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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL METEOROLOGICAL CENTER
OCEAN PRODUCTS CENTER

TECHNICAL NOTE

# OPERATIONAL PROCESSING OF ERS-1 SCATTEROMETER WINDS: A DOCUMENTATION

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## 1. Introduction

This office note describes a new dataset internally available at the National Meteorological Center (NMC): surface wind vectors from the ERS-1 scatterometer. The data are processed in real time using a NMC/NASA-JPL developed system. The system combines quality control and data management procedures designed at NMC with vector ambiguity removal and directional selection algorithms adapted from the United Kingdom Meteorological Office (UK Met. Office). The scatterometer is a spaceborne radar that measures the intensity of its backscattered radiation returned from wind-driven ocean surface waves. Since the magnitude of the ocean roughness is correlated with the wind at the ocean surface, the radar backscatter measurements from the scatterometer (also called sigma naughts) can be processed to obtain surface winds. An empirical transfer function relates the sigma naughts to the surface wind speed. The scatterometer has three separate antennae with which to probe the ocean surface, thus enabling it to produce a direction for the wind as well as a speed. This ability to measure both wind speed and direction makes the scatterometer a potentially valuable source of satellite ocean wind data, particularly in data sparse regions of the equatorial and southern oceans. At present, other satellite based passive instruments (such as the SSM/I or altimeter) cannot determine a wind direction independently.

A brief overview of the ERS-1 scatterometer, along with a more detailed description of the processing scheme and final product follows. The programs to decode the data and perform the processing were implemented as part of the operational job stream on September 7, 1994. It is anticipated that numerical weather prediction (NWP) models, particularly the NMC Global Model (AVN and MRF), will soon begin experiments aimed at assimilating this new dataset.

## 2. The ERS-1 Scatterometer

The scatterometer is an active, five cm C-band radar on board the ERS-1 satellite, which was launched by the European Space Agency (ESA) in July 1991. The instrument has three antennae which emit radar signals, striking the ocean surface at varying angles. The radar power backscattered from the wind-driven wavelets on the ocean surface is then received by the satellite and correlated with surface wind speed. The higher the amount of back-scattered radar power received by the satellite, the rougher the sea surface, and the higher the wind speed. Since the magnitude of the received power for each antenna relates to wind direction differently, having three separate measurements of backscattered power from three different view angles makes the deduction of wind direction possible but somewhat complex. Problems in determining the correct wind field arise due to an incomplete understanding of the physical processes which govern the relationships between winds, ocean waves, and the scattering of the radar signal (Offiler, 1994). An empirically based "transfer function" is required to convert the backscattered power received to a wind speed and direction at a height of 10 meters above the sea surface. Several empirical transfer functions have been derived using data from field experiments conducted during pre-launch and post-launch periods of the ERS-1 satellite (see Attema, 1992; Stoffelen, 1992), each of which produces multiple wind vector solutions. Further processing is necessary to statistically rank the solutions, assigning each a probability of being "correct" in representing the wind field. Finally, a single solution must be chosen as the "correct" one. Outside information, such as a background surface wind field from a numerical model, often assists in the process of deciding which vector represents the most likely solution.

With regard to instrument resolution, the measurements of backscattered power actually consist of a 50 km wide area average of many pulses for each wind cell measurement. The measurement locations (cells) are separated by 25 km, giving an effective resolution of about 50 km. The width of the swath is about 500 km, with nineteen cells across a satellite track. The polar orbital period is roughly 101 minutes, yielding about fourteen orbits per day. The ERS-1 has a sun synchronous circular orbit at a mean altitude of about 785 km and an inclination of 98.5 degrees (a near-polar orbit).

### 3. NMC Processing

NMC has been receiving the ERS-1 scatterometer data since January, 1992 in the form of a "Fast Delivery" (FD) product from ESA. The ESA FD product includes three measurements of backscattered power (sigma naughts) at each measurement location (node), along with wind speeds and directions calculated by ESA, using their own de-aliasing and ranking procedures. The ESA processed vectors provided by the FD product have been monitored at NMC for over two years, and have been found to be lacking in quality. For example, in some regions winds blowing at 180 degrees opposite to each other at adjacent points are commonly observed, indicating that the ESA processing scheme doesn't adequately resolve the correct direction from the available set of solutions (up to six). Problems also arise in regions of light wind speeds, with confused, randomly appearing flow patterns present in the FD vectors. Gemmill et al (1994) present a more detailed evaluation of the ESA FD data, noting several deficiencies. Thus, it was decided that NMC should develop its' own processing scheme for ERS-1 scatterometer data, with two purposes in mind: First, to obtain an improved set of vectors for use by operational forecasters, and second, to upgrade the quality of the ERS-1 vectors for assimilation into numerical models.

### 3.1 Data Receipt and Co-location

The ERS-1 data arrives at NMC via the WMO GTS from ESA-ESRIN (Frascatti, Italy) in BUFR format generally two to four hours after measurements are taken by the scatterometer. The data are decoded from BUFR (see WMO Manual on Codes, Volume 1, FM 94, 1988) and co-located with NMC model data four times per day. Each processing cycle contains a window of plus or minus three hours of scatterometer measurements, i.e. the 12Z cycle decodes data measured from 09Z to 15Z. A delay of at least two hours usually occurs between the actual time of measurement and the time the ERS-1 data arrive at NMC. Occasionally, this delay may be greater, as much as six hours or more. Thus, the NMC/NASA-JPL processing scheme must consider these delays in data arrival. Also, for the data to be of use to NWP models, they must be made available in a timely fashion, say within three hours of real time. These realities led to the decision to initialize the data unpacking and co-location programs several hours "after the fact" (i.e. the 12Z cycle begins execution around 14Z), early enough to be of use to NWP models, but late enough to capture a reasonable amount of data. As a result, some "cut-off" of data is inevitable before assimilating it into the NMC forecast models. One possible remedy we have undertaken is to process twice for some cycles - an early run to get the data ready for assimilation, and a late run to capture all the data in its' entirety (more on this below).

After decoding, measurements at each node are co-located with fields from the NMC global model. Either a six-hour forecast from the AVN run (first guess) or the actual analysis from the Global Data Assimilation System (GDAS) is used to provide surface winds, air temperature, humidity and sea surface temperature. The "early" 00Z, 06Z, and 18Z runs use a six-hour AVN first guess, while the "late" 00Z, and both "early" and "late" 12Z runs take advantage of the availability of the GDAS analysis in their model ingest (see Table 1). The processing scheme makes use of these model fields for quality control and re-ranking procedures, which shall be described below.

### 3.2 Quality Control Procedures

In order to maximize accuracy of the scatterometer wind vectors and minimize unnecessary processing of bad data, some quality control (QC) procedures have been developed. The scatterometer is one of three operating Active Microwave Instrument modes (AMI) operating from the ERS-1 satellite, which also functions in a Synthetic Aperture Radar (SAR) Image mode, or in a SAR Wave mode. Whenever the AMI switches to the Image or Wave mode, data gaps result in the scatterometer measurements. The scatterometer data over land is flagged, but ice is not. To identify data over ice covered regions, the NMC processing utilizes co-located NMC model analysis values of SST equal to zero degrees C or less as a cut off to discard the data. The ESA land flags are used to exclude data over land during processing. Since the data come into NMC from different satellite "view stations" around the globe, they must be time sorted, and any duplicate reports originating from multiple reporting stations removed. During the minimization phase, NMC only processes triplets of sigma naughts (to ensure a directional solution). Another condition for processing is that the "noise to signal" ratio of each sigma naught must be less than 10 %. Each sigma naught represents a series of radar pulses over an interval of time and distance, with the number of "missing" pulses included in the ESA FD data. When the total number of missing pulses from a triplet of sigma naughts exceeds fifteen, we exclude that particular node from further processing. At this point, the data have been quality controlled, and are ready for further processing.

### 3.3 Minimization and Directional Selection Procedures

The minimization and directional selection algorithms developed at the United Kingdom Meteorological Office (UK Met Office) have been adopted as the basis for NMC's processing software (Offiler, 1992, Woiceshyn, 1993). Most of the major changes in the overall processing scheme developed at NMC concern data management, the co-location of NMC field data, and the initialization and quality control procedures described above. Changes to the wind direction selection algorithms received from the UK Met Office were minimal, and will be briefly decribed below. After compiling datasets containing co-located scatterometer winds and buoy reports for one year, both statistics and case studies indicated that vectors derived from the CMOD4 transfer function were more accurate when compared with several other candidate transfer functions (see Gemmill et al, NMC Technical Note; Peters et al, 1994). The CMOD4 transfer function, derived at the European Center for Medium Range Forecasting (ECMWF), was thus chosen as NMC's "operational" empirical algorithm for processing of scatterometer data. It was developed using ECMWF analysis wind fields as the "sea truth" data. Details of the formulation of CMOD4 can be found in Offiler et al, 1994. A combination of two look up tables (LUT's) generated "off-line" from the CMOD4 transfer function, a quadratic function, and derivatives of that function invert the sigma naughts to wind vector solutions at each measurement node. Also established during the minimization are probabilities for each vector solution at each node, reflecting instrument skill in selecting the "most likely" solution. After ranking all vectors based on their relative probabilities, the NMC global model surface wind field is employed as guidance. Probabilities of each vector solution as being "correct" are modified based on estimates of likely errors (standard deviation) in both the background meteorological wind field and the scatterometer wind solutions (Offiler, 1992). The surface six hour "first guess" forecast winds from the GDAS (see Kalnay et al., 1990; Parrish and Derber, 1992), co-located with sigma naughts in step one of the processing system, are used to modify the probabilities. Finally, a local consistency or "buddy" check is performed on the wind field. The buddy check consists of a five by five node array modal filter which the entire wind vector field must pass through. This algorithm, named Sequential Local Iterative Consistency Estimator (SLICE), was developed at the UK Met Office by Offiler (1992), and works by iteratively checking for local inconsistencies and repairing them. The SLICE algorithm repeats until fewer than a threshold number of nodes have had their probabilities re-ranked.

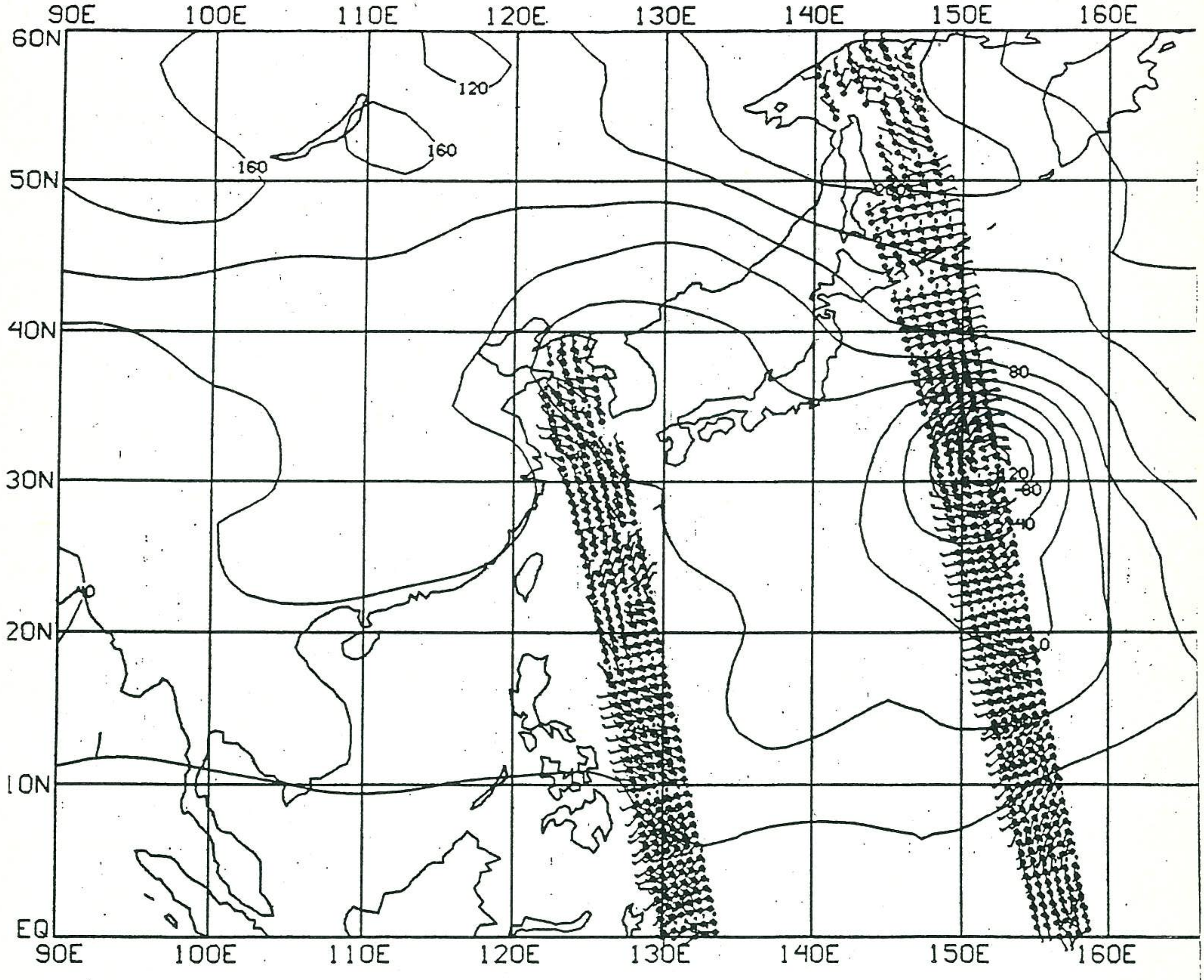
With regard to algorithmic/numerical differences between NMC's processing and the processing done at ESA, the ESA processing uses tables that are discretized in 0.5 m/s increments in speed and five degree increments in direction for finding wind vector solutions during the minimization, while NMC uses a combination of tables, functions, and derivatives to compute the wind vectors. The ESA processing uses an 18 to 36 hour forecast from the ECMWF for the background wind field during directional selection, whereas NMC uses either an analysis or first guess from the AVN model. In addition, ESA and NMC use different direction selection algorithms. The wind direction selection (often called ambiguity removal) algorithms used by NMC produce more meteorologically consistent wind fields than those obtained from ESA.

The processing with SLICE is the final stage of de-aliasing, resulting in a unique wind vector existing at each node of quality controlled scatterometer measurement. Figure 1 demonstrates an example of the de-aliased wind vectors. Figure 2 shows a schematic chart outlining the total NMC/NASA-JPL processing package.

## 4. Final Datasets : Encoding and Further Details

The NMC processed scatterometer vectors, along with the latitude, longitude, and time of each measurement node have been encoded in BUFR, and reside on the NAS-9000. For documentation on BUFR, see "A Guide to the WMO Code Form FM 94 BUFR", by W. Thorpe, or the WMO Manual on Codes, WMO # 306, FM 94 BUFR. The NMC processing scheme uses NMC W3 library routine W3FI85 to encode the vectors in BUFR. Several W3 library routines to decode from BUFR exist: W3FI78, and W3FI88 represent the latest. The data are processed six times per day, once for the 06Z and 18Z cycles, and twice for the 00Z and 12Z cycles. The 00Z and 12Z cycles are processed twice in order to make an "early" run for model assimilation and a "late" run for fuller data capture. For each cycle, data are generally available by about three hours "after the fact"; the 12Z scatterometer vectors, for example, should be available by no later than 15Z. To capture all the available data, waiting until five hours after the cycle time may be necessary. The names of the production datasets containing NMC/NASA-JPL processed scatterometer winds, and the times at which the programs to create these datasets execute are given in Table 1. The NMC scatterometer wind vector datasets contain a series of BUFR messages concatenated into a single file. In order to decode the BUFR messages, it is necessary to know which descriptors were used in the encoding. Descriptors are listed in Table 2.

Figure 1. Example of NMC/JPL processed wind vectors. Background field is AVN 1000 mb height. Valid 12Z 17 Sep 1994.



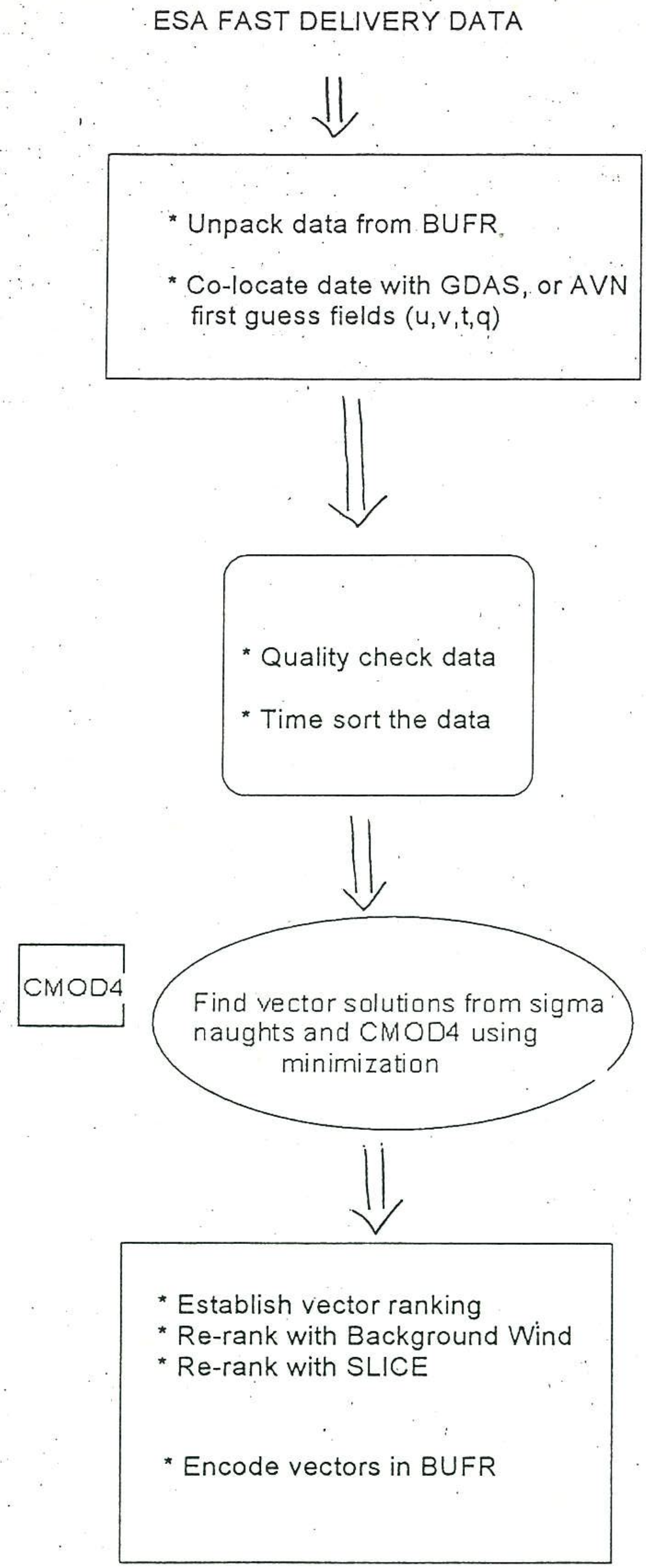



Figure 2. Flow chart showing elements of NMC/JPL processing scheme

**Table 1. ERS-1 Processed Wind Datasets**

| Cycle | Dataset Name * | Execution Begins | Model |
|---|---|---|---|
| 00Z Early | NMC.PROD.ERS1WNDS.BUFRT00Z | 02Z | AVN FG |
| 00Z Late | NMC.PROD.ERS1WNDS.BUFRT00Z | 05Z | GDAS |
| 06Z | NMC.PROD.ERS1WNDS.BUFRT06Z | 11Z | AVN FG |
| 12Z Early | NMC.PROD.ERS1WNDS.BUFRT12Z | 14Z | GDAS |
| 12Z Late | NMC.PROD.ERS1WNDS.BUFRT12Z | 17Z | GDAS |
| 18Z | NMC.PROD.ERS1WNDS.BUFRT18Z | 22Z | AVN FG |

* Note that all datasets reside on the NAS 9000

**Table 2. List of Descriptors Used and their Units**

| Descriptor # | Type | Units |
|---|---|---|
| 1. Year | Integer | --- |
| 2. Month | Integer | --- |
| 3. Day | Integer | --- |
| 4. Hour | Integer | --- |
| 5. Minute | Integer | --- |
| 6. Second | Integer | --- |
| 7. Latitude | Real | Degrees |
| 8. Longitude | Real | Degrees (-180 to 180, Positive Eastward) |
| 9. Wind Speed | Real | meters/sec |
| 10. Wind Direction | Real | Degrees |

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