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Biweekly maps of wind stress for the North Pacific from the ERS-1 scatterometer 1992 – 1995

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November 1997

Technical Report

Funding was provided by the Office of Naval Research through contracts No. N00014-92-J-1486 and N00014-92-J-1656 and by the National Aeronautics and Space Administration under Contract No. 957652.

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Approved for Distribution:

Philip L. Richardson, Chair
Department of Physical Oceanography

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1 Introduction

The European Remote-sensing Satellite (ERS-1) was launched in July 1991 and contained several instruments for observing the Earth's ocean including a wind scatterometer. The scatterometer measurements were processed by the European Space Agency (ESA) and the Jet Propulsion Laboratory (JPL). JPL reprocessed (Freilich and Dunbar, 1992) the ERS-1 backscatter measurements to produced a "value added" data set that contained the ESA wind vector as well as a set of up to four ambiguities. These ambiguities were further processed using a maximum-likelihood estimation (MLE) and a median filter to produce a "selected vector."

This report describes a technique developed to produce time-averaged wind field estimates with their expected errors using only scatterometer wind vectors. The processing described in this report involved extracting regions of interest from the data tapes, checking the quality and creating the wind field estimate. This analysis also includes the derivation of biweekly average wind vectors over the North Pacific Ocean at a resolution of $0.5° \times 0.5°$. This was done with an optimal average algorithm temporally and an over-determined biharmonic spline spatially. There have been other attempts at creating gridded wind files from ERS-1 winds, e.g., kriging techniques (Bentamy *et al.*, 1996) and successive corrections schemes (Tang and Liu, 1996).

There are several inherent problems with the ERS-1 scatterometer. Since this is a multidisciplinary mission, the satellite is flown in different orbits optimized for each phase of the mission. The scatterometer also shares several sub-systems with the Synthetic Aperture Radar (SAR) and cannot be operated while the SAR is in operation. The scatterometer is also a single-sided instrument and only measures backscatter along the right side of the satellite. The processing described here generates biweekly wind maps during the two year analysis period regardless of the satellite orbit or missing data.

Section 2 describes some of the ERS-1 satellite specifications, including orbital parameters, the scatterometer instrument precision and the "value added" data record provided by JPL. The analysis technique is described in detail in section 3 and data validation is discussed in section 4. Some results are discussed in section 5 and a summary of the results is given in section 6. Appendix A contains annual mean winds for 1992 through 1995. Appendix B contains seasonally averaged winds for winter, spring, summer and fall. Appendix C contains sample plots of the biweekly ERS-1 derived wind components, a complete series of monthly mean wind components in the North Pacific and monthly wind vector plots for the California Current region.

2 Satellite and sensor specifications

2.1 Scatterometer

The scatterometer is part of the Active Microwave Instrument (AMI) aboard ERS-1. The AMI has two separate radars, a SAR and a wind scatterometer (WNS). The SAR operates in "image mode" or "wave mode" while the WNS operates in "wind mode." Due to shared subsystems designed to save mass and cost, the WNS cannot operate while the SAR is in "image mode." The WNS can operate while the SAR is in "wave mode"; this is known as the "wind/wave mode." Operation of the AMI in image or wave mode is not covered in this report.

The scatterometer is a C-Band (5.3GHz) radar with 3 separate antennas capable of measuring wind speed (4-24 ms^{-1}) and direction (0-360° ±20°) along a single swath to the right side of of the satellite[1]. The cell spacing is 25 km with a swath width of 500 km and a stand-off of 200 km from nadir (Vass and Battrick, 1992).

2.2 JPL Value-Added Data Record

JPL receives the scatterometer backscatter coefficients from ESA and recomputes the full set of wind vector ambiguities. These are combined with the single ESA computed wind vector to make the JPL value-added product. Each record contains information on all 19 cells between the inner and outer scatterometer swath. Table 1 summarizes the data record (from information supplied with JPL ERS-1 value-added product). The time variable has one value giving the mean time of the record. The latitude and longitude variables are each 19 element arrays specifying the location of the Wind Vector Cell (WVC). The ERS-1 speed and direction variables are also 19 element arrays and give the wind speed and direction determined by ESA. The ambiguities variable gives the number of ambiguities found by JPL in the least significant byte (LSB) and their selected ambiguity in the most significant byte (MSB). The MLE speed and direction variables are 4 by 19 element arrays containing all of the ambiguities found using the MLE value for each WVC. Note that directions are given in meteorological convention (where 0° indicates that the wind is flowing from the north) and ambiguity removal is only performed between 60° S and 60° N.

[1]Note that the NASA Scatterometer (NSCAT), launched in September 1996 produced 2 swaths and a more complete sampling pattern.

Variable	Contents	Size/Bytes	Units
Time	mean time of record	1/4	I*4 seconds from 1/1/87
Latitude	Wind vector latitude	19/38	I*2 0.01°
Longitude	Wind vector longitude	19/38	I*2 0.01°
ERS-1 Speed	ESA selected ambiguity	19/38	I*2 0.01 ms^{-1}
ERS-1 Direction	ESA selected ambiguity	19/38	I*2 0.01° [-180°, 180°]
Flag (See table 2)	Confidence flag	1/2	L*2
Ambiguities	Number of ambiguities (LSB) from MLE and JPL selected ambiguity (MSB)	19/38	I*2 [1–4]
MLE Speed	MLE wind speeds	(4,19)/152	I*2 ms^{-1}
MLE Direction	MLE ordered wind directions	(4,19)/152	I*2 0.01° [-180°, 180°]

Table 1: Wind Vector Cell (WVC) Record

Bits	Description [2]	Values
1	Summary PC factor	0 - Full processing
		1 - PCD bits set
2	Fore-beam flag	0 - Used
		1 - Not used
3	Mid-beam flag	0 - Used
		1 - Not used
4	Aft-beam flag	0 - Used
		1 - Not used
5	Fore-beam arcing flag	0 - No arc
		1 - Arcing
6	Mid-beam arcing flag	0 - No arc
		1 - Arcing
7	Aft-beam arcing flag	0 - No arc
		1 - Arcing
8	Limit of Kp value	0 - All beams < threshold
9	Land-Sea	0 - Sea
		1 - Land
10	Rank-1 solution	0 - Ambiguity removed
		1 Rank-1 solution given
11–13	Ambiguity removal method	0 - Auto ambiguity removal
		1 - Met. tables used after amb. removal
		1 - Meteorological data only
14	Frame checksum	0 - Checksum correct
15–16	Spare	

Table 2: Wind Vector Cell confidence flag

2.3 Orbit

The ERS-1 satellite was designed with multiple orbit capability. There are two 3-day repeat orbits, one 35-day repeat orbit and one 176-day repeat orbit that trade temporal resolution for spatial resolution. After the launch, the satellite was initially placed into a 3-day commissioning orbit and was used primarily for testing. It was then moved into a 3-day ice orbit for three months (Figure 1), followed by a 35-day orbit (Figure 2) for 21 months and then returned to the 3-day ice orbit for three months. The satellite was then moved into a 176-day geodetic orbit (not shown). The 3-day repeat orbit has good temporal resolution, but leaves coverage gaps at the mid- and lower latitudes. The 35-day and 176-day repeat orbits provide high resolution coverage, but leave large temporal gaps in the data. Table 3 lists the key orbital parameters for each orbit.

[2] From User's Manual included with JPL ERS-1 VALUE-ADDED product.

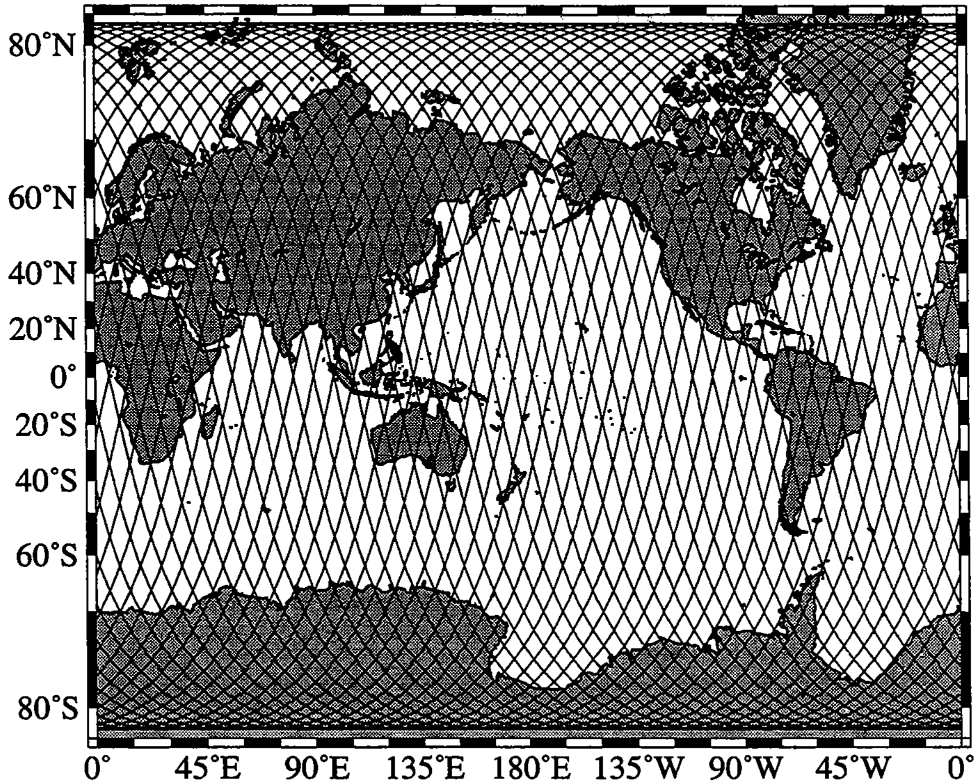

Figure 1: The ERS-1 3-day repeat orbit ground track used during the ice phase of the mission (January–March 1992 and January–March 1994).

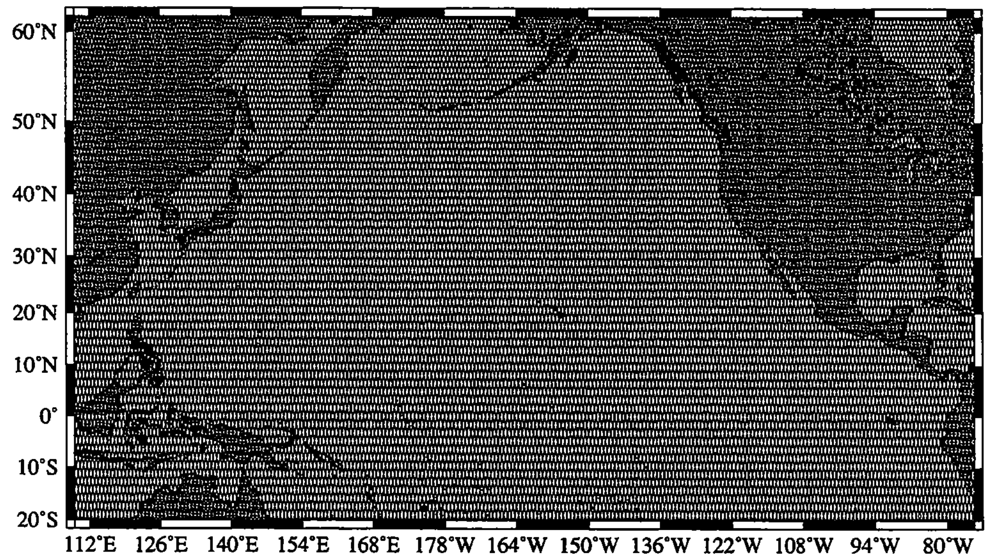

Figure 2: The ERS-1 35-day repeat orbit ground track used during the multidisciplinary phase (April 1992–December 1993) of the mission.

Description	Inc.	Alt.	Asc Node	Orbits	Period
Commissioning 3 days	98.516°	785 km	24.36°E	43	6020.8191 s
Ice 3 days	98.516°	785 km	128.2°W	43	6020.8191 s
Multidisciplinary 35 days	98.543°	782 km	20.96°E	501	6028.8482 s
Geodetic 176 days	98.529	780 km		2527	

Table 3: Orbit parameters

The ERS-1 satellite is maneuvered periodically to maintain or change its orbit. The orbit corrections are usually short and produce small gaps in coverage. The orbit changes generate much longer gaps in coverage and are summarized in Table 4.

Phase	Repeat (days)	Start	End
Commissioning	3	July, 25, 1991	December 10, 1991
Ice	3	December 28, 1991	March 30, 1992
Roll-Tilt	35	April 2, 1992	April 14, 1992
Multidisciplinary	35	April 14, 1992	December 31, 1993
Ice	3	January 1, 1994	March 31, 1994
Geodetic	176	April 1, 1994	Mission end

Table 4: Orbit maneuvers[3]

2.3.1 Numbering

The data records received from JPL are separated into individual segments for easier processing. Each segment is referred to by the revolution number specified in the User's Manual on the data tape. A revolution is defined as a segment of the orbit beginning at the southernmost position of the satellite, through the northernmost position and back to the next southernmost position. These numbers are incremented for each new revolution beginning from the satellite launch.

2.3.2 Coverage

The locations of the measured backscatter for a complete 3-day cycle during the ice phase is shown in Figure 3. The measured backscatter is used to produce a wind vector at each of these locations. In the JPL documentation and in this report, these locations will be referred to as Wind Vector Cells (WVCs). Unfortunately, due to instrument and environmental problems, a valid wind vector is not available for all WVCs. The WVCs with a "selected vector" from JPL from a 3-day period during the ice phase in March 1992 (Figure 4) show relatively good coverage. The WVCs with a valid wind vector supplied by ESA during the same 3-day period (Figure 5) are quite sparse. This is primarily because JPL will often provide a vector when the wind speeds are less than 4 ms^{-1}, while ESA does not. These figures also show the coverage problems encountered during the 3-day orbit phase. Figure 3 shows the characteristic missing data diamonds at approximately 38° N and 123° E, 132° E, 140° E, 148° E. These diamonds are stationary gaps in the 3-day orbit. The tops of other diamonds can be seen at 20° N. The combination of data loss during processing and missing data due to coverage can produce large spatial gaps in the data.

[3]From ERS-1 News produced by the ERS-1 Help Desk.

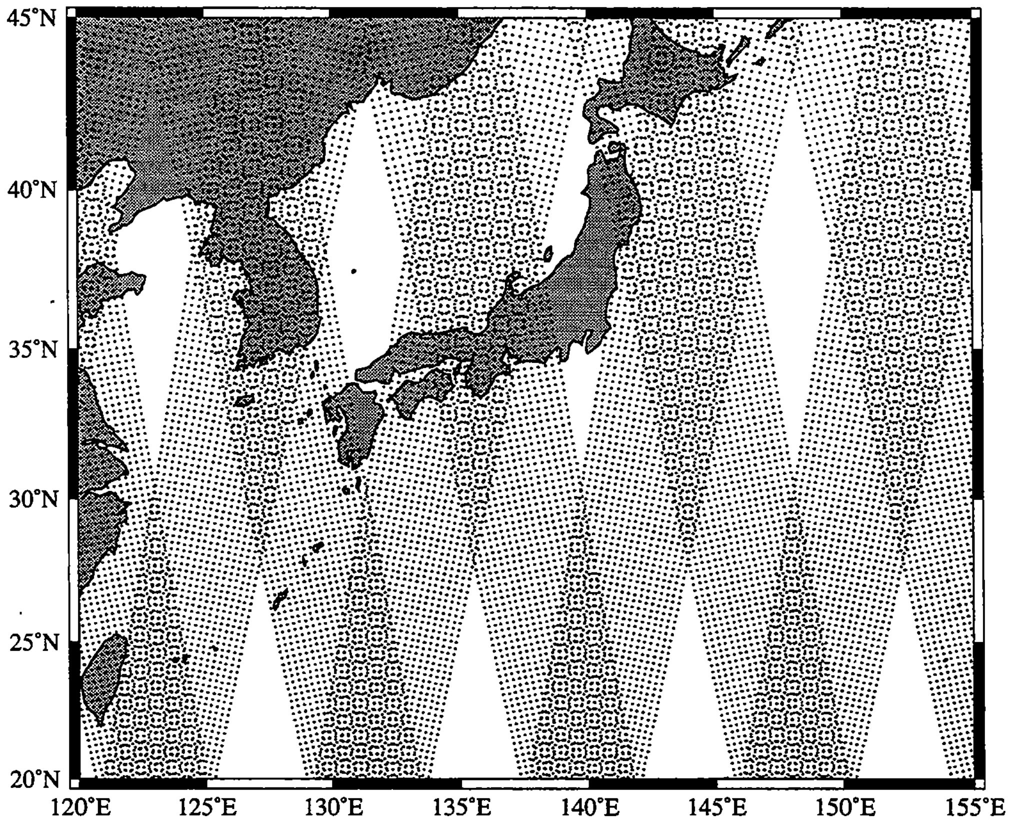

Figure 3: The locations of measured backscatter for one 3-day cycle.

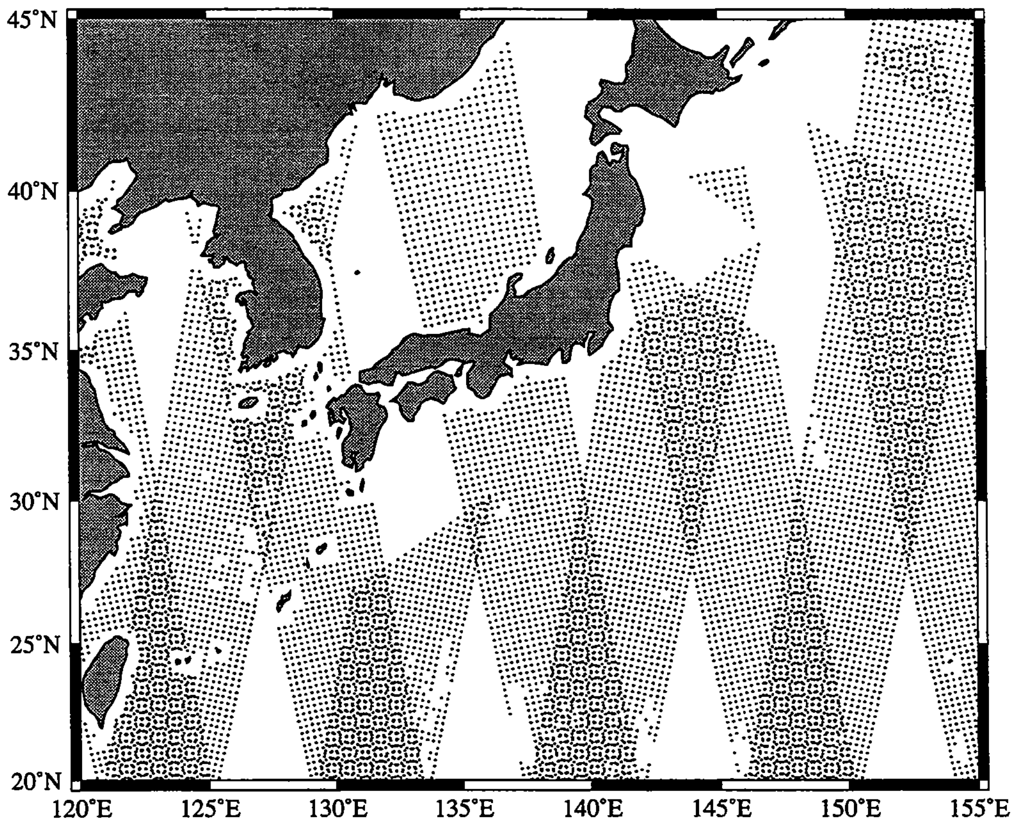

Figure 4: The ground coverage for one 3-day cycle of JPL selected vectors from March 1, 1992 to March 4, 1992.

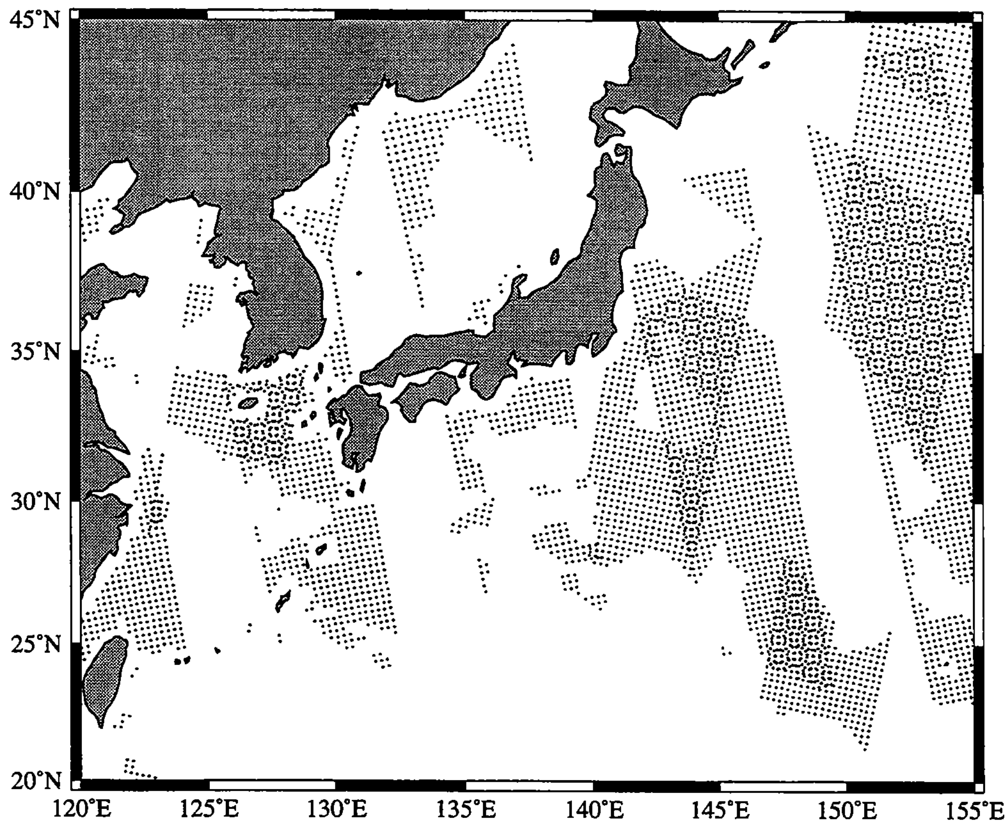

Figure 5: The ground coverage for one 3-day cycle of ESA selected vectors from March 1, 1992 to March 4, 1992.

Figure 6 shows coverage during the first week of September. The satellite is in the 35-day repeat orbit during this time. This figure shows that there are still missing data triangles, but they are not stationary as they are during the 3-day repeat orbit. This figure shows that successive tracks begin to fill in the missing data and some areas (40° N, 150° E) may have up to four separate measurements.

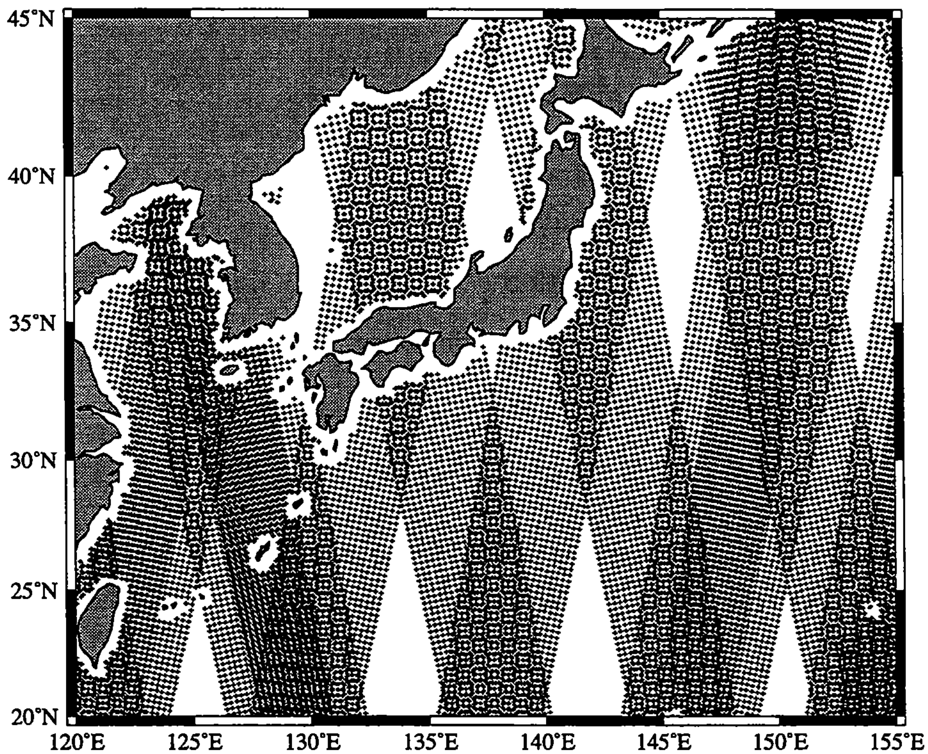

Figure 6: The ground coverage for one fifth of the 35-day cycle, September 1–7, 1993.

3 Scatterometer analysis

The analysis of the scatterometer winds was performed in several steps. Each step is described in detail in this section.

1. Extract data within the region of interest
2. Clean up data records
3. Bin data to 0.5°, 12 hour resolution
4. Perform suboptimal interpolation
5. Spatially interpolate using biharmonic spline
6. Calculate wind stress and curl

3.1 Extraction

Data records from 1992 were extracted for the region 20° S–62° N, 109° E–285° E. No data quality checks are done at this point of the process. Due to the space requirements for the interpolation of this data set, the North Pacific was split into 25 smaller regions (Figure 7). Each region was analyzed separately in steps 1–4 for the meridional and zonal wind components. Since this did not involve any spatial information, the size of each region was chosen to maximize computer resources. The entire North Pacific was reconstructed for steps 5 and 6.

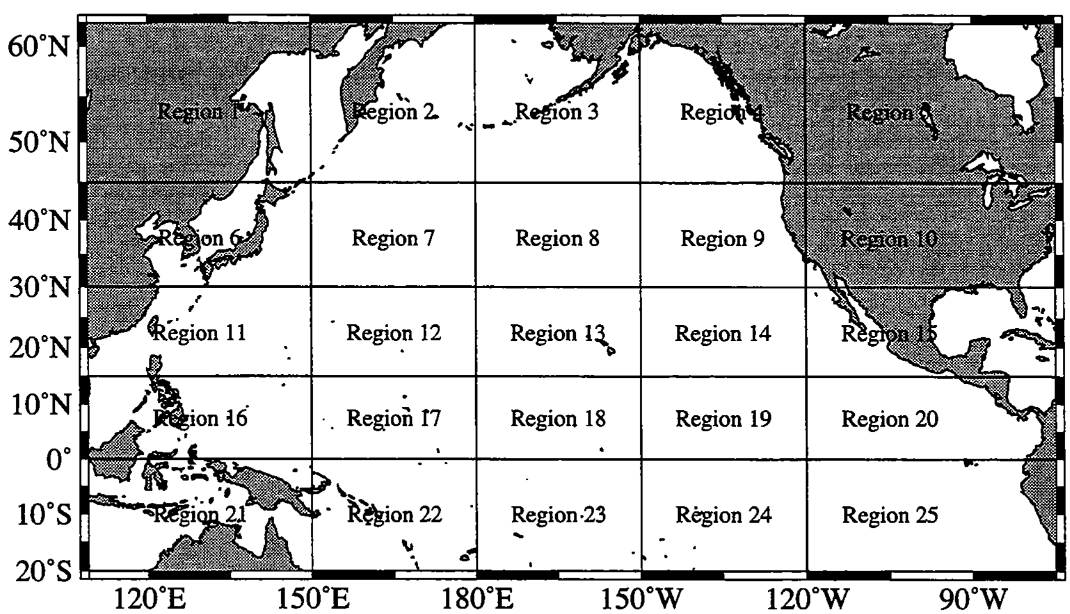

Figure 7: The segmentation of the North Pacific for regional analysis. The data was separated into 25 regions to facilitate handling the large amount of data.