On problems using archived marine wind data: The relation between Beaufort estimations, encoded wind speeds, and real wind speeds

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Introduction

A few years ago the author had the task to determine the wind power potential in coastal sea areas along the coasts of the European Community. This had to be performed using marine (voluntary ships') wind observations only. The data base was the Marine Meteorological archive of Deutscher Wetterdienst, Seewetteramt (Marine Meteorological Office) in Hamburg which presently consists of some 60 million of marine data records, about 1.5 million of those are along European Community coasts.

Of the latter all those wind observations marked as "measured" (about 15%) were discarded. The reason for this was that the measuring height was unknown, a possible flow distortion by the ships' bodies, and the possibility of an inadequate reduction of ship's speed and course in the wind.

The rest of the marine wind values (85%) are marked as "estimations." The data sets in our archive contain both a Beaufort value and a speed in knots. For technical applications the wind can only be used as speeds in metric units. As a first approach we therefore tried to use the Beaufort forces and then transform them to speeds by the "Beaufort equivalent scale" developed by Kaufeld (1981), as the equivalent scale of WMO was known to be biased. Kaufeld derived his scale by comparing the Beaufort estimations of voluntary ships to the measurements of the former Ocean Weather Ships (OWS), using a very sophisticated comparison method in space and time.

The author re-analyzed the Kaufeld scale especially at low speeds (Beaufort 1-3), and corrected it for an assumed speed reduction of the anemometers due to friction at low speeds (see differences in Table 1, column (1), Kaufeld, and (2), Schmidt). We then immediately learned, that the Beaufort values of our archive are NOT the original wind observations, but the speeds recorded in knots. The Beaufort values in our archive have been SET, according to the WMO Beaufort scale. As far as we know, this is true in all the archives, at least for marine observations after World War II.

For Kaufeld's investigation this was no big problem. At that time our archive more or less only consisted of German observations, and the German observers up to then closely followed the WMO scale, encoding only the "equivalent speeds" of the estimated Beaufort force. So the author could combine columns (4) and (2) of Table 1 and develop a continuous non-linear transformation from “WMO encoded speeds” into “real speeds at 25 m height” above sea level (see also Fig. 1).

Analysis

When we nowadays take a close look at the contents of the wind information in our archive, we find, that the observers in many countries (and also our observers) did or do not follow the strict WMO procedure but set all possible wind speed values between the “Beaufort equivalents”. Analyzing the frequency distribution of encoded wind speeds in steps of one knot, we find a lot of different encoding routines (Table 2). This results in a dense, but very inhomogeneous frequency filling of the distribution of “knots”.

Since no one is able to estimate wind speeds just by “feeling”, the author assumed, that all observers implicitly or explicitly use the wind estimation method recommended by WMO (1949): That is, to look at the sea surface, determine the sea state, and according to that a Beaufort wind value, and finally to look up a table defining an equivalent wind speed and write it down. We further assumed, that these “equivalent wind speed” tables in all countries either are the one proposed by WMO or were derived from it.

When we use the above mentioned transformation (called “transform 1”), and apply it to a well covered wind speed distribution (Fig. 2, example for the North Sea with about 500,000 observations, showing frequencies of exceedance versus wind speeds), a step function results due to the inhomogeneous probability density. This has an unfavorable effect on curve fitting routines, especially when they are done automatically in limited intervals (in our case we fitted a Weibull distribution in the speed range 3-20 m/s for the calculation of wind energy).

We therefore went one step further, and developed a second transformation (transform 2 in Fig. 2), by shifting the speed values of the step function horizontally (i.e. on the speed axis) towards a Weibull distribution, which was carefully fitted piece wise over entire periods of the steps in the distribution (Fig. 2 is only the enlarged middle part). The resulting transformation is listed in Table 3, which is further subdivided in German and a mixture of other observation sources. The tables are used in the following way: Given you have a wind speed distribution in knots “encoded”, then the lower boundary of the class, e.g. “25 knots” is (as a real speed at 25 m height) 13.7 m/s for German and 12.9 m/s for a typical mixture of “foreign” observations. The resulting frequency distributions are rather smooth and can easily be treated with curve fitting routines.

Admittedly, the method described above is “brute force”, but (looking at the results, e.g. Fig. 3) it seems to work.

Table 1: Beaufort–scales (lower boundaries of Beaufort classes in Meters/Second.

	Kaufeld	Re-analyzed Schmidt		
Bft	1981	1991	CMM-IV	WMO
	(1)	(2)	(3)	(4)
0	0.0	0.0	0.0	0.0
1	0.8	1.7	1.3	0.3
2	2.8	3.2	2.8	1.8
3	5.4	5.3	4.4	3.3
4	7.5	7.6	6.4	5.4
5	10.0	9.9	8.5	8.0 (8.5)
6	12.1	12.1	11.1	11.1
7	14.7	14.4	13.6	14.1
8	17.2	17.1	16.2	17.2
9	20.3	20.4	19.3	20.8
10	23.4	23.5	22.4	24.4
11	27.0	26.9	26.0	28.6
12	30.6	30.5	29.6	32.7

Scales (1) and (2) are valid for 25 m above sea level, scales (3) and (4) are probably for 10 m above sea level The general problem is now, that in most of the modern marine meteorological archives (after 1950), the original values for estimated wind speeds are not the Beaufort forces, but encoded speeds in “knots” or “m/s”

Table 2: Setting of "Knots" due to different encoding procedures.

Bft	Kts	A	B	C	D	E	F	G	Sum
0	0	X	X	X	X	X	X	–	6
	1	–	—	–	–	–	–	–	–
1	2	X	X	X	–	X	X	–	5
	3	–	–	–	–	–	–	–	–
	4	–	X	X	–	X	–	–	3
2	5	X	–	–	X	–	X	–	3
	6	–	–	X	–	–	–	–	1
	7	–	–	–	–	–	–	–	–
	8	–	X	X	–	X	–	–	3
3	9	X	–	–	–	–	X	–	2
	10	–	–	X	X	–	–	–	2
	11	–	–	–	–	–	–	–	–
	12	–	X	X	–	–	–	–	2
4	13	X	–	–	–	–	X	–	2
	14	–	–	X	–	X	–	–	2
	15	–	–	–	X	–	–	X	2
	16	–	–	X	–	–	–	–	1
	17	–	X	X	–	X	–	–	3
5	18	X	–	–	–	–	–	–	1
	19	–	–	X	–	–	X	–	2
	20	–	–	–	X	–	–	–	1
	21	–	–	X	–	–	–	X	2
	22	–	–	–	–	–	–	–	–
	23	–	X	X	–	X	–	–	3
6	24	X	–	–	–	–	–	–	1
	25	–	–	X	X	–	X	–	3
	26	–	–	–	–	–	–	–	–
	27	–	–	X	–	–	–	X	2
	28	–	–	–	–	–	–	–	–
	29	–	X	X	–	–	–	–	2
7	30	X	–	–	X	–	–	–	2
	31	–	–	X	–	X	X	–	3
	32	–	–	–	–	–	–	–	–
	33	–	–	X	–	–	–	X	2
	34	–	–	–	–	–	–	–	–
	35	–	X	X	X	–	–	–	3
	36	–	–	–	–	–	–	–	–

Table 2: (Cont) Setting of "Knots" due to different encoding procedures.

Bft	Kts	A	B	C	D	E	F	G	Sum
8	37	X	–	X	–	X	X	–	4
	38	–	–	–	–	–	–	–	–
	39	–	–	X	–	–	–	–	1
	40	–	–	–	X	–	–	X	2
	41	–	–	X	–	–	–	–	1

A:	Beaufort Equivalent in knots	NLD, FRG, UK,ISL
B:	Beaufort Equivalent in whole m/s	USA
C:	Continuous scale in m/s	USA, USSR, former GDR
D:	Continuous scale in 5 knot increments	CAN, UK, NLD, FRA, POL, and others
E:	Beaufort equivalent in m/s, (differs from B)	former GDR
F:	Beaufort equivalent in knots (differs from A)	YUG
G:	Additional "half Bft steps in knots (… 15, 21, 27, 33 etc.)	FRG and others
	further: (all observers)	

Preference of even numbers, preference of end digits 0 and 5
Preference of end digits 0 2 5 8 (Israel)

Distribution of observations
total: 537637

NL	7%
USA	27%
UK	27%
F	5%
CAN	0.5%
FRG	17%
ISR	5%
USSR	1%
YUG	2%
POL	3%
GDR	2%

Table 3: Conversion of speeds in knots (encoded according to WMO Beaufort scale, resulting from estimations), into "real speeds" (m/s) at 25 m height above sea level. The "real speeds" are lower boundary values for the original knot classes.

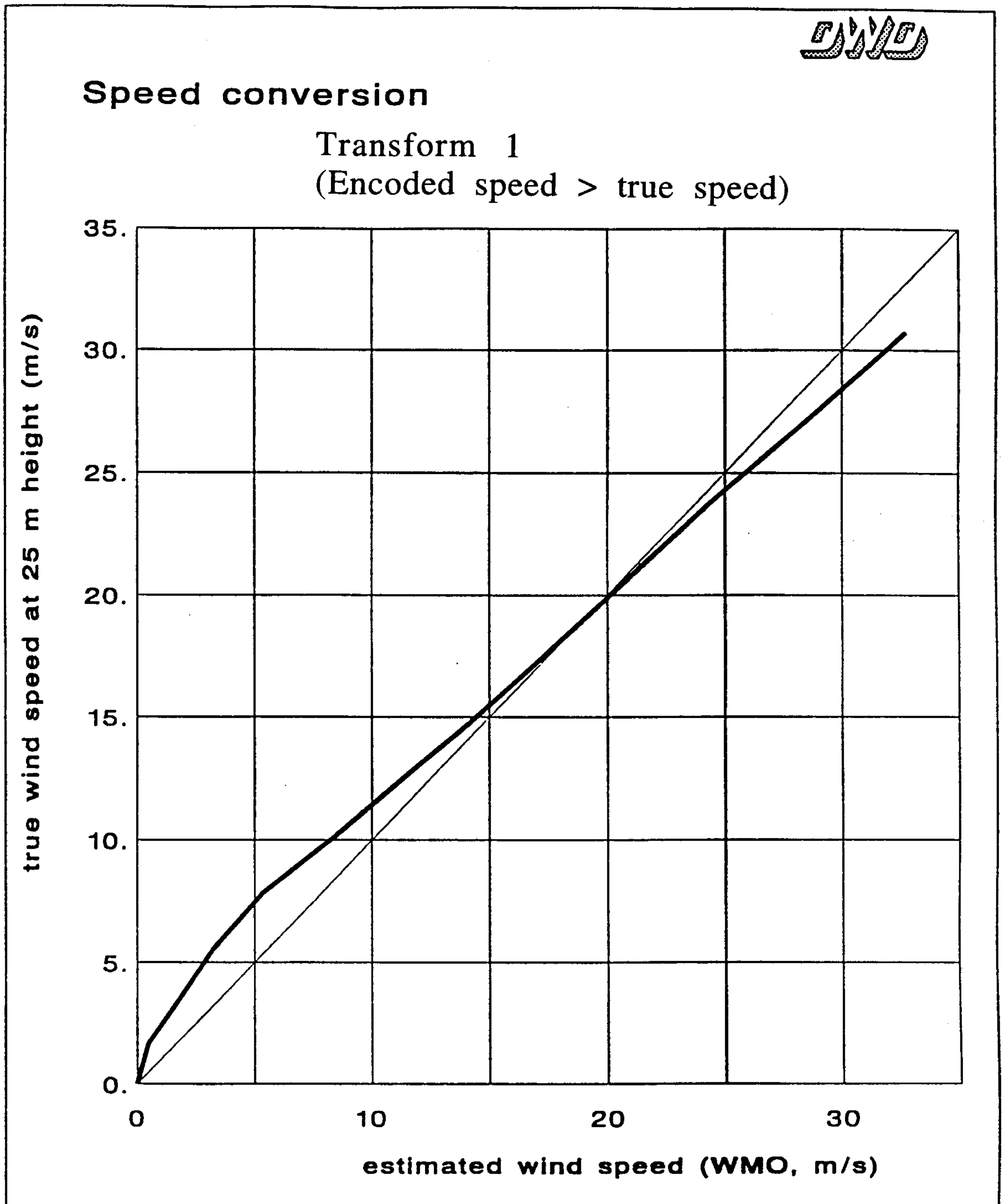
Conversion Table - German Wind Observations

Knots	0	1	2	3	4	5	6	7	8	9
0	0.0	1.6	1.7	3.1	3.2	3.3	5.2	5.3	5.4	5.5
10	7.4	7.5	7.7	7.8	9.4	9.5	9.7	9.8	9.8	11.5
20	11.6	11.7	11.8	11.9	12.0	13.7	13.8	13.9	14.2	14.2
30	14.3	16.4	16.5	16.6	16.9	17.0	17.1	17.2	19.8	20.0
40	20.1	20.5	20.6	20.7	20.8	23.3	23.4	23.6	23.7	24.1
50	24.2	24.3	25.0	27.0	27.1	27.2	27.3	27.7	27.8	28.2
60	28.8	31.0	31.1	31.5	31.6	33.3	33.4	33.5	33.6	34.8

Conversion Table - Typical mix of foreign observations

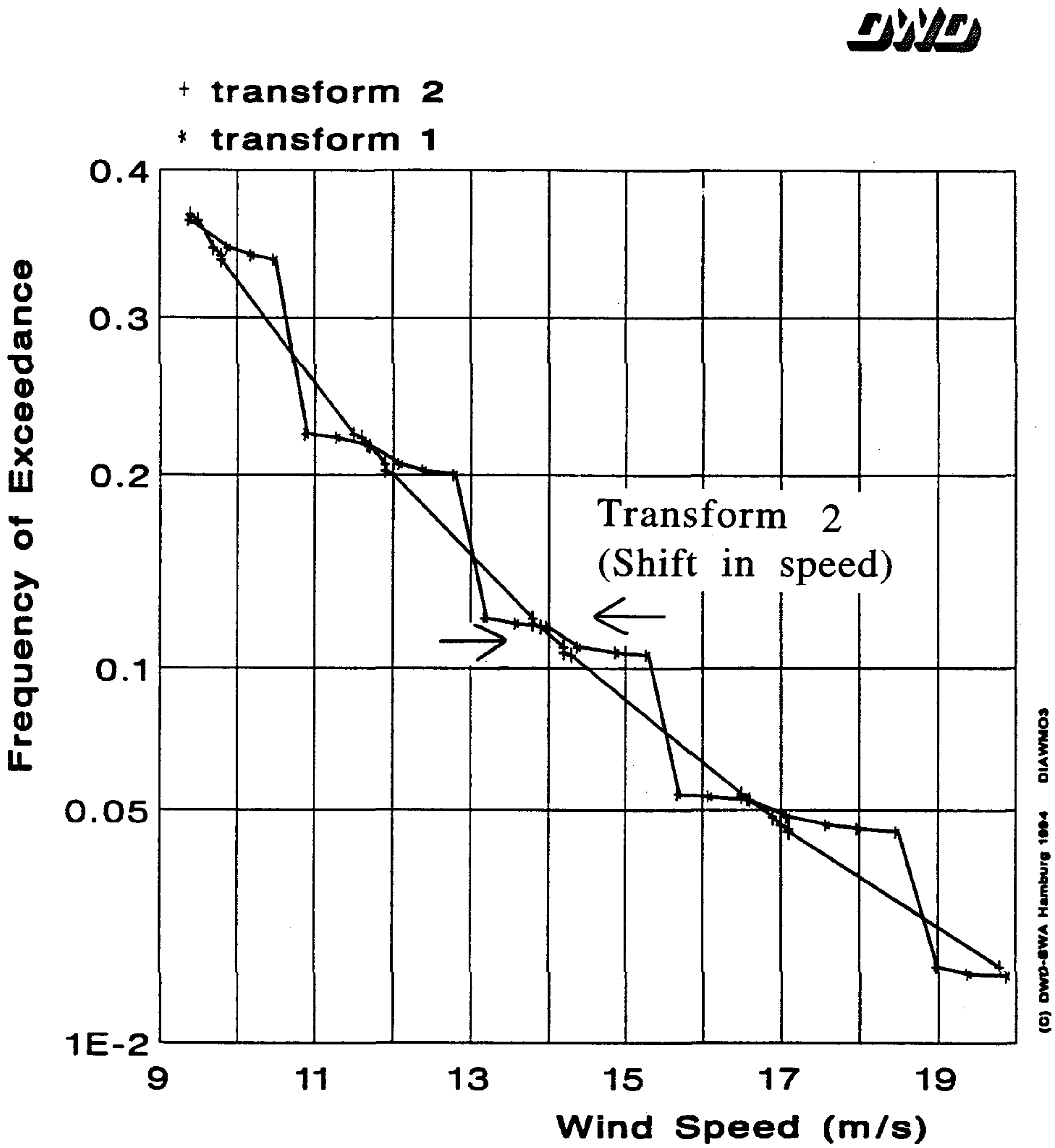
Knots	0	1	2	3	4	5	6	7	8	9
0	0.0	1.8	1.9	2.7	2.8	3.4	4.1	4.5	4.7	5.2
10	6.1	6.6	6.7	7.2	8.0	8.4	8.6	9.1	9.5	10.2
20	10.7	11.0	11.3	11.6	11.9	12.9	13.2	13.4	13.8	14.1
30	14.5	15.8	16.0	16.2	16.5	16.8	17.2	17.4	18.9	19.1
40	19.5	20.2	20.5	20.8	21.1	22.3	23.0	23.2	23.7	24.1
50	24.4	25.0	25.4	26.6	26.7	27.1	27.5	28.1	28.2	28.8
60	28.9	31.0	31.1	31.7	32.1	32.5	33.0	34.2	34.4	35.2

Figure 1:



True wind speeds at 25 m height above sea level after KAUFELD (modified) versus estimated wind speeds (Beaufort estimates encoded to m/s according to the WMO scale)

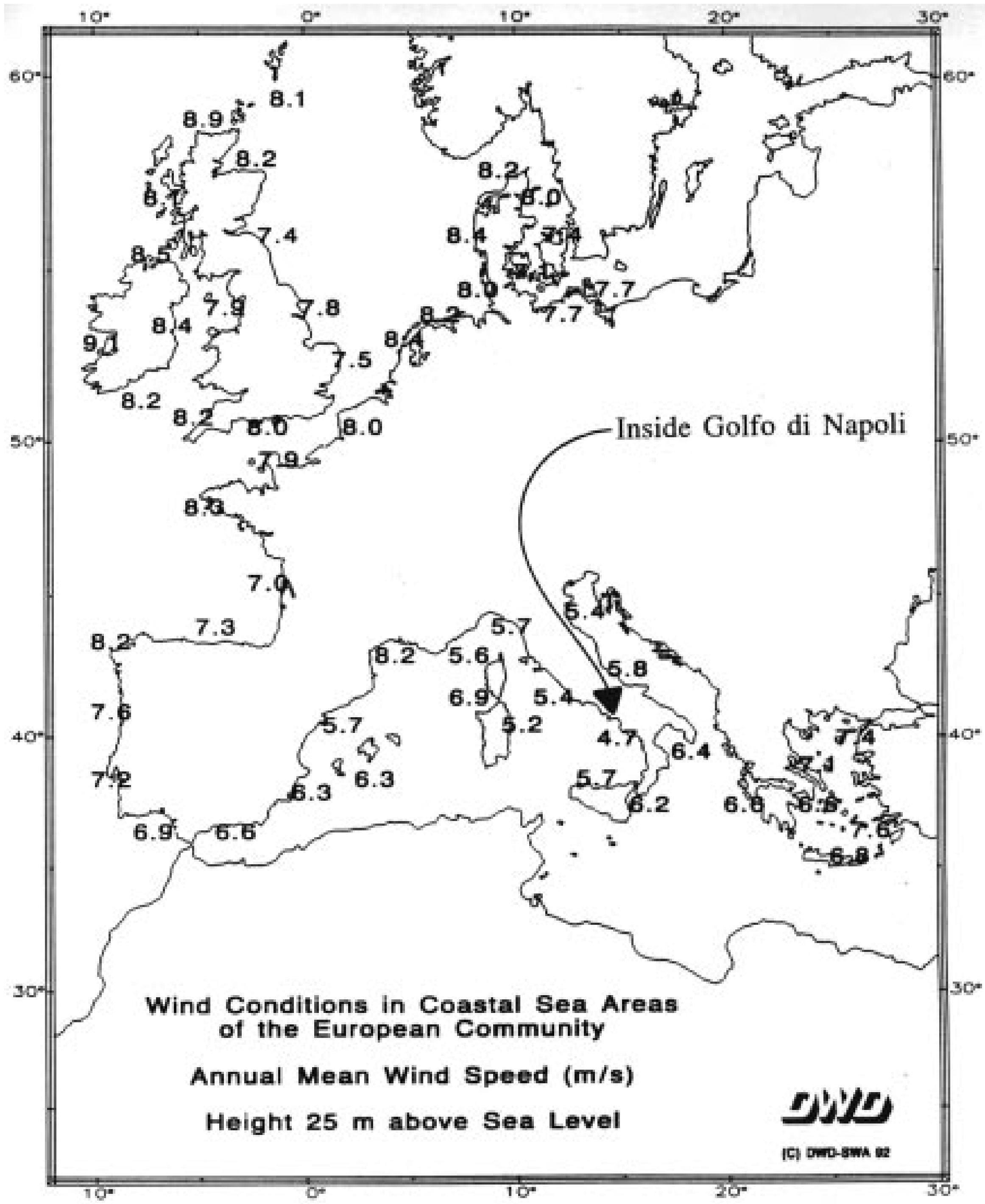
Figure 2:



Frequency Distribution of Wind Speed in the North Sea

(only middle part, enlarged)

Figure 3:


Inside Golfo di Napoli
Wind Conditions in Coastal Sea Areas
of the European Community
Annual Mean Wind Speed (m/s)
Height 25 m above Sea Level
DWD
(C) DWD-SWA 92