts (total and by beam), quality flags, surface flags, 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 are placed in the Level 2 output buffer, and the grouped σ_o data used to produce the wind vectors is written to the Level 1.7 data record. When all WVC's have been processed, control returns to the Grouping algorithm.

6.2 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

$$\sigma_o = F(|U|, c,...; f, p, q) \quad (2)$$

where σ_o is the normalized radar cross-section of the ocean surface, |U| is wind speed, c is the azimuth angle in the horizontal plane between the vector wind and the radar, and (...) represents the (presumed small) influences of other geophysical phenomena on σ_o. The parameters f, p, and q 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 c (with period 2p), it is natural to model the azimuthal modulation as a Fourier series in c.

The upwind-downwind modulation of σ_o, coupled with at least three colocated 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 perfect upwind/downwind symmetry, a 180^o 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 leads to only moderate point-by-point skill in resolving directional ambiguities.

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, J, 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^o apart. On the basis of 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, helps to break this symmetry, yielding a single global extremum.

The NSCAT wind retrieval algorithm uses a Maximum-Likelihood Estimator (MLE) as the objective function for determining wind vector solutions. The MLE is defined by

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

where s_{oi} are the backscatter measurements, $s_m(u,c_i)$ are the model backscatter values corresponding to the measurements, and $Var(s_m)_i = as_{mi}^2 + bs_{mi} + g = (K_p^2)_i$ are the measurement variances. The minus sign is chosen such that the local maxima of *J* correspond to wind vector solutions.

An accurate model function is essential to deriving ocean wind vectors from scatterometer measurements. A variety of Ku-band models exist, some of which are derived from scattering theory, and some which are empirically derived. To maintain complete flexibility in the choice of a model function, while leaving the retrieval algorithm software unaffected, the SWT Model Function subcommittee in February 1987 decided that the form of the NSCAT model function shall be a table of σ_o values. Once the wind retrieval algorithm was modified to handle this tabular model function form, a model-independent wind retrieval technique was obtained. This has powerful implications for post-launch verification, as the model function is refined after comparison of NSCAT data with in situ data from validation experiments. Once the model is more accurately known, the data can be reprocessed without changing the ground system software.

6.3 Ambiguity Removal

The NSCAT 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". 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.

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 [2]. In an ambiguous wind field the majority of the ambiguities with highest likelihood are either in the same direction or the opposite direction 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 is

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 group of data x(1), x(2), ..., x(N) is defined as the number x(M) which minimizes:

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

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's 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's 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.

In the NSCAT algorithm, 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 2.0 record. 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.

6.4 Average Wind Map

The purpose of the Level 3 processor is to map the optimal Level 2 wind vector solutions, as chosen by the ambiguity removal algorithm, from the swath-based wind vector cell (WVC) grid to a global map grid and average them over a fixed time period, nominally 1 day. Various secondary variables, data quality indicators and statistical descriptors accompany the averaged wind vectors.

The following quantities are provided in the Level 3 map product:

Map#	Variable	Definition	How computed
1	n	Data count in cell	- - - -
2	<t>	Mean time tag	<t> = å t/n
3	$<n\sigma_o>$	Mean σ_o count	$<ns_o>$ = å$(n\sigma_o)$/n
4	<u>	Mean u-component of wind vector	<u> = å(u)/n
5	<v>	Mean v-component of wind vector	<v> = å(v)/n
6	<s>	Mean wind speed (scalar)	<s> = å(s)/n
7	rms	rms of wind speed	rms = $(å(s^2)/n)^{1/2}$
8	s(t)	Standard deviation of <t>	s(t) = $(å(t^2)/n)^{1/2}$-<t>
9	s(u)	Standard deviation of <u>	s(u) = $(å(u^2)/n)^{1/2}$-<u>
10	s(v)	Standard deviation of <v>	s(v) = $(å(v^2)/n)^{1/2}$-<v>

7. Acquiring and Extracting the NSCAT Science Data

7.1 Obtaining the Data

The data can be obtained from PO.DAAC either on 8mm tape or via electronic file transfer for three weeks after data processing. Only Level 3 products will be permanently stayed on the FTP site. For PO.DAAC contact information see Section 9.1.1.

7.1.1 NSCAT Science Product (NSP)

The NSP is an 8mm tape cartridge containing a batch (i.e. one week) of levels 1.7, 2.0, and 3.0 data reformatted in HDF with supporting ancillary data, documentation and software.

The NSP tape consists of eight UNIX tar files which contain the following:

1) a listing of the package contents in ASCII;
2) the NSCAT quality assurance report associated with this batch of data;
3) software utilities for reading and displaying the HDF-format files of the NSP, provided by the PO.DAAC;
4) spacecraft revolution versus time data;
5) Level 3 data files in HDF format;
6) Level 2 data files in HDF format;
7) Level 1.7 data files in HDF format;
8) documentation (user's manual).

The NSP tape product will be physically labeled with the batch identification, batch start and stop times, and tape creation time.

The file naming convention is as follows:

Level 3:	S30yyddd.HDF
Level 2:	S20rrrrr.HDF
Level 1.7:	S17rrrrr.HDF

where yy is the last two digits of the year, ddd is the day of the year, and rrrrr is rev number of the data. Thus, a file named S3096300.HDF would contain the Level 3 data for day 300 of 1996. Files S2001503.HDF and S1701503.HDF would both contain data, Level 2 and 1.7 respectively, for rev 1503.

7.1.2 Network Access

The same information that is available on the NSP will also be available on the PO.DAAC FTP site, podaac.jpl.nasa.gov. The data will be located within the /daac/nscat directory during calibration and validation period, /pub/ocean_wind/nscat during regular operation in the following subdirectories:

Level 1.7 data	data/L17/Snnnnnn
Level 2 data	data/L20/Snnnnnn
Level 3 data	data/L30/Snnnnnn
Rev vs. Time, QA report	data/anc/Snnnnnn
Software	software
Documentation	doc

where "nnnnnn" is the ADEOS Batch ID. An ADEOS Batch represents approximately one week of data. PO.DAAC will provide a conversion between the ADEOS Batch ID and the specific time period it includes.

Software, documentation, and level 3 data will always be available. Level 1.7 and 2 data will be available for three weeks after receipt by PO.DAAC. After the three-week time period, these data will be available on 8mm tape.

7.1.3 Web Page Access

Access to the NSCAT Science Products through the World-Wide Web will be possible after the NSCAT calibration and verification period. The URL of PO.DAAC NSCAT home page is http://podaac-www.jpl.nasa.gov/nscat.

7.2 Reading the Data -- HDF Supporting Software and Utilities

Routines and sample programs are supplied to demonstrate to the user ways to access NSCAT HDF data. These programs can then be modified as the user sees fit. The supplied code is designed to be platform-independent and easily customized to the user's specific needs. PO.DAAC would like to know of problems encountered when using this software.

7.2.1 Straight readers in C and FORTRAN

Step 1 - Download and Compile the HDF/netCDF Libraries

In order to access HDF data, the user must first obtain and compile the version 4.0 HDF libraries from NCSA. Pre-compiled codes are ready for different platforms and operating systems from NCSA. If the pre-compiled codes are not available for a specific computer, the user could use the source code we provide on the NSP tape or at the ftp site to compile the HDF libraries. The HDF libraries we use to translate the NSCAT data is version 4.0r2.

The source code, which supports most platforms, is available to the general public via anonymous ftp at ftp.ncsa.uiuc.edu:/HDF (IP Address: 141.142.3.135). Instructions and Makefiles for most platforms are also provided at this ftp site. It is only necessary to download and compile the C versions of the libraries. Note that the libraries, once compiled are quite small, but the source code is extensive and requires significant disk space. It is recommended that the source code be deleted once the libraries are created.

Step 2 - Compile and Run the Sample Programs

The following sample straight readers are available for extracing the NSCAT data.

rdHDF.c

Read Level 1.7 and Level 2 data. It first displays the global attributes (file header), reads time tags and then reads through SDS's of the data file.

rdHDF_30.c

It reads and displays the global attributes and reads SDS's of Level 3 data file.

rdHDF_17.F

It reads and displays the global attributes, reads time tags and then reads SDS's of the Level 1.7 data file.

rdHDF_20.F

It reads and displays the global attributes, reads time tags and then reads SDS's of the Level 2.0 data file.

rdHDF_30.F

It reads and displays the global attributes and then reads SDS's of the Level 3.0 data file.

Step 3 - Modify the Sample Programs for User-Specific Needs

The programs outlined in Step 2 are designed to provide the user with a template so that user-specific programs can be more easily derived.

7.2.2 IDL Read Utilities

Interactive Data Language (IDL) is a software tool used for the analysis and display of scientific data. It is a registered trademark of Research Systems, Inc. for the computer software and its associated documentation. IDL already contains the necessary HDF routines required for reading HDF data. Using IDL as a programming language, a reading and displaying application has been created. The name of this program is 'display_data'. This is a menu-based application, where the user is guided to select the data file, parameter, and the display device. The program will produce a two-dimensional display of the world and the requested parameter.

Display_data uses version 4.0 of IDL. This program is provided so that the user can get quick visual access to the data. In its current form, 'display_data' does not perform any of the customary data analysis functions. However, the user is encouraged to adapt this software to meet his or her personal analysis needs. This is not expected to be a difficult task since IDL provides simple and easy-to-use functions that can perform complex data analysis tasks.

8. Using the NSCAT Science Data

8.1 General Considerations

For users interested in combining the Level 2 (winds) and Level 1.7 (σ_0) data, the HDF data products are designed so that each data record in Level 1.7 and 2.0 match-up to one another. Thus, data record 133 of Level 1.7 contains the σ_0 data used to produce the wind data in data record 133 of the Level 2 file.

When using Level 1.7 or 2 data files, it should be remembered that WVC 1-12 always represent data taken on the left side of the spacecraft and WVC 13-24 include data from the right side of the spacecraft. There is a "nadir" gap of 600 km between cell 12 and 13.

8.2 Use of Data Quality Flags

Level 3

There are no data quality "flags", as such in the Level 3 product. However, there are statistics which can be used to evaluate the quality of the data in a given map cell. Specifically, Avg_Sigma0_Count and WVC_Count specify the amount of data that was used to calculate the average winds. The RMS_Wind_Speed, Wind_Vel_U_StdDev, and Wind_Vel_V_StdDev provide measures of the distribution of wind speeds and directions that produced the average value.

Level 2

The primary data quality flag for the Level 2 data is the WVC_Quality_Flag. The highest quality data have this set to 0. However, there may be some regions of interest where researchers will still want the wind data even though this flag is set to 1 (some σ_0's flagged for land or ice and not used) or 2 (some σ_0 flagged for absorption and not used). If the winds are retrieved with less than six σ_0's and with at least one measurement from 3 different azimuths, then WVC_Quality_Flag is set to 3. If the measurements are from less than 3 azimuths, it is set to 4.

The low and high wind speed flags simply indicate that the derived wind speed is outside of wind speed range (3-30 m/s) given in the mission requirements (see Section 2.2). Thus, it is possible that these wind speeds may not meet the same accuracy requirements. It is recommended that the low and high wind speed flags be used for informational purposes, unless there is a desire to exclude low and/or high wind speed solutions.

Level 1.7

The Sigma0_Quality_Flag has 11 different (bits 0-10) quality indicators. For usable data, the first four bits (0-3) should be set to 0. The remaining indicators should be considered informational.

Bit 10, negative σ_0, denotes the sign of the normal (ratio) space σ_0. Any use of the σ_0's must take into account this bit flag. The σ_o measurements are provided in dB, so to properly use the data the following conversion must be used:

$$\sigma_o \text{ [ratio]} = (-1)^{(\text{bit } 10)} \; 10^{(0.1 \sigma o[\text{dB}])}$$

The Sigma0_Usable_Flag(s) are set to 0 when data are usable, i.e. when data are not over ice or land points and are not out of range (-70 dB to 30 dB). Additional checks on the Sigma0_Quality_Flag will assure that there are no problems with the measurements (bits 0 through 3 are 0).

The Surface_Flag should always be set to 0 for ocean-only investigations.

The WVC_Quality_Flag is the same as discussed for Level 2 data.

8.3 Some frequently asked questions

1. Why do some unsigned integers appear as negative numbers in FORTRAN and IDL? How can one get the right numbers?

One of the most common problems when extracting NSCAT data using FORTRAN or IDL is dealing with unsigned integers.

FORTRAN or IDL handle all integers as signed integers. An integer*2 (signed) can only represent numbers from -32768 to 32767, while an uint16 in C can hold numbers from 0 to 65535. Likewise, an integer*1 can represent numbers from -256 to 255. Positive integers that exceed 255 or 32767 will appear as negative numbers in IDL or FORTRAN.

The NSCAT data files are generated using C programs and contain unsigned integers. When the data are extracted using FORTRAN or IDL, the unsigned integers may appear as negative numbers. To fix the problem, one will need to add 65536 to the negative numbers for unsigned integer*2 arrays and use integer*4 arrays to store the numbers. Similarly, 256 must be added to the negative numbers obtained from unsigned integer*1 arrays generated in C and the correct numbers stored as integer*2 arrays before scaling the numbers. This is done in our recently distributed read software.

2. Do I need to link to the HDF library to use the read software? Where do I get the library?

If IDL is used to extract the data in HDF format, there is no need to link to the NCSA HDF library. However, you'll need to get the HDF library if you run a C or FORTRAN code.

The best way to do that is to go to NCSA's home page (current address is http://hdf.ncsa.uiuc.edu) and get the specific pre-compiled HDF library for your computer and

operating system. FTP site is ftp.ncsa.uiuc.edu/HDF. Go to HDF4.0r2 or HDF_current and get the code.

If you can't find the pre-compiled code for your workstation, you could use the source code (HDF4.0r2.tar.Z) we provide on the NSP tape or at our FTP site and then compile it on your own machine.

3. Is there a way of knowing the dates in order to choose the desired data files which are in rev order?

Each batch contains one week of data (maximum approximately 100 revs). For example, the first distributed batch S2 contains data for the week of Sept 15, 1996, S15 starts from Dec. 11, 1996. If one knows rev and date of a data file, one can figure out what the approximate rev numbers should be for a particular date.

4. What is the repeat cycle for NSCAT? How long does it take to complete one rev?

The repeat cycle is 41 days for NSCAT. It takes approximately 101 minutes to complete one rev and 525 revs are completed in one repeat cycle.

5. Why might one get spurious L2 or L1.7 data when the WVC_Quality_Flag is equal to 0?

It is suggested that you look at Num_Ambigs before you check quality flags, if Num_Ambigs are not 0, the data are retrieved. If Num_Ambigs are zero (e. g. over the land), then even the quality flag looks OK, the Lat and Lon are set to minimum (-90.0 and 0.) and wind speed and other variables are set to 0 (there is no data available at the point).

6. Ho do you determine when a Sigma0 is usable for wind retrieval?

The correct Sigma0_Usable_Flag can be determined for a given sigma0 value by requiring the following (please see Table 5.8):
The Sigma0 is usable if

1) sigma0 within limits: -70 dB < sigma0 < +30 dB
2) no land: Surface_Flag, Bit 0 is zero
3) no ice: Surface_Flag, Bit 2 is zero
   (Note: if Bit 1 is 1, no ice data was available)

In addition, you probably will want to check that there were no problems with sigma0 measurement: Sigma0_Quality_Flag, Bits 0 thru 3 are zero.

7. What is the difference between nudged and un-nudged NSCAT data?

In nudged NSCAT Standard Product the winds are selected based on the Numerical Weather Product (NWP) initialization of the ambiguity removal algorithm. Either the first or the second ranked NSCAT wind vector, whichever is closer to the direction of NWP wind vector, is

chosen as the initial guess used by the ambiguity removal algorithm. Batches 1-15 (Sept 15, 1996 to Dec 18, 1996), that were distributed before the Calibration/Verification meeting, used the standard ambiguity removal scheme that uses only the first ranked NSCAT wind vector as the initial guess in the ambiguity removal algorithm (so-called un-nudged or baseline). A new model function (NSCAT-1) will be used to reprocess all the NSCAT data in April 1997 and the wind vectors product will be nudged.

8. Can one get near real time NSCAT data in numeric or graphic formats?

Yes, you can get NSCAT near real time data in graphic format through NOAA. They have a nice web page that displays GIF images of NSCAT wind speeds and directions. Please check out their home page at http://manati.wwb.noaa.gov/. If you have more questions, please contact the following person:

Paul Chang
NOAA/NESDIS/Office of Research and Applications
World Weather Building Rm102
Mail Stop E/RA13
Camp Springs, MD 20746
Phone:301-763-8231
pchang@orbit.nesdis.noaa.gov

9. Are there other useful web sites where I can find more information about NSCAT data and other scatterometers?

To know more about JPL scatterometer projects (NSCAT and SeaWinds), check out
http://www.jpl.nasa.gov/winds/
To find more information on NSCAT data, check out
http://podaac.jpl.nasa.gov/nscat/.
To know more about HDF format, visit
http://hdf.ncsa.uiuc.edu.
To know more information about ERS2 scatterometer, visit
http://services.esrin.esa.it/specer2.htm.

10. Is there any easy way to get subsets of the data?

Yes, we have on-line subsetting where you can select certain dates and locations for different level of data. The URL is http://podaac.jpl.nasa.gov/nscat.

11. Will you be distributing data on CD-ROM?

Yes, we have one CD-ROM product to be released soon that will contain the L2, L3 and 25 km wind-only data.

9. Appendices

9.1 PO.DAAC Points of Contact

Questions and comments concerning the NSCAT 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
Telephone: (818) 354-9890
FAX: (818) 393-2718
IMS: telnet eosims.jpl.nasa.gov 12345
FTP: ftp podaac.jpl.nasa.gov

User Services Office, MS 300-320
JPL PO.DAAC
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109 U.S.A.

If you wish to receive e-mail product announcements concerning NSCAT and other products, please add yourself to the mailing list at the bottom of http://podaac.jpl.nasa.gov.

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 using the wind solutions retrieved from the scatterometer measurements. The NSCAT data level processing software performs ambiguity removal using a median filter. Details can be found in Section 6.3.

Doppler Binning — A technique used on NSCAT to adjust the sigma0 cell bandpass frequencies as a function of orbit location in order to maintain accurate beam-to-beam cell coregistration 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 sigma0 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 (sigma0) 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 NSCAT, 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 sigma0 measurements to the model function. Since the model function gives sigma0 as a function of wind velocity, the wind retrieval process attempts to invert the model function to derive the wind solutions. The NSCAT algorithm is a non-linear search for extrema of a maximum-likelihood objective function.

9.3 Abbreviations & Acronyms

ADEOS	Advanced Earth Observing Satellite
AOCS	Attitude and Orbital Control Subsystem
APC	Antenna Pattern Correction
ASA	Antenna Switching Assembly
BBS	Bullitin Board Service
BPF	Band Pass Filter
CCSDS	Consultative Committee on Science Data System
C&DH	Communications and Data Handling Subsystem
COMETS	COMmunications and broadcast Engineering Test Satellite
CRC	Cyclic Redundancy Check
DDE	Data Dictionary Entry
DN	Data Number
DP&IO	Data Processing and Instrument Operations
DSS	Digital SubSystem
dB	decibels
dBi	decibels isotropic
dBm	decibels relative to 1 milliwatt
dBW	decibels relative to 1 watt
deg	degrees
deg C	degrees Celsius
deg K	degrees Kelvin
deg/sec	degrees per second
ECI	Earth Center Inertial
EOC	Earth Observation Center at Hatoyama , Japan
EOSDIS	Earth Observing System Data and Information System
ESDIS	Earth Science Data and Information Systems project
EU	Engineering Unit
FRB	Functional Requirements Baseline
FTP	File Transfer Protocol
HDF	Hierachical Data Format
HKDT	housekeeping data
Hz	hertz
ICD	Interface Control Document
IO	Instrument Operations
IOCE	Instrument Operations Cognizant Engineer
IOCS	Inter-Orbital Communications Subsystem
IOS	Instrument Operations System
IOT	Instrument Operations Team
ISO	International Organization for Standardization
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory
LAD	latest-available-data

LMDR	Low Mission Data-Rate Recorders
MLE	Maximum-Likelihood Estimator
MSA	Mission Support Area
m	meters
m/sec	meters per second (also m/s)
NASDA	National Space Development Agency of Japan
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSCAT	NASA Scatterometer
NSP	NSCAT Science Product or NSCAT Standard Product
N/A	not applicable
OCL	Operations Coordination Letter
OIS	Operation Interface Specification
PO.DAAC	Physical Oceanography Distributed Active Archive Center
QA	Quality Assurance
RCS	Reaction Control Subsystem
RDD	Release Description Document
rev	revolution
RFS	Radio Frequency Subsystem
RMS	Root Mean Square
SAPIENT	Science Algorithm Performance and Instrument Engineering Team
SASS	Seasat-A Satellite Scatterometer
S/C	Spacecraft
SDPS	Science Data Processing System
SDS	Scientific Data Set
SE	System Engineer
SIS	Software Interface Specification
SP	Science Processing program set
SPOT	Science Processing Operations Team
SRD	Software Requirements Document
SSD	Software Specification Document
SSM/I	Special Sensor Microwave Imager
SWT	Science Working Team
sec	seconds
TBD	To Be Determined
TCP/IP	Transmission Control Protocol/Internet Protocol
TEDA	Technical Engineering Data Acquisition Equipment
TM	Trademark
TMDF	Time Difference
TP	Telemetry Processing program set
TWT	Traveling Wave Tube
TWTA	Traveling Wave Tube Amplifier
UTC	Coordinated Universal Time
WVC	Wind Vector Cell

9.4 Scatterometry References/Bibliography

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9.5 The ADEOS Orbit Cycle and Data Retrieval

Many NSCAT data users are interested in locating data in specific regions (*e.g.* near buoy arrays or aircraft underflight paths,). This appendix presents the ADEOS "Reference System for Planning" (RSP) which is used for command planning. The formulae for the RSP calculations are based on the nominal 41-day repeat cycle of the ADEOS orbit, giving the transformations between ground location and the corresponding path number (convertible to orbit number) for the spacecraft. Please note that this is not a high-precision calculation, but should be useful for typical data search and subsetting tasks. The formulae are taken from the ADEOS Operation Interface Specification, Appendix C.5 (version 4.2, 17 June 1996).

9.5.1 Basics of the RSP

The ADEOS orbit cycle consists of a 41-day, 585 orbit repeating sequence of satellite subtracks. In the RSP calculation, each unique subtrack, starting from the ascending node, is referred to as a *path*. The location of any point on the Earth's surface can be expressed in terms of the path number and the argument of latitude g, where the argument of latitude is the angle measured along the orbit starting from the ascending node. The basic definitions of the RSP are:

(1) Coordinates are expressed by the path of the satellite's orbit and the argument of latitude.
(2) The path number starts at the ascending node; numbering is *westward* from path 585 (which is also path 0), with ascending node longitude of 0.030°W.
(3) The RSP defines the subsatellite point, *not* the observing point.

9.5.2 RSP Transformations

To convert from (P, g) to (latitude,longitude) = (f_{CO}, l_o) use the following sequence of equations:

$$
\begin{array}{lcll}
l_A & = & l_{AO} - 360*P/n & \\
f_{CO} & = & \sin^{-1} (\sin g \sin I) & \\
f_{DO} & = & \tan^{-1} [(a/b)^2 \tan f_{CO}] & \\
q_o & = & \tan^{-1} (\cos I \tan g) & [0 \leq g < 90^o] \\
 & = & 90^o & [g = 90^o] \\
 & = & \tan^{-1} (\cos I \tan g) + 180^o & [90^o < g < 270^o] \\
 & = & 270^o & [g = 270^o] \\
 & = & \tan^{-1} (\cos I \tan g) + 360^o & [270^o < g < 360^o] \\
l_o & = & l_A - q_o - (W_e/W) g &
\end{array}
$$

To convert from (latitude,longitude) = (f_{CO}, l_o) to (P, g) use the following sequence of equations:

$f_{CO} = \tan^{-1} [(b/a)^2 \tan f_{DO}]$

$g = \sin^{-1} (\sin f_{CO} / \sin I)$ [ascending, $f_{CO} \geq 0^o$]

$= 360^o - | \sin^{-1} (\sin f_{CO} / \sin I) |$ [ascending, $f_{CO} < 0^o$]

$= 180^o - \sin^{-1} (\sin f_{CO} / \sin I)$ [descending, $f_{CO} \geq 0^o$]

$= 180^o + | \sin^{-1} (\sin f_{CO} / \sin I) |$ [descending, $f_{CO} < 0^o$]

$q_o = \tan^{-1} (\cos I \tan g)$ [$0 \leq g < 90^o$]

$= 90^o$ [$g = 90^o$]

$= \tan^{-1} (\cos I \tan g) + 180^o$ [$90^o < g < 270^o$]

$= 270^o$ [$g = 270^o$]

$= \tan^{-1} (\cos I \tan g) + 360^o$ [$270^o < g < 360^o$]

$l_A = l_o + q_o + (W_e/W) g$

$P = (l_{AO} - l_A) n/360$ [if $P \leq 0$ then $P = P + 585$]

where:

n	=	number of orbits covering the Earth's surface = 585
P	=	RSP path number
g	=	RSP argument of latitude
I	=	180^o - orbit inclination = $180^o - 98.59^o = 81.41^o$
l_{AO}	=	longitude of ascending node of path 585 = $0.030^o W = -0.030^o$
W_e	=	angular velocity of Earth rotation = 0.25^o/min
W	=	satellite orbital angular velocity = 3.5672^o/min
l_A	=	instantaneous longitude of the ascending node
a	=	equatorical radius of the Earth = 6378.136 km (GRS80)
b	=	polar radius of the Earth = 6356.751 km (GRS80)
q_o	=	angular difference between the ascending node longitude and the subsatellite longitude
l_o	=	geodetic east longitude of the subsatellite point
f_{CO}	=	geocentric latitude of the subsatellite point ($\|f_{CO}\| \leq I$)
f_{DO}	=	geodetic latitude of the subsatellite point

The approximate time (UTC) for a given (P, g) can be computed if the time at the ascending node UTC(AN) is known, from the equation:

$$UTC(g) = UTC(AN) + (g/360^o)*[\text{orbit period}]$$

where the nominal orbit period is 100.92 minutes.

The relationship between the path number P and the orbit number N_c within a repeat cycle is given by

$$P = [41*(N_c - 1)] \textbf{\textit{mod}} 585 + 1$$

The total orbit number N_t is the accumulated number of orbits starting from the first ascending node after launch. For NSCAT data products, the first rev starts from approximately 1/4 of an orbit period before the first ascending node crossing. There are N_o = 525 orbits in the partial "cycle 0" which is the repeat cycle during the immediate post-launch period. At any given time in the mission, the total orbit number (and approximately, the rev number corresponding to a given NSCAT data file) can be decomposed as follows:

$$N_t = N_o + (m - 1)*585 + N_c$$

where m is the number of complete 585-orbit cycles after cycle 0.

To conclude this discussion, the procedure for finding the appropriate rev numbers for data passing near the point (f,l) is outlined here:

(1) Use the second set of RSP equations to determine the (P,g) for the location (f,l) of interest;

(2) Invert the relationship between P and N_c to find the orbit number in the cycle N_c;

(3) Given N_o and N_c, compute the total orbit number N_t ~ rev for values of m = 0,1,2,...

(4) For locations on ascending tracks in the southern hemisphere, subtract 1 from the values of N_t to get the applicable rev numbers.