Session 3: Wind data analysis- Wind wave predictions

Session 3: Analyse de données de vent-Prévision des vagues

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3.1 Wind characteristics

Wind direction

Table 3.1 *Major wind directions*

Wind	Major Direction (^{0})	Wind sector (^{0})
North (N)	0	338-23
NorthEast (NE)	45	23-68
East (E)	90	68-113
SouthEast (SE)	135	113-158
South (S)	180	158-203
SouthWest (SW)	225	203-248
West (W)	270	248-293
NorthWest (NW)	315	293-338

3.1 Wind characteristics

Wind speed

The wind speed (i.e. the distance covered by the air mass in a time unit) depends on the elevation of the measurement.

For oceanographic applications, the reference datum is set to be at 10 m above the sea level

If speed measurements have been obtained at a different elevation, these should be translated into speeds at the 10 m level (U_{10}) through:

$$U_{10} = U_Z (10/z)^{1/7}$$

where U_z the wind speed at elevation z above the sea level and U_{10} the wind speed at an elevation of 10 m above the sea.

3.1 Wind characteristics

Wind speed

Usual units of wind measurements are:

m/sec, km/h, miles/h (1609 m/h) and knots (1852 m/h)

Therefore:

1 m/s = 3.6 km/h = 2.24 miles/hour = 1.94 knots

A widely used measurement scale of wind speed is the Beaufort scale. The units in the Beaufort scale can be translated into m/s using the empirical expression:

$$U_{(m/s)} = 0.836B^{3/2}$$

where $U_{(m/s)}$ is the wind speed in m/s and B the units of the Beaufort scale

3.1 Wind characteristics

Wind speed

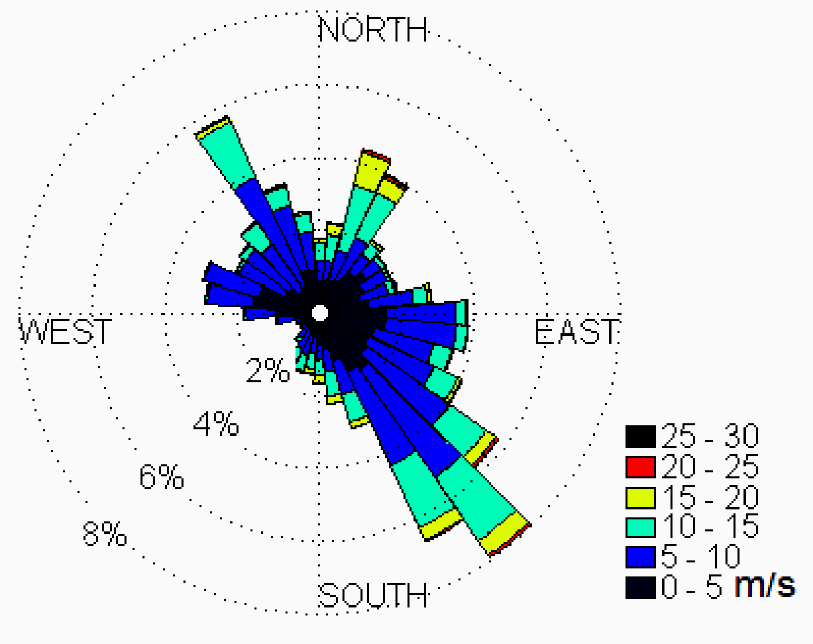
Table 3.2 *Beaufort scale and its translation in other units according to the National Meteorological Service of Greece.*

Wind Intensity (Beaufort Scale)		**Wind speed**			
B	Wind	**m/s**	**km/h**	**knots**	**miles/h**
0	Calm	0-0,2	< 1	< 1	<1
1	Light air	0.3-1.5	1-5	1-3	1-3
2	Light breeze	1.6-3.3	6-11	4-6	4-7
3	Gentle breeze	3.4-5.4	12-19	7-10	8-11
4	Moderate breeze	5.5-7.9	20-28	11-16	13-18
5	Fresh breeze	8.0-10.7	29-38	17-21	19-24
6	Strong breeze	10.8-13.8	39-49	22-27	25-31
7	Moderate gale	13.9-17.1	50-61	28-33	32-38
8	Fresh gale	17.2-20.7	62-74	34-40	39-46
9	Strong gale	20.8-24.4	75-88	41-47	47-54
10	Storm	24.5-28.4	89-102	48-55	55-63
11	Violent storm	28.5-32,6	103-117	56-63	64-74
12	Hurricane force	>= 32.7	>= 118	>= 64	>=75

3.1 Wind characteristics

Wind rose

A significant graphical tool is the wind rose, which gives a concise view of how wind speed/direction are distributed at a particular station. Using a polar coordinate system, the frequency of winds over a long time period is plotted by wind direction, with color bands showing wind ranges. The directions of the rose with the longest beam show the wind direction with the greatest frequency



3.2 Wind data analysis

Wind data

Wind data consist observations obtained with a particular sampling frequency (usually half-hourly or hourly observations but, some times, more frequently)

The records containing information of wind speed, wind direction, the date and time of observations.

3.2 Wind data analysis

General analysis

is carried out in the following steps:

1) Translation of speed measurements into m/s (if the speed measurements are taken in other units).

2) Translation of speed measurements into U_{10} speeds

1) Estimation of the duration of winds with certain speeds and directions (from the time records).

3.2 Wind data analysis

General analysis

The following analysis may take place for each of the 8 major direction sectors:

- Isolation of the wind records from each sector;
- Separation of records according to speed;. And
- Classification of records with duration of e.g. longer than 3 hours into speed classes and estimation of the mean (and maximum) speeds, the wind duration as well as of the frequency of these events.

3.2 Wind data analysis

Specialised analysis

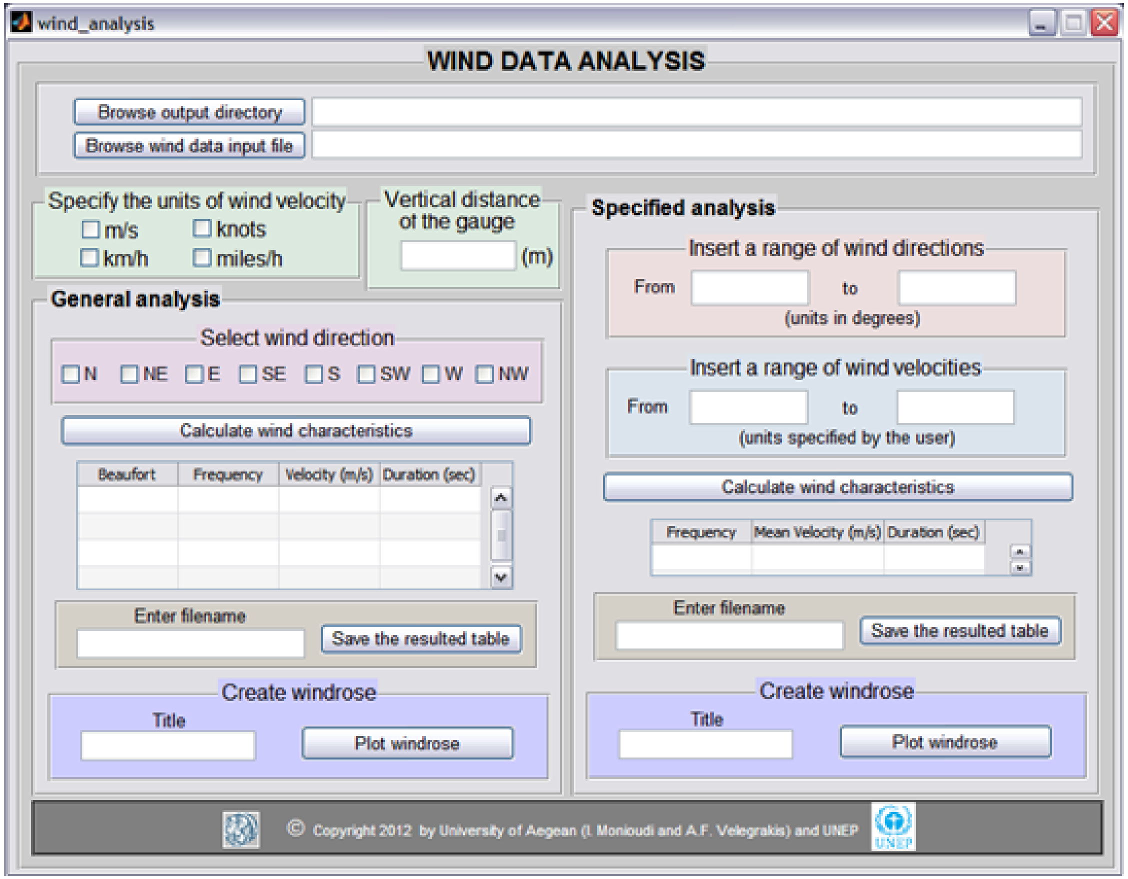
Can provide information on e.g. the wind statistics (mean and maximum speeds, duration and frequency) that can affect a beach with a particular orientation.

With regard to extreme events the criterion of Sanchez-Arcilla et al. (2008) can be used. According to this criterion, storm wave conditions can be generated by strong winds with minimum duration of 6 hours

3.2 Wind data analysis

The Wind Data Analysis GUI

In order to provide a user-friendly tool, the estimations are carried out using a specifically designed Guide User Interface (GUI). For further information on its use, see the accompanying manuals.



3.3 Wave characteristics

Progressive wind waves are characterized by certain basic parameters:

- wavelength L (in m), i.e. the distance from two consecutive crests
- period T (in sec), i.e. the time needed for the wave to travel distance equal to the wavelength L
- wave height H (in m), i.e. the vertical distance between the wave crest and the wave trough; and amplitude a, i.e. the half wave height (H/2) (in m).
- Another important factor affecting the manner that the wave energy influences the inshore waters/beach, is the water depth h (in m) which controls the wave dissipation and breaking.

3.4 Wind wave generation

In the open sea, wind waves are considered to be generated in the stages, following the wind generation (Komar, 1998):

(i) formation of capillary waves (with period T < 1 sec, H about 0.01-0.02 m) due, possibly, to the action of turbulent eddies within the air sea boundary layer

(ii) generation of larger waves (in terms of wavelength L, height H and period T) due to e.g. the differential air pressure and separation of flow

(iii) transfer of energy from the shorter to longer waves due to offshore wave breaking.

Therefore, the wave conditions at the generation point (‘sea’) are polychromatic, with many different, in terms of length height and period, co-existing waves

3.5 Wave generation controls

Wind wave development depends on 3 parameters:

I. ***the wind speed*** The higher the wind intensity/speed, the higher the air-sea energy transfer. In wave hindcasting, the controlled wind speed U_A is used, which can be estimated from U_{10} using the empirical expression:

$$U_A = 0.71(U_{10})^{1.23}$$

II. ***the wind duration***. the air- sea energy transfer increases with the time of wind flow above the sea surface

III. ***the fetch.*** the maximum distance between two obstructions (e.g. coasts. Islands) along which the wind can flow unhindered; small fetches do not allow for the development of large waves

3.5 Wave generation controls

The effective fetch at the location is estimated within a sector with a range ±45° relatively to the major direction, using the following expression (Koutitas, 1994):

$$F_{eff} = \frac{\sum_i F_i \cdot (\cos a_i)^2}{\sum_i \cos a_i}$$

where i describes the radius direction even 5° on either side of the wind direction, F_i is the linear fetch of direction i and α_i is the angle of radius i with the wind direction.

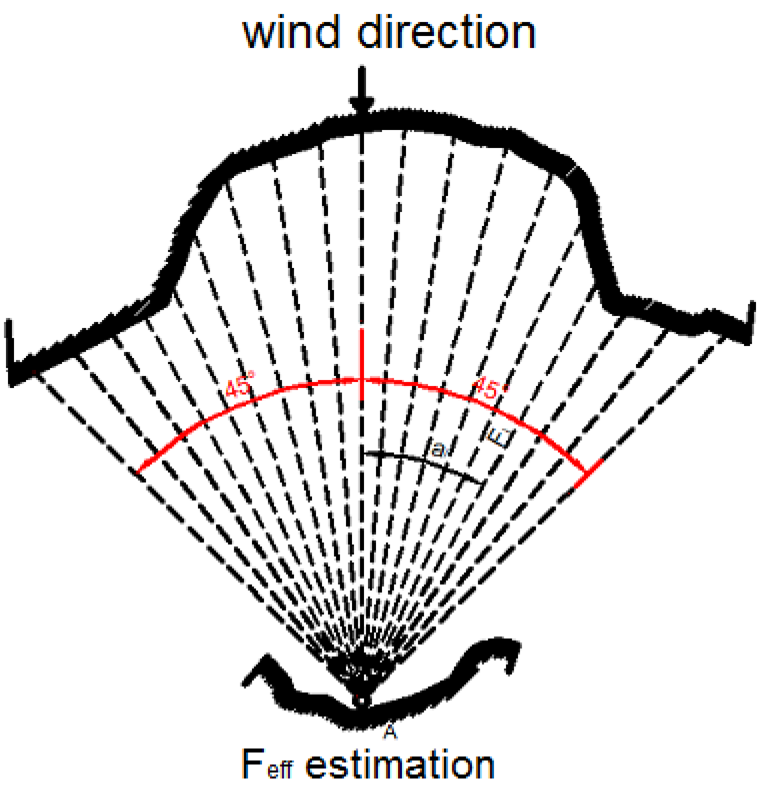


Fig. 3.2 *Fetch estimation using the radii directions (every 5°) on either side of the wind direction (Koutitas, 1994).*

3.5 Wave generation controls

An example of effective fetch estimation for SE winds (135° N) for the Tsamakia beach (E. Lesbos, Greece)

The sector used has a range of 90-180° N;

however Tsamakia beach is protected from winds with orientations 155-180° N,

So the sector which has been used is 90-150° N.

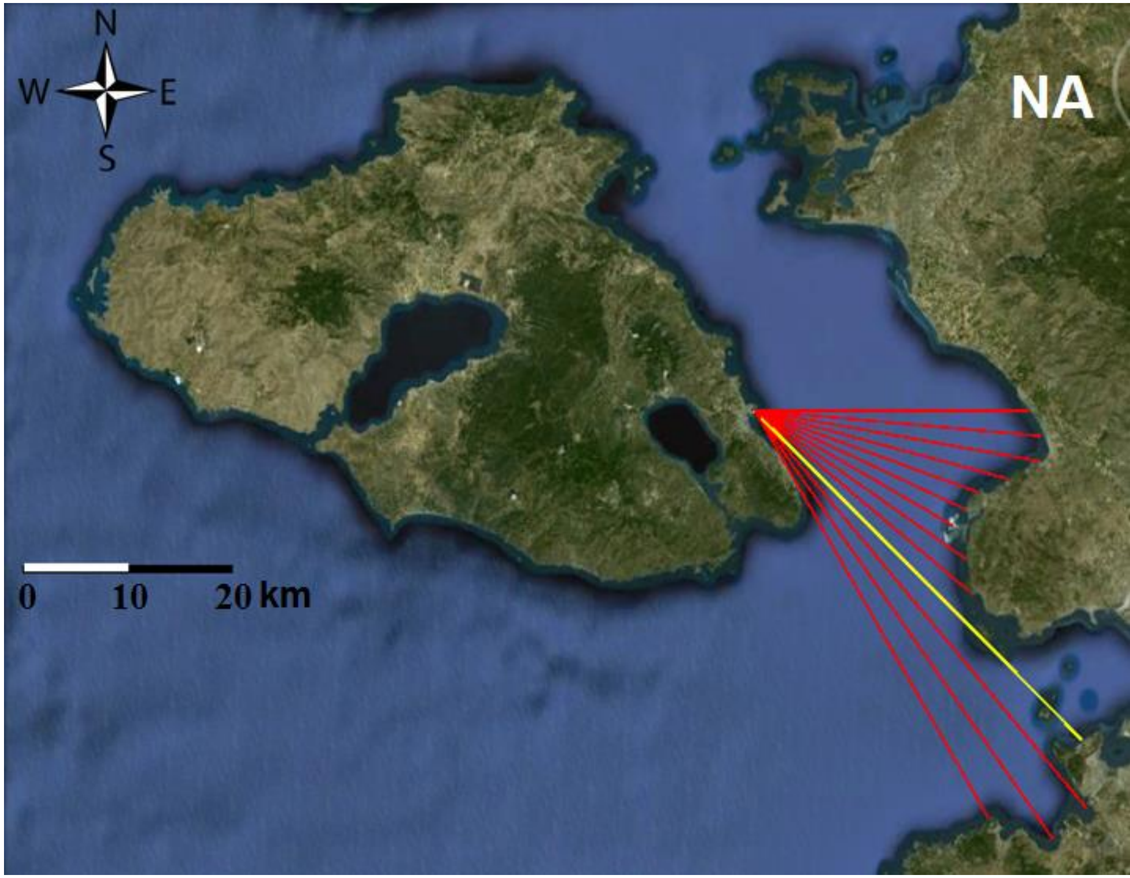


***Fig. 3.3** Effective fetch of Tsamakia beach (E. Lesbos, Greece) for SE winds.*

3.5 Wave generation controls

Table 4.1 *Fetches of Tsamakia beach (E. Lesbos, Greece) for winds from the 90-150° N sector, on the basis of radius directions every 5°.*

Radius	a_i	Direction	$\cos(a_i)$	$\cos^2(a_i)$	F_i [km]	$F_i*\cos^2(a_i)$ [km]
1	345	150	0.97	0.93	44.50	41.52
2	350	145	0.98	0.97	49.40	47.91
3	355	140	1.00	0.99	49.00	48.63
4	0	135	1.00	1.00	44.00	44.00
5	5	130	1.00	0.99	26.50	26.30
6	10	125	0.98	0.97	24.35	23.62
7	15	120	0.97	0.93	21.60	20.15
8	20	115	0.94	0.88	22.00	19.43
9	25	110	0.91	0.82	22.70	18.65
10	30	105	0.87	0.75	24.90	18.68
11	35	100	0.82	0.67	27.50	18.45
12	40	95	0.77	0.59	27.30	16.02
13	45	90	0.71	0.50	26.00	13.00
Sum	**-**	**-**	**11.90**	**-**	**-**	**356.35**

$$F_{eff} = \frac{\sum_i F_i \cdot (\cos a_i)^2}{\sum_i \cos a_i}$$

$$F_{eff} = 29.95 km$$

3.5 Wave generation controls

Wave conditions can be differentiated on the basis of the above parameters (wind speed, duration and fetch) into:

- ***Fully Developed Sea (FDS),*** which is supplied with the full energy of a wind of particular speed; this condition does not depend any more on the wind duration t_D or the fetch F_{eff}, with the wave parameters being controlled only by the wind speed (U_A).

- ***Fetch-Limited Sea development (FLDS)*** fetch F is shorter than that required for the transfer of the maximum energy from a particular wind speed U_A; this condition does not depend on the wind duration t_D, with the wave parameters being controlled by the wind speed U_A and the effective fetch F_{eff}.

- ***Duration-Limited Sea Development (DLSD)*** wind duration t_D is shorter than that required for the transfer of the maximum energy from a particular wind speed U_A; this condition does not depend on the fetch, with the wave parameters being controlled by the wind speed U_A and the wind duration t_D.

3.6 Wave projections based on wind data

Wind generated waves in the open sea are *polychromatic*, i.e. the wave condition can be approximated by the synthesis of many *monochromatic* waves with different wave characteristics (lengths, heights and periods).

In order to estimate this condition, the energy density spectrum i.e. the distribution of the energy density within the different frequencies (periods) can be employed.

It is assumed that the wave conditions under particular wind forcing and duration can be described by particular wave energy density spectra, such as:

- the ***JONSWAP Spectrum****,* which is better suited in cases where there are fetch limitations
- the ***Pierson-Moskowitz (P-M) Spectrum****,* which is better suited for fully developed seas

3.6 Wave projections based on wind data

The JONSWAP-Pierson-Moskowitz method

First, the validity of the following expression is examined:

$$\frac{gF}{U_A^2} \geq 22.8 \cdot 10^3 \quad [3.5]$$

If the expression holds, then the waves are fully developed and the expressions related to the *Pierson-Moskowitz spectrum* can be used:

$$\frac{gH_s}{U_A^2} = 0.243 \quad [3.6] \qquad \frac{gT_p}{U_A} = 8.13 \quad [3.7]$$

where H_s the significant wave height και T_p the peak wave period.

3.6 Wave projections based on wind data

The JONSWAP-Pierson-Moskowitz method

If, however, the expression does not hold, then the following expressions (*JONSWAP spectrum*) can be used (Hasselmann et al., 1976):

$$\frac{gH_s}{U_A^2} = 0.0016\left(\frac{gx}{U_A^2}\right)^{0.5} \quad [3.8] \qquad \frac{gT_p}{U_A} = 0.286\left(\frac{gx}{U_A{}^2}\right)^{0.33} \quad [3.9]$$

In order to estimate the *x* in the above expressions the validity of the following expression is examined:

$$\frac{gt_D}{U_A} > 68.8\left(\frac{gF_{eff}}{U_A{}^2}\right)^{0.66} \quad [3.10]$$

where t_D is the wind duration.

If the expression [3.10] holds, then the fetch is constrained and x = F_{eff}.

If, however, it does not, then the two terms of the expression [3.10] are considered equal, a new F_{eff} is estimated which can be used then as *x* in the expressions [3.8] και [3.9], from which the values of H_s και T_p can be estimated.

the wave period T_s is estimated from the peak period T_p using: $T_s = 0.9T_p$

3.6 Wave projections based on wind data

Equivalent (effective) waves

The (annual) morphodynamics of a particular beach is controlled by a characteristic annual wave condition the *equivalent/effective waves*

- On the basis of a annual wind record are estimated: f, t_D and U_{10} for the different wind intensity classes (e.g. Beaufort scale).
- Using the JONSWAP-Pierson-Moskowitz method, the wave heights (H_i) and periods (T_i) of the different intensity classes are estimated.
- The equivalent (effective) wave period T_e in the opens sea is estimated using:

$$T_e = \frac{\sum f_i T_i}{\sum f_i}$$

The equivalent wave height H_e is estimated on the basis of the expression (Borah και Balloffet, 1985):

$$H_e^2 T_e = \frac{\sum H_i^2 f_i T_i}{\sum f_i}$$

3.7 The wave estimation Guide User Interface (GUI)

In order to provide a user-friendly tool, the estimations are carried out using a specifically designed Guide User Interface (GUI)