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www.waveclimate.com: An Online Climate Assessment System for the Dredging Industry

Abstract

Worldwide satellite data on the offshore wind and wave climate are now available through the Internet. A few mouse-clicks at "www.waveclimate.com" can give easy and quick access to precise information on the height, period and direction of the waves that a dredging company must deal with in its daily activities. This information is available for all oceans and coastal seas all over the world.

Introduction

To plan dredging operations, companies regularly need reliable information concerning the wind and wave climate of the region where the operation will take place (Figure 1).

In regions where no reliable wave buoy records are available, wind and wave climate estimates are derived from a ship's observations or from predictions by numerical wave models running at a meteorological office. Often the quality of the information from these sources does not match the requirements of the users. And, if available, it is very difficult to get access to the data and to integrate them into other software packages.

Several satellites operated over the past decade have carried microwave sensors that give information about the sea-state and about the wind above open water. The most widely used sensor for this purpose is the radar altimeter. This sensor is capable of measuring the wind speed and the significant wave height along its ground track. Since the mid 1980s several satellites have carried radar altimeters (such as GEOSAT, ERS-1, ERS-2, TOPEX/POSEIDON), each of which produced records several years long.

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C.F. (Cees) de Valk is Senior Project Manager of ARGOSS and has 15 years of experience in developing new methods for analysis of oceanographic data (acquired both in situ and from space) and for assimilation of data in numerical models to improve predictions of waves, currents and water quality. In addition, he is an expert in extreme value statistics of environmental loads and risk analysis, and has carried out many research and consultancy projects.

Figure 1. Wind and waves along the Dutch coastline. To plan dredging operations, companies regularly need reliable information concerning the wind and wave climate of the region where the operation will take place.

Data from satellites have been exploited in several global wave climate atlases. However, the value of these products is restricted by the lack information about wave directions and periods. Moreover, to produce these atlases, the data collected before a certain date have been condensed into a number of statistical parameters for pre-defined regions, which are generally rather large. Consequently new data are not used, and zooming in on a particular region of interest is not possible.

To provide better information, an online climate assessment system has been developed which allows greater flexibility in the selection of a region of interest, and is updated automatically with new data. Moreover, it exploits the spectral wave information provided by imaging radar (SAR) using new data analysis techniques.

Data and Quality Control

To assess wind and wave climate three types of microwave sensors are of particular interest (see also Table I):
– the altimeter;
– the scatterometer; and
– the SAR.

Table I. Overview of variables, sensors and satellites to measure waves and wind.

Variables	Sensors	Satellites	Time period covered
Significant wave height	radar altimeter	Geosat	from March 1985 to Dec 1989
Significant wave height and wind speed	radar altimeter	ERS1/ERS2 Topex/Poseidon	from Aug 1991
Wind speed and direction	scatterometer	ERS1/ERS2	from Jan 1993
Wave spectral density and mean direction in 25 frequency bands, together with coincident wind speed and direction	synthetic aperture radar (SAR) and scatterometer	ERS1/ERS2	from April 1993

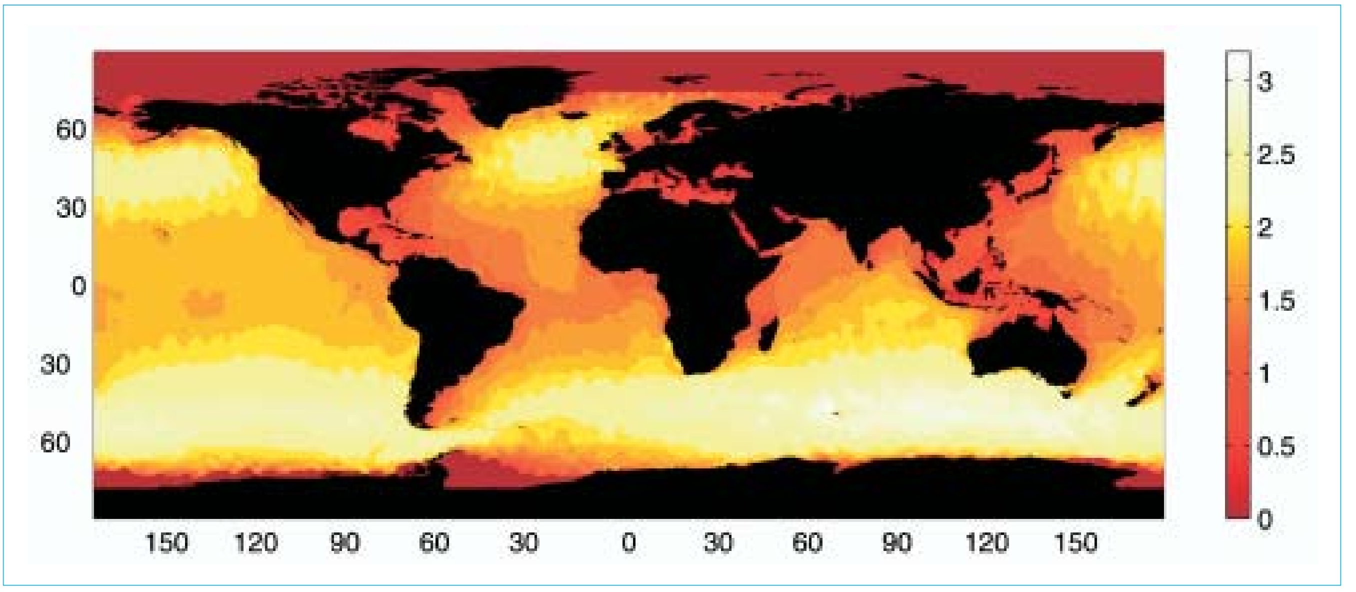
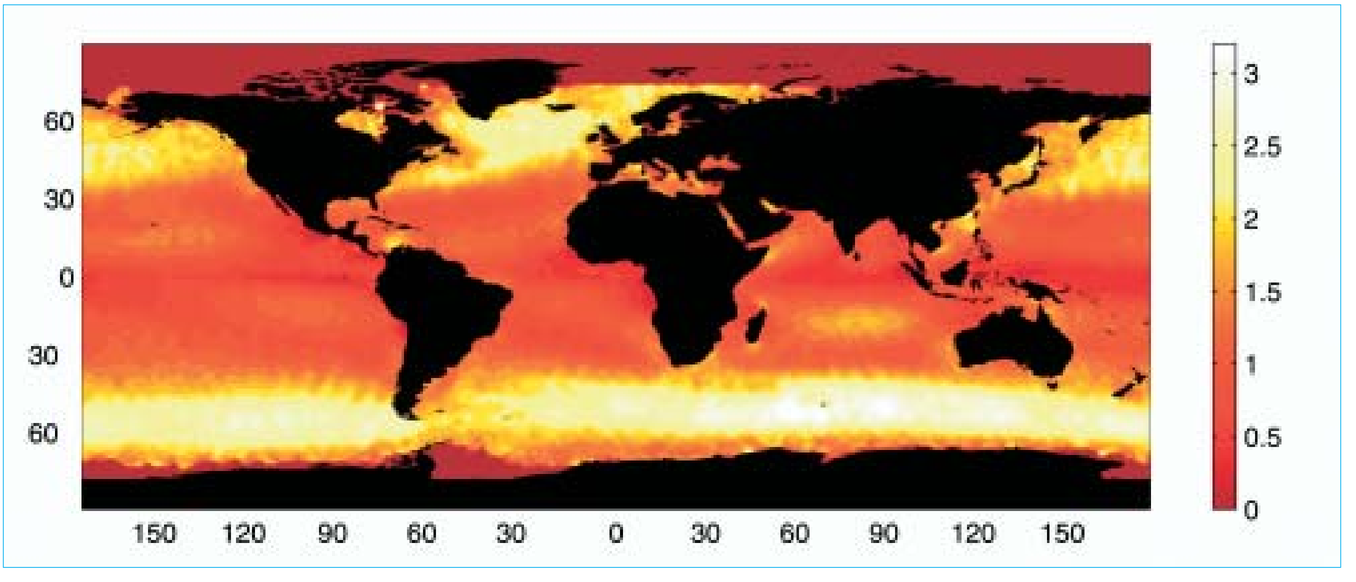


Figure 2. Annual mean significant height of swell only, in metres. © ARGOSS

Figure 3. Annual mean significant height of wind-sea only, in metres. © ARGOSS



The primary use of the altimeter is its capability to measure the significant wave height along its ground track. In addition to the wave height, the altimeter also produces estimates of the wind speed.

The scatterometer yields estimates of the wind vector (speed and direction) above open water.
The SAR is able to detect the energy and propagation direction of waves.

New retrieving algorithms have been developed to extract wave spectra out of multi sensor satellite observations (see *J. Geophys. Res.*, 105, 3497-3516). This technique uses the SAR spectrum as well as the scatterometer wind vector acquired at the same place and time by the ERS satellites.

The quality of the data is assured by various automated procedures such as range checks, checks for error flags and detection of outliers along a track. For wave spectra obtained from SAR, spectra with very low signal-to-noise levels are rejected.

Currently the databases cover all of the world's seas and oceans up to the year 2001 (see Figures 2 and 3).

Generation of Information Products

The service is for all companies that regularly need information about the offshore climate for their operations. Because companies' needs differ from one another, the information in www.waveclimate.com can

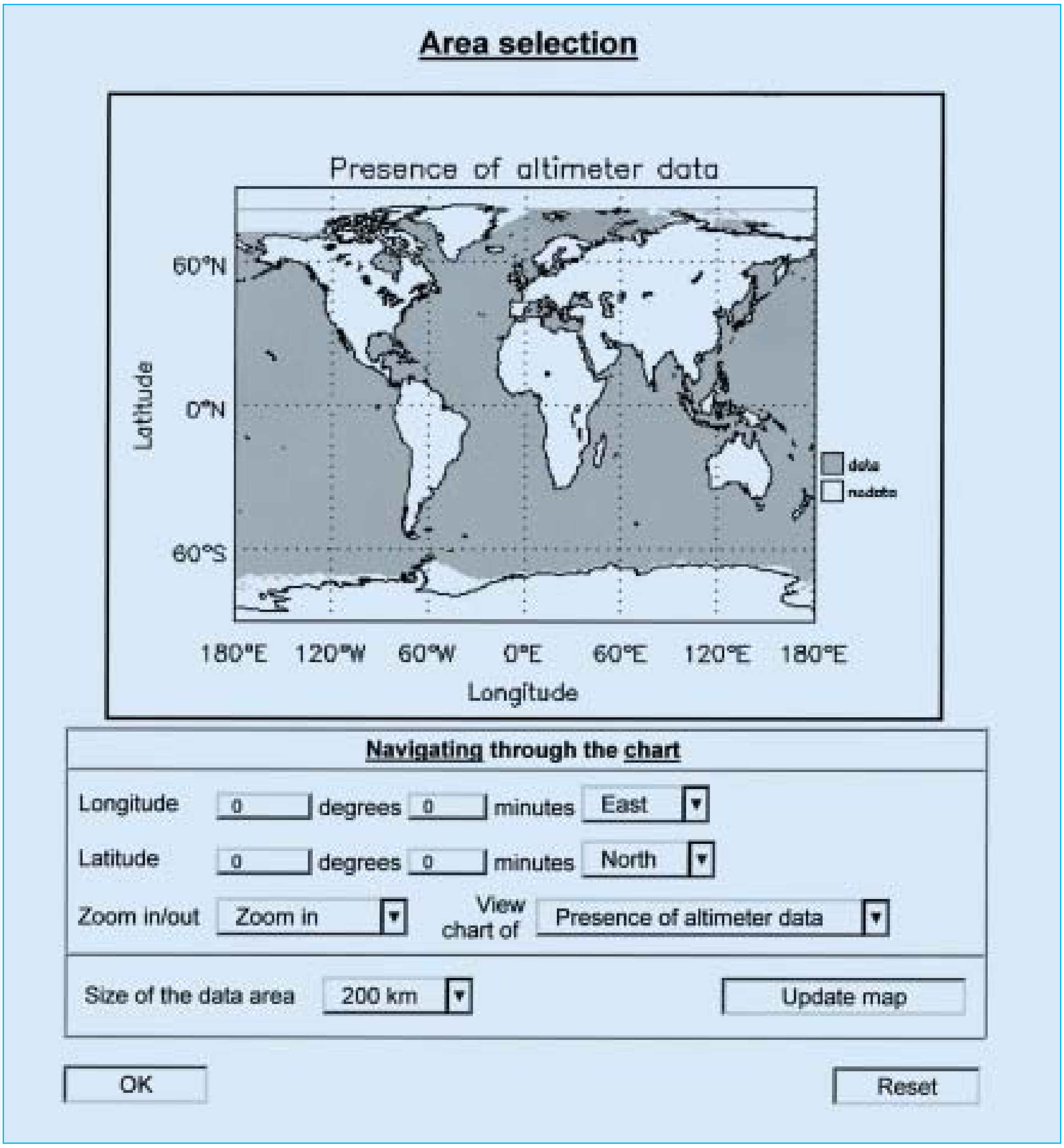


Figure 4. The area selection screen.
The area selection screen is meant for selection of the area of interest.
Navigating around the globe can be started by clicking anywhere inside the default (global) map. Alternatively, one can set the center of the new area by entering a longitude-latitude pair. Setting zoom in/out allows zooming into the new location or zooming out of the current location. The system answers to zoom actions by plotting the newly selected area. A (more) detailed map is used as soon as the plot area reaches a certain minimum size. The size of the data selection area can be set. In addition, one may choose the kind of chart used while navigating. At any time, one can return to the (initial) global map.

easily be tailored to the requirements of each individual user by the user (Figure 4).

The online system is regularly augmented with the most recent measurement data and is, as a result, always up-to-date. Whilst other sources lose their value as time passes, www.waveclimate.com continues to become more valuable because with each passing year the volume of data increases.

Amongst a mass of observations www.waveclimate.com offers the user a range of functions:
– probability distributions;
– joint probability tables;
– season selection (months); and
– short time series.

Tables II and III are examples of the service and are easily copied into Excel.

Table II. Example of joint probability distribution of significant wave height and mean wave period (in % of occurrence).

Relative occurrence of significant wave height (m) in rows versus mean wave period(s) in columns

	<3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	16
< 0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5-1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0-1.5	0	0	0	0	0	0.1	0.4	0.3	0	0	0	0	0	0
1.5-2.0	0	0	0	0	0.1	0.7	1.6	2.8	1.9	0.2	0	0	0	0
2.0-2.5	0	0	0	0	0.3	1.1	2.5	4.5	4.8	2.1	0.3	0	0	0
2.5-3.0	0	0	0	0	0.1	1.4	2.9	3.5	5.1	4.3	1.5	0.1	0	0
3.0-3.5	0	0	0	0	0	0.8	2	3.1	3.7	3.8	2.3	0.5	0	0
3.5-4.0	0	0	0	0	0	0.3	1.9	2.6	3.3	2.8	2.7	0.7	0	0
4.0-4.5	0	0	0	0	0	0	1	1.9	1.9	2.7	1.7	0.3	0.1	0
4.5-5.0	0	0	0	0	0	0	0.3	1.6	1.3	1.3	1.4	0.3	0.1	0
5.0-5.5	0	0	0	0	0	0	0.1	0.5	1.1	1.1	1	0.4	0	0
5.5-6.0	0	0	0	0	0	0	0	0.3	0.8	0.7	0.7	0.1	0	0
6.0-6.5	0	0	0	0	0	0	0	0	0.6	0.6	0.3	0.1	0.1	0
6.5-7.0	0	0	0	0	0	0	0	0	0.4	0.4	0.2	0.1	0	0
7.0-7.5	0	0	0	0	0	0	0	0	0.1	0.3	0.2	0	0	0
7.5-8.0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
8.0-8.5	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
8.5-9.0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
	<3	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**16**

Table III. Example of probability distribution of significant wave height for every month (in % of occurrence)

Monthly distribution of significant wave height (m)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
< 0.5	0	0	0	0	0	0	0	0	0	0	0	0
0.5-1.0	0	0	0	0	0.1	0	0	0	0	0	0	0.3
1.0-1.5	0.8	0.8	0.2	0.6	0.3	0.3	0	0	0	0.5	0	1.3
1.5-2.0	9.9	8.6	7.1	4	2.8	3.6	0.6	0.2	0.6	2.9	8.2	7
2.0-2.5	22.6	21.9	21.7	12.4	10	9.7	3.3	3.1	5.7	11.7	20.9	19.2
2.5-3.0	29.5	25.6	29.9	24.1	18.1	15.9	9.4	10	14.2	20.2	25	28.3
3.0-3.5	18.3	16	18.4	16.6	17	15.6	15.3	12.5	17.2	16	16.6	17.2
3.5-4.0	10.9	11.7	11.5	14.8	17.1	15.4	19.3	19.4	18.1	17.5	12.8	11.9
4.0-4.5	4.5	6.7	4.7	9.4	11.1	11.6	15.9	15.2	13.4	11.5	5.9	5.9
4.5-5.0	1.6	5.1	2.8	7.1	8.3	9.8	12.4	13.8	11.6	8.9	4.2	3.9
5.0-5.5	0.7	2.4	1.6	4	7.1	6.2	7.9	10.1	7.9	4.8	2.7	2.6
5.5-6.0	0.3	0.7	0.8	2.3	4.5	4.1	5.2	6.5	5.5	2.2	1.6	1
6.0-6.5	0.3	0.4	0.3	1.5	1.7	2.2	2.9	3.3	2.4	1.2	0.4	0.8
6.5-7.0	0.2	0.1	0.5	1.4	0.7	2.2	2.8	3.1	1.4	1	0.6	0.4
7.0-7.5	0.1	0	0.6	0.7	0.4	1.5	1.7	1.5	0.7	0.8	0.4	0.1
7.5-8.0	0.1	0	0.1	0.5	0.3	1.3	1.3	0.8	0.6	0.4	0.1	0
8.0-8.5	0.1	0	0	0.3	0.3	0.3	0.9	0.3	0.2	0.1	0	0
8.5-9.0	0.1	0	0	0.1	0.3	0.2	0.5	0.1	0.2	0.2	0	0
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**

Table IV. Accuracy of wind speed and wave height.

Statistics of all wave height and wind speed observations	Sensor	Buoy mean	RMS error	Relative error[%]
Significant wave height	Altimeter	2.31 m	0.33 m	12
Significant wave height	SAR	2.39 m	0.42 m	16
Wind speed	Altimeter	7.67 m/s	1.61 m/s	19
Wind speed	Scatterometer	7.69 m/s	1.26 m/s	15

Validation

The service offered has been validated against buoy data. At the site extensive validation reports can be downloaded freely from www.waveclimate.com.

The accuracy of significant wave height and wind speed data is summarised in Table IV. These are averages over all sensors and satellites. The figures are based on comparisons against wave buoy data at 28 locations in the Pacific and Atlantic (including the Gulf of Mexico) from the U.S. National Oceanic and Atmospheric Agency (NOAA) and Environment Canada. These buoys report hourly one-dimensional energy density spectra and wind.

The degree of mismatch between satellite and buoy data is expressed in terms of the root-mean-square error as well as a relative error measure.

The root-mean-square (RMS) error of say, significant wave height, is

$$\text{RMS error} = \sqrt{n^{-1} \sum_{i=1,\dots,n} \left| H_i^{retrieved} - H_i^{buoy} \right|^2}$$

with $H_i^{retrieved}$ the wave height of sample no. i retrieved from satellite data, and H_i^{buoy} the coincident buoy measurement of the wave height. It is similar to the standard deviation, but also includes the bias error.

Table V. Pacific: Statistics of data from SAR.

	Buoy mean	rms error	Relative error [%]
Significant wave height	2.64 m	0.40 m	14
Mean period	8.78 s	0.75 s	8
Zero-crossing period	6.87 s	0.60 s	9
Height of long waves (periods above 12 s)	1.13 m	0.40 m	26

Table VI. Atlantic: Statistics of data from SAR.

	Buoy mean	rms error	Relative error [%]
Significant wave height	2.03 m	0.45 m	20
Mean period	6.90 s	1.30 s	18
Zero-crossing period	5.77 s	0.97 s	16
Height of long waves (periods above 12 s)	0.36 m	0.36 m	54

Bias errors are in all cases small. The relative error is the RMS error normalised by the root-mean-square value of the buoy wave height:

$$\text{relative error} = \sqrt{\frac{\sum_{i=1,\ldots,n} \left| H_i^{retrieved} - H_i^{buoy} \right|^2}{\sum_{i=1,\ldots,n} \left| H_i^{buoy} \right|^2}}$$

To validate the wave spectra obtained from SAR, the buoys are grouped into two geographical regions: Pacific (North American west coast and Hawaii) and Atlantic (North American east coast and Gulf of Mexico). The following wave parameters, derived from retrieved ocean wave spectra were validated: significant wave height; mean period T_m; zero-crossing period T_z; and significant height of only those waves with periods above 12 s. The mean period and zero-crossing period are defined as:

$$T_m = \frac{\int f^{-1} F(f)\, df}{\int F(f)\, df}$$

$$T_z = \sqrt{\frac{\int F(f)\, df}{\int f^2 F(f)\, df}}$$

with f denoting the frequency in Hz and $F(f)$ the sea surface variance spectrum [in m2/Hz] in f.

Overview

Statistical information is provided about the overall sea-state (wave height, period, direction) but also about wind-sea only, or swell only. Wind-sea consists of the waves having crests moving no faster than 1.2 times the wind speed, so they are growing. Longer (and therefore faster moving) waves are called “swell”. Statistics of wind-sea and swell are derived from SAR data. Table VII indicates the various statistics of the overall sea-state which can be provided, and the source of the data (sensor) from which the statistics are derived.

Conclusions: Outlook

To further serve the dredging industry a new Web-based service on tidal currents and sea level is currently under development. In this service, measurements of 10,000 tidal stations are integrated with 16 years of satellite data to provide accurate information on tidal sea level and tidal currents for every location in the world.

Table VII. Statistics for total sea-state.

	Source of Data
Histogram	
Probability distribution of wind speed	scatterometer
Probability distribution of wind direction	scatterometer
Probability distribution of wave height	altimeter
Probability distribution of mean period	SAR
Probability distribution of zero-crossing period	SAR
Probability distribution of wave direction	SAR
Monthly distribution	
Monthly probability distribution of wave height	altimeter
Monthly probability distribution of wind speed	scatterometer
Scatter diagram	
Joint probability distribution of wind speed and wind direction	scatterometer
Joint probabilty distribution of significant wave height and wind speed	altimeter
Joint probability distribution of significant wave height and mean period	SAR
Joint probability distribution of significant wave height and zero-crossing period	SAR
Joint probabiltiy distribution of significant wave height and wave direction	SAR
Extreme value analysis	
Extreme value distribution of significant wave height	altimeter
Extreme value distribution of wind speed	scatterometer