



## WAsP Utility Programs

**Mortensen, Niels Gylling; Landberg, Lars; Troen, Ib; Lundtang Petersen, Erik**

*Publication date:*  
2004

*Document Version*  
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

*Citation (APA):*  
Mortensen, N. G., Landberg, L., Troen, I., & Lundtang Petersen, E. (2004). *WAsP Utility Programs*. Risø National Laboratory. Risø-I No. 2261(EN)

---

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Risø-I-2261(EN)

## WAsP Utility Programs

Niels G. Mortensen, Lars Landberg, Ib Troen,  
Erik L. Petersen, Ole Rathmann and Morten Nielsen

**Author:** Niels G. Mortensen, Lars Landberg, Ib Troen, Erik L. Petersen, Ole Rathmann and Morten Nielsen  
**Title:** WAsP Utility Programs  
**Department:** Wind Energy Department

**Abstract (max. 2000 char.):**

The Wind Atlas Analysis and Application Program (WAsP) is a PC-program for horizontal and vertical extrapolation of wind data. The program contains a complete set of models to calculate the effects on the wind of sheltering obstacles, surface roughness changes and terrain height variations. The analysis part consists of analysis of raw wind data (speed and direction) and generation of wind atlas data. The wind atlas data set can subsequently be applied for estimation of the wind climate and wind power potential, as well as siting of specific wind turbines. The program comes with a User's Guide consisting of an introduction to the program, a description of the hardware requirements and installation procedure, a program reference section and a User's Guide.

This report describes the WAsP Utility Programs package, which contains a number of auxiliary programs to analyse, transform, view and plot WAsP data.

Product names mentioned herein may be trademarks or registered trademarks of their respective companies.

**Risø-I-2261(EN)**  
**September 2004**

**Contract no.:**  
n/a

**Groups own reg. no.:**  
1105 002-01

**Sponsorship:**  
WAsP has been developed with support from the Commission of the European Union.

**Cover:**

---

**Pages: 52**  
**Tables: 0**  
**References: 13**

Risø National Laboratory  
Information Service Department  
P.O.Box 49  
DK-4000 Roskilde  
Denmark  
Telephone +45 46774004  
[bibl@risoe.dk](mailto:bibl@risoe.dk)  
Fax +45 46774013  
[www.risoe.dk](http://www.risoe.dk)

# Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
1.1	System requirements	3
1.2	Running the Utility Programs	3
<b>2</b>	<b>Wind climatological fingerprint</b>	<b>4</b>
2.1	The mean year	4
2.2	The mean days	4
2.3	The wind rose	4
2.4	The spectrum	5
2.5	The time print	6
2.6	Running the program	6
2.7	Output files	9
<b>3</b>	<b>Fitting and plotting wind distributions</b>	<b>11</b>
3.1	The histogram	11
3.2	The wind rose	12
3.3	Options	12
3.4	Screen output	14
3.5	Output files	14
<b>4</b>	<b>Weibull statistics</b>	<b>18</b>
<b>5</b>	<b>Map coordinate conversion</b>	<b>21</b>
5.1	Points, lists and maps	21
5.2	Converting a map file	22
<b>6</b>	<b>Map file format conversions</b>	<b>23</b>
6.1	Maps stored in BNA files	23
6.2	Maps stored in DXF files	24
6.3	Coastlines stored in DAT files	25
<b>7</b>	<b>Map and grid transformations</b>	<b>26</b>
7.1	From grid to map	26
7.2	From map to grid	27
<b>8</b>	<b>The ruggedness of 'complex terrain'</b>	<b>30</b>
8.1	The ruggedness index (RIX)	30
8.2	Using the ruggedness index	32
<b>9</b>	<b>Interpolation of wind atlas data</b>	<b>35</b>
9.1	The LIB-file interpolator	35
9.2	User interface	36
9.3	Options	36
<b>10</b>	<b>Plotting the power curve</b>	<b>37</b>
10.1	The power curve	37
10.2	The power coefficient curve	38
10.3	Options	38
10.4	Output files	39

<b>11 Resource to grid files</b>	<i>41</i>
11.1 Grid file types	<i>42</i>
11.2 Options	<i>42</i>
11.3 Input file	<i>43</i>
11.4 Output files	<i>43</i>
<b>12 Reporting</b>	<i>45</i>
12.1 Printing the wind atlas	<i>45</i>
12.2 Finding the PostScript bounding box	<i>45</i>
12.3 Sample station description	<i>47</i>
<b>Acknowledgements</b>	<i>52</i>
<b>References</b>	<i>52</i>

“If all else fails, read the instructions ...”

*Donald E. Knuth, creator of T<sub>E</sub>X*

# 1 Introduction

The complete WASP Utility Programs package consists of a User's Guide (the present report, Risø-I-2261) and one or more installation file(s). Each installation file is a password-protected self-extracting archive file which contains installation instructions (Installation.pdf) and an End User Licence Agreement (License.pdf). The files may contain a Readme.pdf file with the latest information and a brief history of the package development. You may also visit [www.wasp.dk](http://www.wasp.dk) for more information.

## 1.1 System requirements

The WASP Utility Programs have the same system requirements as the WASP software: a PC with Windows 98/ME/NT4/2000/XP.

Most of the graphs shown in this report were produced using Grapher and Surfer, two general-purpose programs for plotting  $(x, y)$  and  $(x, y, z)$ -data, respectively. Several of the utility programs actually produce Grapher GRF files—with the right data files, axes, scaling, labels etc—or Surfer GRD files. So, if you use Grapher and Surfer you should be able to produce similar plots with a minimum of effort.

However, the utility programs also produce ASCII data files which can be read, viewed, printed and plotted using almost any general purpose plotting program. So the WASP Utility Programs do not require that you use any specific programs, even though it is very convenient if you use Grapher and Surfer.

The wind-climatological fingerprint program described in Section 2 requires either a PostScript printer or software that can process PostScript or Grapher/Surfer PLT files, in order to view and plot the fingerprint graphic, Fig. 1. One such program is Ghostscript which can be used to preview, convert and print PostScript and PDF files. The tables are standard ASCII text files.

## 1.2 Running the Utility Programs

The present edition of the User's Guide describes version 3.0 of the WASP Utility Programs. Most of the Utility Programs are command line tools and they must be run from within a 'Command Prompt' window under Windows.

Some of the Utility Programs, like the Lib Interpolator described in Section 9, are standard Windows programs. These may be invoked as any other Windows software.

## 2 Wind climatological fingerprint

The so-called wind-climatological fingerprint was first introduced in the European Wind Atlas (Troen and Petersen, 1989). The purpose of these graphical presentations of wind data given at the end of each national section in the Atlas is to give a compact and informative overview of the wind data used for the Atlas, an example is shown in Fig. 1. The first line states the name of the meteorological station and the period over which the data were collected. This is followed by the height above ground level where measurements were taken, the mean value, the standard deviation and the mean value of the cube of the measured wind speeds. The graphical presentation consists of five graphs, described below.

### 2.1 The mean year

The average seasonal variation of the measured wind speed (full line) and cube of wind speed (dashed line) is shown in the top left graph. All data associated with the same calendar month are averaged and the results plotted at the midpoint in each of the indicated monthly intervals. The unit on the ordinate is  $\text{m s}^{-1}$  for mean speeds and  $\text{m}^3\text{s}^{-3}$  for the mean of the cube of the wind speed. Values read from the graph must be multiplied by the scale factor given to the right. The continuous curves are obtained by interpolation using a periodic cubic spline. The speed data are also contained in the tables on the station description pages.

### 2.2 The mean days

The average daily variation of the measured wind speed for the months of January and July is shown in the top right graph. The average hourly variation of wind speed is shown in full lines for January and July and for the cube of wind speed dashed lines are used. Data from all months of January (July) associated with the same time of day are averaged. Results obtained for each of the indicated standard hours are plotted using an interpolating smooth curve (periodic cubic spline). The mean ordinate for each curve is identical to the ordinate on the corresponding mean year curve (top left graph) at the January (July) points. The unit on the ordinate is  $\text{m s}^{-1}$  for mean speeds and  $\text{m}^3\text{s}^{-3}$  for the mean of the cube of speed. Values read from the graph must be multiplied by the scale factor given to the left. Mean days for each calendar month are calculated and define – for each calendar month – a mean or reference day which is used as reference in calculating the spectrum below. The speed values are contained in the tables in the station descriptions.

### 2.3 The wind rose

The relative frequencies of winds coming from each of twelve sectors are shown in the middle left graph as the radial extent of the circle segments spanning the sectors (thick lines). The contribution from each sector to the total mean speed and to the total mean cube of speed are given as the narrower segments and the central segments respectively. For each quantity the normalization is such that the largest segment extends to the outer dotted circle. The corresponding value for each of the three quantities is given in the small box in per cent (numbers given to the nearest integer). The inner dotted circle corresponds to half of this value.

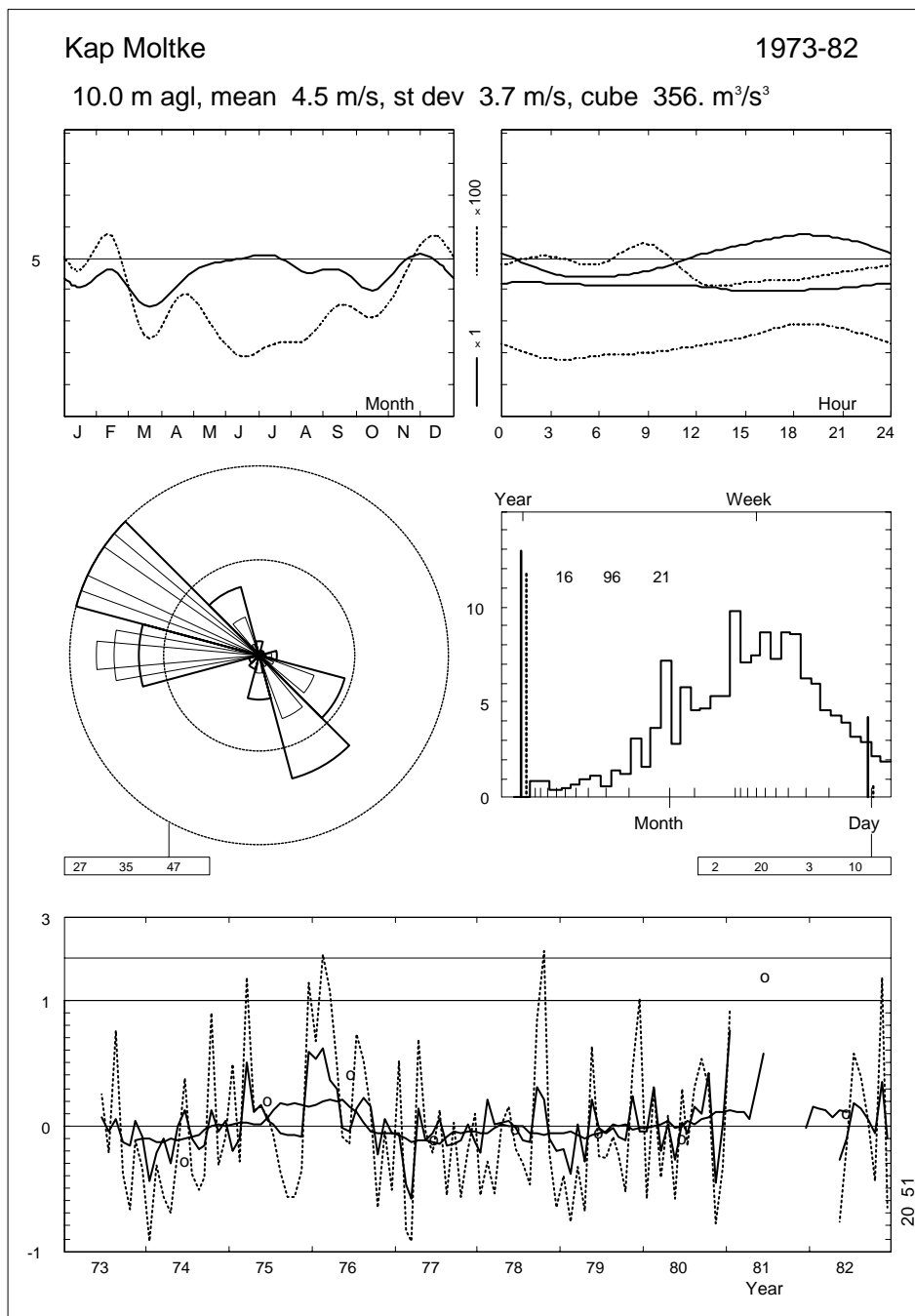


Figure 1. The wind climatological fingerprint. Data from the Kap Moltke station in NE-Greenland by courtesy of E. Knuth.

## 2.4 The spectrum

The contribution to the total variance of wind speed for a range of periods is shown by the full curve in the middle right graph. The vertical scale is arbitrarily adjusted to centre the curve. The abscissa gives the periods on a logarithmic scale. The curve is calculated from the total time series by first subtracting the monthly mean day values from each day data, hour by hour. The monthly mean days for all twelve months were calculated as described for January and July above. The mean days are in this context considered deterministic in contrast to the calculated time series of deviations which



form the stochastic part. This is followed by a Fourier transform of the deviations and the spectral estimates are squared and block averaged over bands of equal relative bandwidth corresponding to the widths of the steps in the curve.

The full vertical bar on the left side gives the contribution to the standard deviation of wind speed in the whole set of data from periods which fit into one year. This is calculated as the standard deviation of the *mean year* (top left). The adjacent dashed bar gives similarly the mean year contribution to the standard deviation of the cube of wind speed. Units are per cent of the total standard deviation of the data. Similarly the bars on the right give the contributions to the standard deviations of speed and cube of speed by periods which fit into one day, ie 24, 12, 8 and 6 hours in the present case of basic 3-hourly data. The numbers listed at the top left inside the graph are the contribution to the total standard deviation in per cent by the random variations contained in the variance spectrum, divided into the part with periods longer than one year, periods between one year and one day, and periods smaller than one day (the sum of squares of the contributions of the three random parts together with the contributions from the deterministic mean year and mean day adds to unity). The numbers in the small box below the graph give the relative standard deviation for speed and cube of speed for the mean January day (first two numbers) and the mean July day (last two numbers).

## 2.5 The time print

The month-by-month relative deviation from the mean months is shown in the bottom graph. For each month the average speed and cube of speed is calculated and the expected value from the corresponding calendar month in the *mean year* (top left) is subtracted. The relative deviation is shown by the jagged lines - full line corresponding to speed and dashed line corresponding to cube of speed. The smoother full line shows the year-by-year relative deviation of mean speed from the total average. Each point on this curve gives the relative deviation in the period extending backwards and forwards one half year (centred block averages). The centre value for each calendar year thus gives the deviation for that particular year. The open circles show similarly the relative deviation of the mean cube of speed for each calendar year. The numbers to the right give the root mean square of the calendar year deviations in per cent for speed (lower number) and cube of speed (upper number). The vertical scale is linear from  $-1$  to  $+1$ , and shifts at  $+1$  to a coarser linear scale which is adjusted to accommodate the largest deviations.

## 2.6 Running the program

The program is invoked by typing its name at the prompt in a Command Prompt window, with the following five command line arguments:

```
finger <data file> <height> <heading> <plot type> <plot file> [<options>]
```

The command line arguments and options are also shown if the program is started with a question mark 'finger -?'. The meaning of each of the command line arguments is described below.

### Data file

The data file is the input file containing the time-series to be processed. The name of the file is any valid file name, including specification of disk drive,

path etc:

$\langle data\ file \rangle = [\langle drive \rangle][\langle path \rangle]\langle file\ name \rangle[\langle ext \rangle]$

The file must contain observations of wind speed and direction - one observation per file record - as well as information on the observation time in ASCII (plain text) format. The specific format of the file records is specified in the file `format.dat`, which should reside in the same directory as the executable file, eg:

```
'(4f2.0,f5.1,f4.0)'    NEEDS '(')' TO DELIMIT STRING OR '*'
1      TIME IN SEPARATE VALUES (OTHERWISE 0 (NO))
0      NOT USED HERE          (OTHERWISE POSITION OF TIME)
1      YEAR IS FIRST VALUE    (OTHERWISE DIGITS IN YEAR)
2      MONTH IS SECOND VALUE  (OTHERWISE DIGITS IN MONTH)
3      DAY IS THIRD VALUE     (OTHERWISE DIGITS IN DAY)
4      HOUR IS FOURTH VALUE   (OTHERWISE DIGITS IN HOUR)
0      MIN IS NOT AVAILABLE   (OTHERWISE DIGITS IN MIN)
5      SPEED IS FIFTH VALUE
6      DIRECTION IS SIXTH VALUE
0      NUMBER OF LINES IN HEADER (SKIPPED)
1.0    SPEED FACTOR (SPEED IS IN 0.1 M/S)
0.0    SPEED OFFSET
1.0    DIRECTION FACTOR (DIRECTION IS IN DEGREES)
0.0    DIRECTION OFFSET
6      COUNT OF ARGUMENTS IN FORMAT OR LIST (LINE #1)
```

This format description corresponds to the following format of the data file (YYMMHHMMUUUDDD):

```
83010100  5.0 239
83010103  4.1 214
83010106  4.1 207
83010109  4.3 213
83010112  5.5 238
...
```

The meaning of each of the lines in the file `FORMAT.DAT` is given below.

**Data file format** Line 1 contains a valid Fortran format string containing only floating point format specifiers, eg `f2.0` for a two-digit integer and `f5.1` for a real number occupying 5 spaces and with one digit after the decimal point. The format string must be enclosed in single quotation marks and parentheses: `'(format string)'`. Alternatively, the format string can be specified as a single asterisk, `'*'`, which specifies a list read (free format) where the all numbers are separated by space(s) or comma(s).

**Time group argument** Line 2 must be either 1 or 0 (zero). The value 0 indicates that the time is given in a single value, typically as `YYYYMMDDHHMM`. The value 1 indicates that year, month, day, hour and minutes are given in separate values in the format string (and data file).

**Time positioning arguments** These arguments depend on the time group argument. Below is a description of the interpretation of each argument according to the two valid values of the time group argument:

#	Time group argument	0 = single value	1 = separate values
3	Time group position	Position in format/list of the time group	Can be any valid integer value. The value is not used.
4	Year position/length	Number of digits in the year given in the time group. Typically 2 or 4.	Position of the year argument in the format/list.
5	Month position/length	Number of digits in the month given in the time group. Almost always 2.	Position of the month argument in the format/list.
6	Day position/length	Number of digits in the day given in the time group. Almost always 2.	Position of the day argument in the format/list.
7	Hour position/length	Number of digits in the hour given in the time group. Almost always 2.	Position of the hour argument in the format/list.
8	Minute position/length	Number of digits in the minute given in the time group. If seconds is given in the time group, the digits of these must be included. Typically 2 or 4.	Value must be present but is not needed.

**Speed position argument** The position of the wind speed value in the format statement/list.

**Direction position argument** The position of the wind direction in the format statement/list.

**Header length argument** The number of lines to skip at the beginning of the data file.

**Speed factor and offset arguments** The program offers the possibility of scaling the wind speeds linearly if the measurements are not given in  $\text{m s}^{-1}$  or if the data need to be re-calibrated. The scaling factor and offset are applied in the following way:

$$U_{\text{new}} = \langle \text{scaling factor} \rangle \times U_{\text{raw}} + \langle \text{offset} \rangle \quad (1)$$

where  $U$  represents wind speed and  $U_{\text{raw}}$  is the speed value given in the data file.

**Direction factor argument** Likewise, the wind directions may be scaled linearly if the measurements are not given in degrees or if the data need to be re-calibrated – eg to take the magnetic declination into account. The scaling factor and offset are applied in the following way:

$$D_{\text{new}} = \langle \text{scaling factor} \rangle \times D_{\text{raw}} + \langle \text{offset} \rangle \quad (2)$$

where  $D$  represents wind direction and  $D_{\text{raw}}$  is the direction value given in the data file.

**Argument count argument** Gives the number of arguments in the format statement/list.

### Anemometer height

The anemometer height in meters above ground level is given as command line argument number two, eg 10.0.

## Text heading

The heading on the fingerprint plot is given as command line argument number three. The text must be delimited by single quotation marks, eg 'Waspdale Airport'.

## Plot type

The plot type is given as command line argument number four. The following plot types are valid: POST for PostScript file or PLT for Grapher/Surfer PLT-file. If PLT is chosen the two pens used to plot the fingerprint are specified in the file `plt.dat`.

## Plot file

The name of the output plot file is given as command line argument number five, eg `FILENAME.EPS` for a Postscript plot or `FILENAME.PLT` for a Grapher/Surfer plot file.

## Options

The five command line arguments may be followed by one or more options: `/U=xx.x` sets the discretization bin width for wind speed (also called the randomization speed), `/D=xx.x` sets the discretization bin width for wind direction (or the randomization direction) and `/P=xxyy` sets the period to be processed and plotted to 19xx-19yy. The WASP help facility describes the problem of data discretization in more detail.

The following examples are thus valid command lines when invoking the program:

```
FINGER rawdata.dat 10.0 'Waspdale' POST rawdata.ps
FINGER spro8493.dat 69.7 'Sprogoe' PLT spro8493.plt
FINGER wind.dat 10.0 'Anholt' POST anholt.ps /U=0.5144 /D=11.25 /P=6271
```

## 2.7 Output files

The program produces three output files: the plot file, the so-called DYV-file, which contains mean wind speeds as a function of month in the year and hour of the day (Fig. 2), and the so-called LYV-file, which contains mean wind speeds as a function of month in the year for all the years processed (Fig. 3). The DYV and LYV files can further be transformed into  $\LaTeX$  code using the `dyv2tex` program.

The mean speed values in Figs. 2-3 are calculated from observations where the wind speed is between 0 and  $90 \text{ ms}^{-1}$  and the direction is between 0 and  $360^\circ$ . Observations where the wind speed is zero  $\text{ms}^{-1}$  are considered calms and a random wind direction in the interval  $0-360^\circ$  is used. Wind directions in the interval  $-180^\circ$  to  $360^\circ + 180^\circ$  are transformed and used; directions outside this interval are considered erroneous. As always, it is safe to use 99.9 and 999 as dummy values for wind speed and direction, respectively.

Note, that the daily, monthly and/or yearly values listed in Figs. 2 and 3 below may not always be representative. The mean values represent the data actually measured and no weighting has been applied to account for missing data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	4.2	4.6	3.4	3.8	4.9	5.2	5.2	4.6	4.7	3.9	5.0	4.7	4.6
1	4.2	4.7	3.5	3.8	4.7	5.0	4.9	4.5	4.5	3.9	4.9	4.8	4.5
2	4.2	4.7	3.5	3.7	4.5	4.9	4.7	4.4	4.4	3.9	4.9	4.8	4.4
3	4.2	4.8	3.5	3.7	4.5	4.7	4.5	4.1	4.4	4.0	4.9	4.8	4.4
4	4.1	4.8	3.5	3.8	4.5	4.5	4.5	3.9	4.4	4.0	5.0	4.8	4.3
5	4.2	4.8	3.4	4.1	4.4	4.5	4.4	3.9	4.3	4.0	4.9	4.8	4.3
6	4.1	4.8	3.4	4.2	4.4	4.5	4.4	4.0	4.4	3.9	4.9	4.9	4.3
7	4.2	4.7	3.5	4.2	4.5	4.5	4.5	4.1	4.5	4.0	4.9	4.9	4.4
8	4.1	4.6	3.5	4.3	4.6	4.5	4.5	4.1	4.5	4.0	4.9	4.9	4.4
9	4.2	4.4	3.6	4.3	4.6	4.5	4.6	4.2	4.7	4.0	4.9	5.1	4.4
10	4.2	4.5	3.6	4.3	4.6	4.6	4.8	4.3	4.8	4.2	4.9	5.1	4.5
11	4.1	4.4	3.5	4.4	4.7	4.7	5.0	4.5	4.8	4.2	4.9	5.1	4.6
12	4.1	4.4	3.6	4.3	4.8	4.8	5.1	4.6	4.7	4.0	4.9	5.1	4.6
13	4.1	4.5	3.6	4.3	4.9	4.8	5.2	4.6	4.7	3.9	4.9	5.0	4.6
14	4.0	4.5	3.7	4.3	4.9	5.0	5.3	4.7	4.7	3.9	4.9	5.1	4.6
15	4.0	4.5	3.7	4.4	4.9	5.2	5.5	4.9	4.8	3.9	5.0	5.1	4.7
16	3.8	4.5	3.7	4.5	5.1	5.3	5.6	5.0	4.7	4.0	5.0	4.9	4.7
17	4.0	4.6	3.6	4.4	5.2	5.5	5.7	5.1	4.8	4.0	4.9	5.0	4.8
18	4.0	4.7	3.5	4.4	5.3	5.5	5.7	5.1	4.8	4.0	5.0	4.9	4.8
19	4.0	4.7	3.5	4.3	5.2	5.6	5.7	5.1	4.8	4.0	5.0	4.8	4.7
20	4.0	4.7	3.5	4.2	5.2	5.6	5.7	5.0	4.7	4.0	5.0	4.7	4.7
21	4.1	4.7	3.5	4.1	5.2	5.6	5.6	5.0	4.6	4.0	4.9	4.8	4.7
22	4.1	4.8	3.4	4.1	5.1	5.4	5.4	4.8	4.7	4.0	5.0	4.8	4.7
23	4.0	4.8	3.4	4.0	5.1	5.3	5.3	4.7	4.7	4.0	4.9	4.8	4.6
Mean	4.1	4.6	3.5	4.2	4.8	5.0	5.1	4.6	4.6	4.0	4.9	4.9	4.5

Figure 2. The daily and yearly variation of mean wind speed contained in the DYV-file.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1973	—	—	—	—	—	5.3	4.9	4.8	4.0	3.3	5.1	4.5	4.5
1974	2.3	3.6	3.1	2.9	4.8	5.6	4.6	3.7	3.9	4.5	4.7	5.1	4.1
1975	3.3	4.2	5.3	4.6	5.6	5.2	5.1	4.3	4.3	3.7	4.5	7.8	4.8
1976	6.3	7.5	4.8	5.4	4.8	4.7	5.8	5.6	5.3	3.1	5.2	4.6	5.2
1977	3.9	2.4	1.5	4.8	4.3	4.7	5.3	3.8	4.0	3.6	5.0	4.2	4.0
1978	3.2	5.6	3.5	4.3	5.0	4.9	4.5	3.9	6.0	4.9	4.4	3.9	4.5
1979	3.3	2.9	3.6	3.0	5.8	4.9	4.8	4.5	4.2	3.5	6.1	4.7	4.3
1980	3.9	6.0	2.8	4.2	3.5	5.2	4.8	5.3	5.0	5.7	2.7	5.0	4.5
1981	7.2	—	—	—	—	—	—	—	—	—	—	—	7.2
1982	—	—	—	—	3.5	4.5	6.0	5.2	4.9	3.7	6.6	4.4	5.0
Mean	4.1	4.6	3.5	4.2	4.8	5.0	5.1	4.6	4.6	4.0	4.9	4.9	4.5

Figure 3. The yearly and interannual variation of mean wind speed contained in the LYV-file. Months with no data are marked —.

## 3 Plotting the wind distributions

The purpose of the program `tab2dat` is to transform a WASP Observed Wind Climate (TAB) file into three data files, `rose.dat`, `hist.dat` and `sect.dat`, which can be used to plot the wind rose and distributions of wind speed (total and sector-wise). The plots can be made using either the Grapher files `rose.grf`, `hist.grf` and `sect.grf` - which are generated automatically by the program - or most other general purpose plotting program for  $x$ - $y$  graphs.

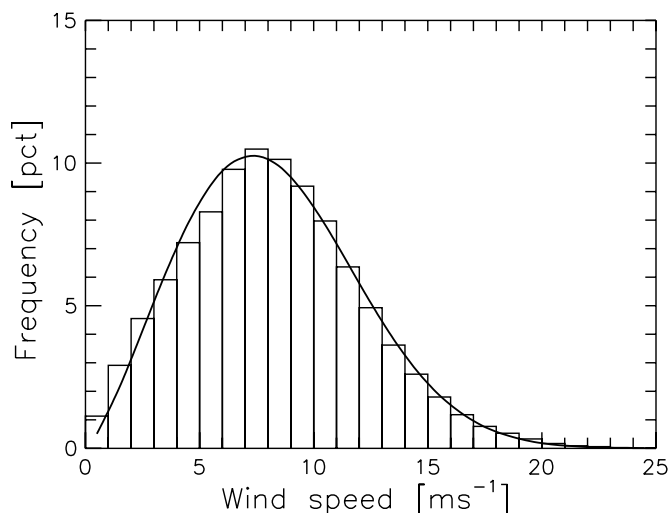
The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the TAB-file as argument:

```
TAB2DAT [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<file name>*[*<ext>*]. If neither *<filespec>* nor *<options>* are given the program will run interactively; note, that some options are not available in this mode. A summary of command line arguments is shown if the program is started with a question mark '`tab2dat -?`'.

### 3.1 The histogram

To view and plot the total distribution of wind speeds start the Grapher program and load `HIST.GRF`. Press `<F2>` to view the graph. Note, that the  $x$ - and  $y$ -axes are scaled automatically according to the histogram in question. However, this and other characteristics of the graph may be changed by the user and saved in a different graph file, see also Section 3.3 below.



*Figure 4. Distribution of wind speeds in the processed time-series. A Weibull distribution function has been fitted to the data. The graph was plotted using the Grapher program.*

The Weibull distribution function is fitted using the exact same procedure as the one used in WASP, ie the fit is weighted on the higher wind speeds.

The distribution of wind speeds in each of the sectors can be viewed and plotted using the `sect.grf` graph file. The distribution in the north sector, ie from  $345^\circ$  to  $015^\circ$ , is shown as default; but by changing the columns to plot, other sectors can be viewed and plotted as well. The correspondence between Grapher column labels and sectors is:

Sector	Angle	Columns	Sector	Angle	Columns
1	0	B C	7	180	N O
2	30	D E	8	210	P Q
3	60	F G	9	240	R S
4	90	H I	10	270	T U
5	120	J K	11	300	V W
6	150	L M	12	330	X Y

The first column listed above is the observed frequency, the second contains the Weibull-fitted value. The wind speed values ( $x$ -coordinate) are listed in the first (A) column.

## 3.2 The wind rose

Start the Grapher program and load ROSE.GRF. Press  $\langle F2 \rangle$  to view the wind rose. The  $x$ - and  $y$ -axes, as well as any other characteristic of the graph, may be changed by the user and saved in a different graph file.

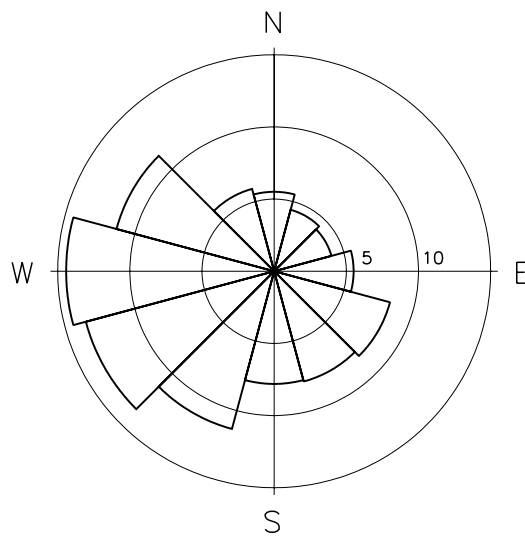


Figure 5. Sector-wise distribution of winds in the processed time-series. The circles are drawn at 5% intervals. The graph was plotted using the Grapher program.

## 3.3 Options

The program can be invoked with one or more options - separated by blank characters - in the command line:

- h# The Grapher pen numbers used for the histogram. Default values are pens 3 and 4, corresponding to -h3,4. The two pen numbers must be separated by a comma.
- j Plot joint distributions of wind speed and direction in the wind rose, see Fig. 6. The distribution of wind speeds,  $U$ , in each sector are shown in four classes:  $0 \leq U < 3$ ,  $3 \leq U < 6$ ,  $6 \leq U < 9$ ,  $9 \leq U \text{ ms}^{-1}$ .
- l Write the TAB-file summary in  $\text{\LaTeX}$  format for inclusion into a  $\text{\LaTeX}$  document. The formatting of the table is given in the file wasp.sty. Default is a standard text file, see Section 3.5 below.

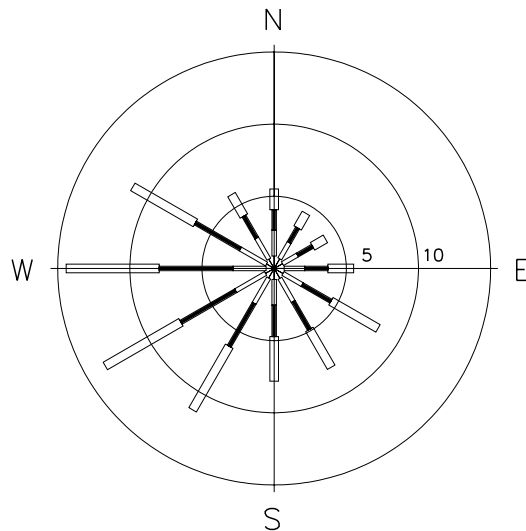


Figure 6. Joint distribution of wind speed and direction in the processed time-series. The circles are drawn at 5% intervals. The graph was plotted using the Grapher program.

- o Only the total distribution of wind speeds and the wind rose are calculated. Note, that this option is implemented as a command line argument only - it cannot be used in interactive mode.
- r# The Grapher pen numbers used for the wind rose. Default values are pens 1, 3 and 4, corresponding to -r1, 3, 4. The three pen numbers must be separated by commas.
- s Make a separate GRF-file for each sector. The files are named SECT000.GRF-SECT330.GRF (with 12 sectors) and may be viewed and plotted one at a time or combined into a single plot, see Fig. 7. This option also works with 8 and 16 sectors.
- t Choose alternative layout for the TAB-file summary table. This layout is available both as a simple ASCII table (-t) or in  $\LaTeX$  format (-t -1). All the wind speed classes present in the TAB-file are listed and the mean wind speed and mean power density contribution for each sector are also calculated.
- w Convert any previous TAB-file to the default WAsP for Windows format; converted file has default extension OWC.
- x# User-specified axis limits when plotting the wind rose and histogram using Grapher. The command line option *must* specify three numbers, ie -x#1,#2,#3, separated by commas. The numbers are: #1 is the maximum frequency in the wind rose plot [%], #2 is the maximum wind speed in the histogram plot [ $\text{ms}^{-1}$ ], and #3 is the maximum frequency in histogram plot [%].
- ' Add text heading to plot(s). If an opening single quotation mark is specified only, eg -', a default heading is used, corresponding to the text in the first line of the histogram file. If a closing single quotation mark is specified as well, eg -'Hurghada 1991-94', the entire text between the single quotation marks is used as heading.

The slash may be used instead of the hyphen, eg /j, /L, /s, /H1, 5, /r4, 8, 12, /X30, 20, 20, and /' are valid options. If only one pen number is specified all



pens will be assigned this value. Pen #1 is used for the axes and %-circles, pen #2 for the text and pen #3 for the rose itself.

### 3.4 Screen output

The following characteristics of the overall mean wind climate is printed directly on the screen when running `tab2dat`:

Mean wind vector:

<Direction> [deg] = 241.160      <Magnitude> [m/s] = 3.01223

Mean Weibull parameters, wind speed and power density:

A= 9.17718      k= 2.27051      <U>= 8.12913      <E>= 559.582

### 3.5 Output files

The file `hist.dat` contains data for the total histogram plot. Column one of this file is wind speed [ $\text{ms}^{-1}$ ], column two is observed frequency [pct] and column three is the corresponding Weibull fit. The file `sect.dat` contains the same information for each sector - the format was given above (Section 3.1).

The file `<filename>.TXT` contains a summary of the TAB-file - corresponding to the data summary given by WASP 4/5, see Fig. 8. If the `-l` option is used, the same table can be included directly in a  $\text{\LaTeX}$  document, see Fig. 9.

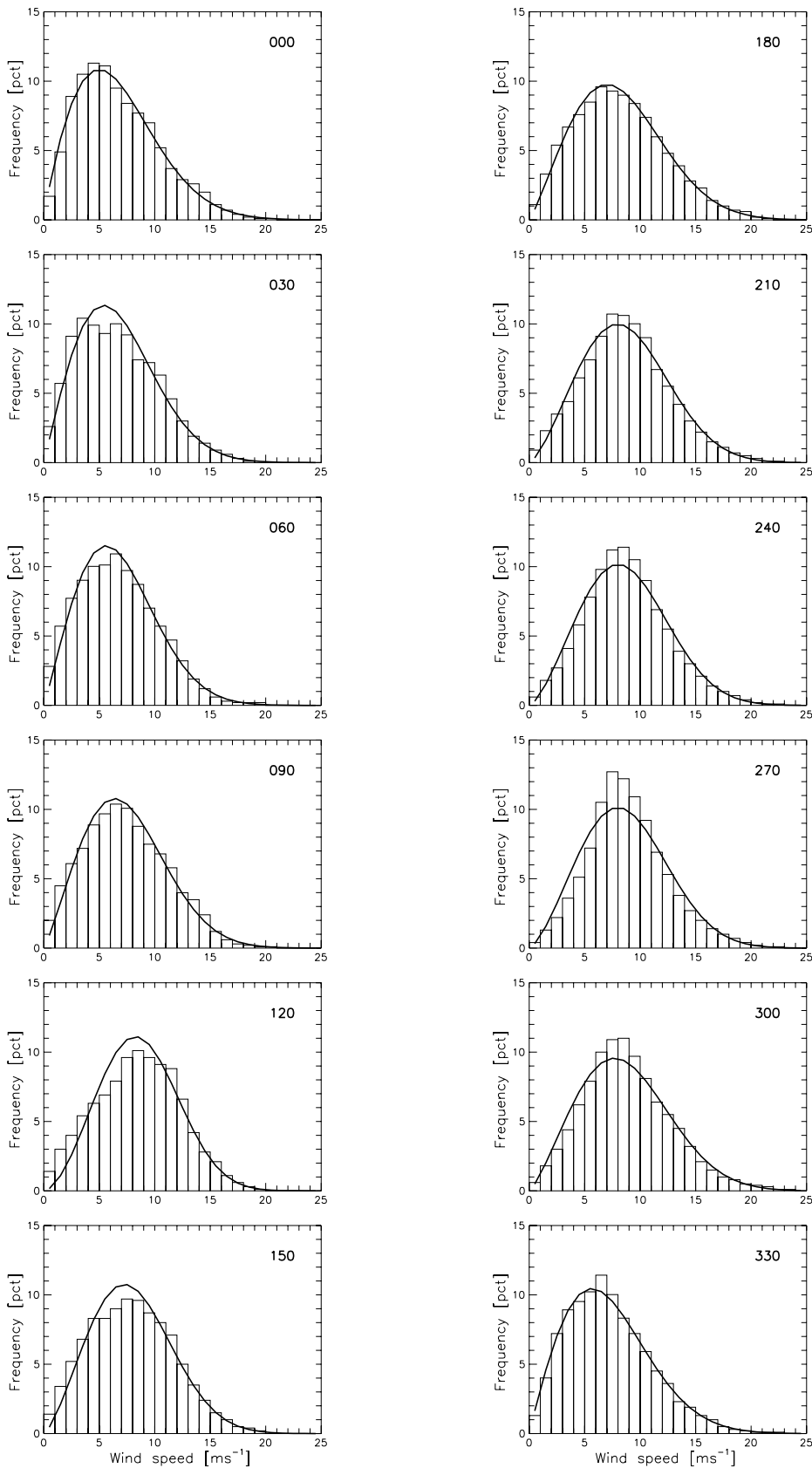


Figure 7. The wind speed distributions of all sectors. Twelve GRF files were generated using the `-s` option (and `-h2,3`), then combined in a batch file, `SECTORS.BAT`, and finally plotted using the *Grapher* program.

Sect	Freq	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A	k
0	5.0	17	51	94	117	130	112	86	80	63	100	73	52	18	7	7.3	1.72
30	3.8	29	60	110	120	114	101	105	92	66	113	53	21	13	4	6.9	1.89
60	3.4	33	63	76	100	124	118	127	115	98	95	33	10	6	1	6.9	2.31
90	4.9	22	56	71	88	98	92	89	89	81	157	86	49	13	8	8.2	2.11
120	7.2	16	34	41	61	74	79	88	109	112	189	138	43	12	3	9.1	2.84
150	7.4	13	32	48	67	88	96	108	111	112	161	91	46	21	7	8.7	2.40
180	8.0	7	29	46	61	84	104	118	106	95	161	88	49	33	19	8.8	2.13
210	12.3	4	19	32	44	63	81	99	115	105	190	121	62	34	31	9.8	2.33
240	15.2	3	16	22	35	53	81	105	117	115	187	130	75	34	29	9.9	2.40
270	14.2	4	13	20	37	47	76	109	133	119	190	128	65	33	25	9.8	2.44
300	12.2	4	15	29	43	59	77	105	117	112	166	122	80	40	32	9.8	2.23
330	6.3	9	38	70	94	95	109	119	102	79	123	77	45	25	15	8.1	1.90
Total	100.0	9	28	43	60	74	88	105	112	103	166	107	57	28			
20	9.2	2.27															

Figure 8. Summary table of the TAB-file.

Sect	Freq	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A	k
0	5.0	17	51	94	117	130	112	86	80	63	100	73	52	18	7	7.3	1.72
30	3.8	29	60	110	120	114	101	105	92	66	113	53	21	13	4	6.9	1.89
60	3.4	33	63	76	100	124	118	127	115	98	95	33	10	6	1	6.9	2.31
90	4.9	22	56	71	88	98	92	89	89	81	157	86	49	13	8	8.2	2.11
120	7.2	16	34	41	61	74	79	88	109	112	189	138	43	12	3	9.1	2.84
150	7.4	13	32	48	67	88	96	108	111	112	161	91	46	21	7	8.7	2.40
180	8.0	7	29	46	61	84	104	118	106	95	161	88	49	33	19	8.8	2.13
210	12.3	4	19	32	44	63	81	99	115	105	190	121	62	34	31	9.8	2.33
240	15.2	3	16	22	35	53	81	105	117	115	187	130	75	34	29	9.9	2.40
270	14.2	4	13	20	37	47	76	109	133	119	190	128	65	33	25	9.8	2.44
300	12.2	4	15	29	43	59	77	105	117	112	166	122	80	40	32	9.8	2.23
330	6.3	9	38	70	94	95	109	119	102	79	123	77	45	25	15	8.1	1.90
Total	100.0	9	28	43	60	74	88	105	112	103	166	107	57	28	20	9.2	2.27

Figure 9. Summary table of the TAB-file printed with the L<sup>A</sup>T<sub>E</sub>X text formatting software (option -1).

U	0	30	60	90	120	150	180	210	240	270	300	330	
1	17	29	33	22	16	13	7	4	3	4	4	9	9
2	51	60	63	56	34	32	29	19	16	13	15	38	28
3	94	110	76	71	41	48	46	32	22	20	29	70	43
4	117	120	100	88	61	67	61	44	35	37	43	94	60
5	130	114	124	98	74	88	84	63	53	47	59	95	74
6	112	101	118	92	79	96	104	81	81	76	77	109	88
7	86	105	127	89	88	108	118	99	105	109	105	119	105
8	80	92	115	89	109	111	106	115	117	133	117	102	112
9	63	66	98	81	112	112	95	105	115	119	112	79	103
10	56	61	67	83	104	86	89	100	102	102	92	70	90
11	44	52	28	74	85	75	72	90	86	88	74	53	75
12	40	36	20	51	79	55	53	67	70	69	62	42	59
13	33	17	13	35	59	36	35	54	60	59	60	35	48
14	30	12	7	28	27	23	27	37	43	39	47	26	33
15	22	9	3	21	16	23	22	25	32	26	33	19	24
16	11	8	2	8	8	11	20	20	21	19	23	13	16
17	7	5	4	5	4	10	13	14	13	14	17	12	12
18	4	3	1	3	3	5	8	10	10	11	11	7	8
19	2	1	0	2	0	2	5	7	7	8	8	3	5
20	1	0	0	1	0	0	3	5	5	4	5	2	3
21	0	0	0	1	0	0	2	4	2	1	4	1	2
22	0	0	0	1	0	0	1	2	2	1	2	1	1
23	0	0	0	0	0	0	0	2	1	0	1	1	1
24	0	0	0	0	0	0	0	1	1	0	1	0	0
25	0	0	0	0	0	0	0	0	1	0	0	0	0
A	7.3	6.9	6.9	8.2	9.1	8.7	8.8	9.8	9.9	9.8	9.8	8.1	9.2
k	1.72	1.89	2.31	2.11	2.84	2.40	2.13	2.33	2.40	2.44	2.23	1.90	2.27
U	6.5	6.2	6.1	7.2	8.1	7.7	7.8	8.7	8.8	8.7	8.7	7.1	8.1
E	19	11	8	21	34	34	42	82	104	92	86	28	560
Freq	5.0	3.8	3.4	4.9	7.2	7.4	8.0	12.3	15.2	14.2	12.2	6.3	

Figure 10. Summary table of the TAB-file printed with option -t.

U	0	30	60	90	120	150	180	210	240	270	300	330	All
1	17	29	33	22	16	13	7	4	3	4	4	9	9
2	51	60	63	56	34	32	29	19	16	13	15	38	28
3	94	110	76	71	41	48	46	32	22	20	29	70	43
4	117	120	100	88	61	67	61	44	35	37	43	94	60
5	130	114	124	98	74	88	84	63	53	47	59	95	74
6	112	101	118	92	79	96	104	81	81	76	77	109	88
7	86	105	127	89	88	108	118	99	105	109	105	119	105
8	80	92	115	89	109	111	106	115	117	133	117	102	112
9	63	66	98	81	112	112	95	105	115	119	112	79	103
10	56	61	67	83	104	86	89	100	102	102	92	70	90
11	44	52	28	74	85	75	72	90	86	88	74	53	75
12	40	36	20	51	79	55	53	67	70	69	62	42	59
13	33	17	13	35	59	36	35	54	60	59	60	35	48
14	30	12	7	28	27	23	27	37	43	39	47	26	33
15	22	9	3	21	16	23	22	25	32	26	33	19	24
16	11	8	2	8	8	11	20	20	21	19	23	13	16
17	7	5	4	5	4	10	13	14	13	14	17	12	12
18	4	3	1	3	3	5	8	10	10	11	11	7	8
19	2	1	0	2	0	2	5	7	7	8	8	3	5
20	1	0	0	1	0	0	3	5	5	4	5	2	3
21	0	0	0	1	0	0	2	4	2	1	4	1	2
22	0	0	0	1	0	0	1	2	2	1	2	1	1
23	0	0	0	0	0	0	0	2	1	0	1	1	1
24	0	0	0	0	0	0	0	1	1	0	1	0	0
25	0	0	0	0	0	0	0	0	1	0	0	0	0
A	7.3	6.9	6.9	8.2	9.1	8.7	8.8	9.8	9.9	9.8	9.8	8.1	9.2
k	1.72	1.89	2.31	2.11	2.84	2.40	2.13	2.33	2.40	2.44	2.23	1.90	2.27
U	6.5	6.2	6.1	7.2	8.1	7.7	7.8	8.7	8.8	8.7	8.7	7.1	8.1
E	19	11	8	21	34	34	42	82	104	92	86	28	560
Freq	5.0	3.8	3.4	4.9	7.2	7.4	8.0	12.3	15.2	14.2	12.2	6.3	100

Figure 11. Summary table of the TAB-file printed with options -t and -l.

## 4 Weibull statistics

The purpose of the `weibull` program is to calculate some simple characteristics of a Weibull distribution function, given the scale parameter  $A$  and the shape parameter  $k$ . The program is invoked by typing its name at the prompt in a Command Prompt window with the Weibull  $A$ - and  $k$ -parameters as arguments:

```
weibull [A k] [(options)]
```

A summary of command line arguments is shown if the program is invoked with a question mark '`weibull -?`'. The command-line options are:

- a# Air density. Default value:  $1.225 \text{ kg m}^{-3}$ . Use `density.exe` to calculate air density from elevation/altitude and air temperature.
- m# Power for calculation of  $m$ th moment of the Weibull distribution.
- d# Wind speed increment for calculation of the frequency table. Default value is  $1 \text{ ms}^{-1}$ .
- n# Minimum wind speed for calculation of the power density in the window  $u_n$  to  $u_x$ . Default value:  $0.0 \text{ ms}^{-1}$ .
- x# Maximum wind speed for calculation of the power density in the window  $u_n$  to  $u_x$ . Default value:  $25.0 \text{ ms}^{-1}$ .
- p<filespec> Name of WASP power curve file. Default extension is POW. This production is *not* corrected for the air density specified by the -a option.

The slash may be used instead of the hyphen and the program is not case-sensitive. The Weibull characteristics calculated are (Troen and Petersen, 1989):

$$\begin{aligned}
 \text{mean value: } & A\Gamma\left(1 + \frac{1}{k}\right) \\
 \text{mean square: } & A^2\Gamma\left(1 + \frac{2}{k}\right) \\
 \text{mean cube: } & A^3\Gamma\left(1 + \frac{3}{k}\right) \\
 \text{mean } m\text{th power: } & A^m\Gamma\left(1 + \frac{m}{k}\right) \\
 \text{variance: } & A^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right] \\
 \text{modal value: } & A\left(\frac{k-1}{k}\right)^{1/k} \\
 \text{median: } & A(\ln 2)^{1/k}
 \end{aligned} \tag{3}$$

Furthermore, the available wind power density,  $E$ , is calculated. This is proportional to the mean cube of the wind speed:

$$E = \frac{1}{2}\rho A^3\Gamma\left(1 + \frac{3}{k}\right) \tag{4}$$

where  $E$  is power density ( $\text{Wm}^{-2}$ ) and  $\rho$  is air density,  $\sim 1.225 \text{ kg m}^{-3}$  for a temperature of  $15^\circ\text{C}$  and a standard sea level pressure of  $1013.25 \text{ hPa}$ . The results of running the program are written to the screen with seven significant digits, as shown in Fig. 12.

```

Weibull A-parameter = 7.300000 [m/s]
Weibull k-parameter = 2.280000

    Mean value = 6.466578 [m/s]
    Mean square = 50.84700 [m^2/s^2]
    Mean cube = 458.2222 [m^3/s^3]
    Mean 4th = 4583.912 [m^4/s^4]
    Variance = 9.030381 [m^2/s^2]
Standard deviation = 3.005059 [m/s]
    Modal value = 5.667034 [m/s]
    Median = 6.215978 [m/s]

    Air density = 1.225000 [kg/m^3]
    Total power density = 280.6611 [W/m^2]
    Max. power wind speed = 9.622390 [m/s]

Window power density = 280.6597 [W/m^2]
fraction of total = 0.9999951
in window from = 0.000000E+00to 25.00000 [m/s]

Power production = 1.0957919E+09 [Wh/y]

```

Figure 12. The results displayed on the screen when running weibull with the command line: weibull 7.3 2.28 -m4 -pv39-600.

The Max. power wind speed in Fig. 12 is the wind speed at which the highest power density is available, and is given by:

$$u_m = A \left( \frac{k+2}{k} \right)^{1/k} \quad (5)$$

In addition to the results written on the screen, a table containing corresponding values of  $U$  ( $\text{ms}^{-1}$ ),  $f(U)$  (in %), and  $F(U)$  (also in %) is written to the file WEIBULL.DAT, see Fig. 13.

The Weibull distribution,  $f(U)$ , is the frequency of occurrence of wind speed  $U$  and is given by:

$$f(U) = \frac{k}{A} \left( \frac{U}{A} \right)^{k-1} \exp \left( - \left( \frac{U}{A} \right)^k \right) \quad (6)$$

The frequencies  $f(u)$  are given as the frequency of occurrence for each speed interval  $\Delta u$ , and will thus add up to 100.

The cumulative Weibull distribution,  $F(U)$ , is the probability of the wind speed exceeding the value  $U$  and is given by:

$$F(U) = \exp \left( - \left( \frac{U}{A} \right)^k \right) \quad (7)$$

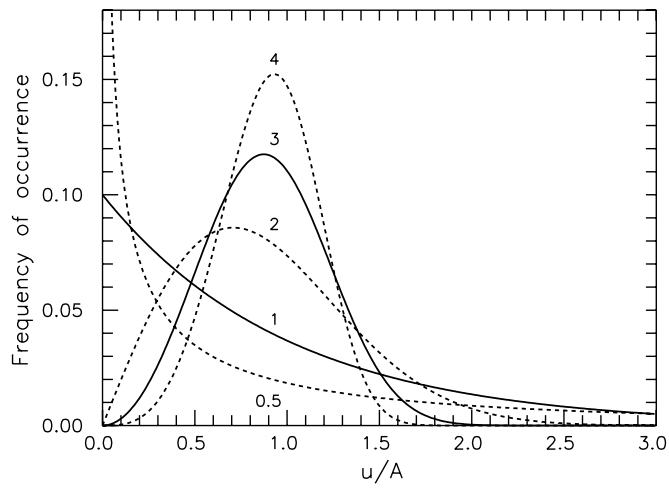


Figure 13. The shape of the Weibull distribution function for different values of the shape parameter  $k$  (0.5, 1, 2, 3, 4).

# 5 Map coordinate conversion

The purpose of the program UTM.EXE is to convert map coordinates from one coordinate system to another or to reformat a WASP map file. The following conversions are available:

1. Geographical latitude/longitude to UTM (ED50 or WGS84).
2. UTM to geographical latitude/longitude (ED50 or WGS84).
3. UTM zone 32 to UTM zone 33 (ED50 only).
4. UTM zone 33 to UTM zone 32 (ED50 only).
5. System 34 Jylland to UTM zone 32 (ED50 only).
6. Conversion of WASP map file.

The Universal Transverse Mercator (UTM) system is a Cartesian coordinate system in meters and therefore extremely well suited for WASP map files. Furthermore, it is used and printed on most recent topographical maps.

The conversions between geographical and UTM coordinates (1 and 2) are performed as described by Andersson and Poder (1981) and referenced to either European Datum 1950 (ED 50) or World Geodetic System 1984 (WGS 84). This limits the straightforward use of the program to countries using these datums. The datum setting is specified in the file UTM.CFG; the default value is ED50.

*Datum setting in  
UTM.CFG*

The conversions between UTM zones 32 and 33 (3 and 4) are of course only interesting if the area is divided by 12°E, like eg parts of Denmark and Germany. The conversion from "System 34 Jylland" to UTM zone 32 (5) is a local transformation for the western parts of Denmark.

## 5.1 Points, lists and maps

The program can be used to convert a single pair of coordinates, a free-format list (text file) of coordinate pairs, or an entire WASP map file.

### Converting one point

The conversion of one point is conveniently done by simply invoking the program at the DOS prompt and choose the appropriate transformation:

1: Latitude, longitude → UTM	5: System 34 Jylland → UTM 32
2: UTM → latitude, longitude	6:
3: UTM 32 → UTM 33	7:
4: UTM 33 → UTM 32	8: Convert WASP map file (ASCII)

The program will then prompt for the information needed, eg:

Enter latitude

In this interactive mode, geographical latitude and longitude may be entered as decimal degrees, degrees/decimal minutes, or degrees/minutes/decimal seconds, ie:

55.694833    55 41.69    55 41 41.4

Since latitude North and longitude East are considered positive, the coordinate above is either latitude North or longitude East. To specify latitude South or longitude West, the following notations may be used:



-55.694833 or 55 41.69 S or 55 41 -41.4  
-12.0895 or 12 5.37 W or 12 -5 22.2

If the degrees, minutes and/or seconds are negative, the latitude and longitude are considered South and West, respectively. Or, it may be flagged using 'S' or 's' for South and 'W' or 'w' for West.

The latitude and longitude of the meteorological tower at Risø (using ED50) are 55° 41.69' N and 12° 5.37' E, respectively. The corresponding UTM coordinates are displayed by the program as:

UTM 33 E 317070.4 m N 6176091.2 m

Here, the UTM zone is 33, the Easting is 317 070 meters, and the Northing is 6 176 091 meters.

### Converting a list or a map file

A free-format list (text file) of coordinates - or a WAsP map file - may be converted by invoking the program in the following way:

UTM *<batch mode>*

where *<batch mode>* is simply the number corresponding to the conversion in question, eg UTM 3 for UTM zone 32 to zone 33 transformation.

In batch mode, geographical latitude and longitude *must* be specified in decimal degrees. In free-format lists (text files) of coordinates, latitude must precede longitude in each line of the file, Easting must precede Northing, and numbers must be separated by spaces or commas in the file.

## 5.2 Converting a map file

Maps files were usually stored in binary format by WAsP 4/5, since these files are smaller and much faster to read and write than ASCII (text) files. However, to inspect the map file visually using a text editor - or if the map is to be used as input to the programs WAsP 6/8, *wgrid*, *biggrid* or *map2grd* - the map file must be stored in ASCII format from within WAsP (DOS versions), eg:

DUM\* [*<type>*]

where the optional *<type>* is either blank, ORO or ROU. These ASCII map files are stored in scaled Cartesian coordinates, ie the coordinates are given as numbers between -1 and +1, which are subsequently scaled by WAsP using the fixed points given in line 2 and 3 of the map file.

Occasionally, the unscaled coordinates of the height contour or roughness lines are needed. The program *utm.exe* contains an option to obtain the 'true' coordinates of the map. First, the map must be stored (dumped in WAsP 4/5) as an ASCII file. Next, the *utm* program is started from the prompt in the Command Prompt window; choose 'Convert WAsP map file (ASCII)' by entering the corresponding number of the menu. The program will then prompt for the names of the input map file and output map file, respectively. Furthermore, you may change the output format used. As an example, the program chooses 10I8 for UTM coordinates - ie 4 pair of coordinates per line. If you'd rather have one coordinate pair per line you can specify eg 2I8 or 2F10.1. The height contour interval can also be specified.

Finally, the program can write a *b1n-* or *xyz-*file, that can be input to Surfer. Using this option you can eg overlay the roughness lines on a contour map or surface generated by Surfer, or let Surfer make a grid of terrain heights.

## 6 Map file format conversions

In addition to the coordinate conversions described above – which may take standard WASP map files as input – the contour line coordinates and elevations may also be given in file formats other than the WASP map file format. This chapter describes how to convert *bna* and *dxf* files to WASP map files.

### 6.1 Maps stored in BNA files

Golden Software's *Didger* is an example of a digitizing program designed to run under Windows. With *Didger*, you can digitize points, polylines, and polygons off paper maps and export this information to data files for use in other programs. One of the available export formats is the Atlas (*.bna*) file and the purpose of the *bna2map* program is to translate an Atlas *bna* file into a WASP map file that can be imported directly by the WASP program.

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the *bna*-file as command line argument:

```
bna2map [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[.*<ext>*] specifies the *bna*-file. The default *<ext>* is *bna*. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '*bna2map -?*'. The program can be invoked with the following options in the command line:

- f Convert the contour line heights from feet to meters, ie the contour line values of the *bna*-file are multiplied by 0.3048 to get a metric map file.
- i# Vertical contour line interval in meters, ie only height contours which are multiples of the specified interval value are extracted.
- p# Spot heights (elevations), which have been digitized as single points in *Didger*, are translated into circles with the specified radius (#, in meters).
- r#1, #2 Elevation range for extracted height contours, ie only contours with height values between #1 and #2 are extracted to the map file.
- t# Horizontal tolerance (#, in meters) when processing the contours. This option reduces the numbers of points in the contours, corresponding to the specified tolerance or accuracy.

The output file is a WASP map file in ASCII format – with the same *<filespec>* as the input file, but with the extension *map*. Any existing file with the same specification will be overwritten. Finally, the program displays a brief summary of the map file just established.

#### Using *Didger* with WASP

Both height contours and roughness lines can be digitized using *Didger* and they retain their characteristics when translated into a map file by the *bna2map* program. However, it is important to adhere to the following (arbitrary) convention: the elevation of a height contour should be given as the Primary ID and the two roughnesses as the secondary ID. In practice, the height value is then simply entered as one number (only) in the 'Primary ID' box and the roughnesses are entered as two numbers (only, and separated by a comma or one or more blanks) in the 'Secondary ID' box. The first roughness value

corresponds to the left-hand roughness and the second value to the right-hand roughness. One line may be a height contour and a roughness line at the same time (eg a coastline), in which case three numbers must be given: one in the 'Primary ID' box and two in the 'Secondary ID' box. Height contours and roughness lines may be digitized either as polylines (end points not connected) or as polygons (closed curves, end points connected). Spot heights may be digitized as single points. Lines and points with no values assigned will be skipped in the translation.

Didger records coordinate pairs continuously if the locator or mouse button is pressed while digitizing a line. Depending on the actual Didger settings this may lead to very many points in each line and thus fairly large *bna* and *map* files. The data can be reduced by specifying the tolerance (option *-t#*) when processing the map. Every point on a reduced line will be closer than the specified distance (tolerance) to the original line. Processing the *MAP* file with an accuracy of, say, 1 m, may greatly reduce the number of points and thus the size of the *MAP* file - without compromising the accuracy of the map significantly with respect to wind flow modelling. The *WASP* Map Editor also features a command, by which the maximum allowed error introduced by deleting points in contour and roughness lines can be specified.

## 6.2 Maps stored in DXF files

AutoCAD's *dxf*-file format (Drawing eXchange Format) has become a common format for exchange of line drawings between different programs, and several digital map suppliers use *dxf*-files as a means of storing and exchanging map data. Also, the height contours of a map can be exported to a *dxf*-file if AutoCAD is used to digitize the map.

The program transforms an ASCII *dxf*-file into a *WASP* map file that can be imported directly by *WASP*. The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the *dxf*-file as command line argument:

```
dx2map [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[.*<ext>*] specifies the *dxf*-file. The default *<ext>* is *dxf*. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '*dx2map -?*'. The program can be invoked with the following options in the command line:

- d#* Number of digits after decimal point in map coordinates; allows coordinates in decimal degrees to be handled as well.
- f* Convert the contour line heights from feet to meters, ie the contour line values of the *dxf*-file are multiplied by 0.3048 to get a metric map file.
- l* elevation or height contour value stored in 'layer name' - rather than 'primary z-coordinate' or 'height of object', which are the defaults.
- i#* Vertical contour line interval in meters, ie only contours which are multiples of the specified interval value are extracted.
- r#1, #2* Elevation range for extracted contours, ie only contours with height values between *#1* and *#2* are extracted to the map file.
- p* contours defined by pairs of coordinated points, ie with the AutoCad *LINE* command.

The output file is a WASP map file in ASCII format - with the same *<filespec>* as the input file, but with the extension *map*. Existing files with the same specification(s) will be overwritten. Finally, the program displays a brief summary of the map file just established.

### 6.3 Coastlines stored in DAT files

For application of WASP in offshore conditions, it is often sufficient for an initial estimate of the wind resource to use a simple map of the coastline in the area. This provides information on the distribution of land and water surfaces and the distance to the all important roughness change between these two classes.

Coastlines - as well as rivers and political boundaries - may be downloaded using the so-called Coastline Extractor, which is an Internet tool hosted by the National Geophysical Data Center (NGDC). One of the data sets provided is the World Vector Shoreline - the download and processing of these data are done in the following way:

1. Enter the geographical range of the area, specified in decimal degrees.
2. Choose the appropriate coastline data base, e.g. World Vector Shoreline (designed for 1:250,000).
3. Choose the 'ZIP' compression method for the extracted ASCII data.
4. Choose the 'Mapgen' format option.
5. Choose the 'GMT Plot' preview option.
6. Submit your request to extract the coastline data.

The Coastline Extractor will now show a preview of the coastline map you have specified and this can be downloaded as a \*.zip file. An ASCII data file with extension *dat* can be extracted from the \*.zip file.

The purpose of the *dat2map* program is to translate a Coastline Extractor *dat* file into a WASP map file that can be imported directly by the WASP Map Editor program. The map must be transformed to metric coordinates before it can be used in WASP.

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the *dat*-file as command line argument:

```
dat2map [<filespec>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[.*<ext>*] specifies the *dat*-file. The default *<ext>* is *dat*. If a *<filespec>* is not given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '*dat2map -?*'.

## 7 Map and grid transformations

This chapter describes how to obtain a WASP map file from gridded height information and how to make a grid file from WASP map data.

### 7.1 From grid to map

Information about the height variations of a terrain surface can be given in two different ways: either as the coordinates and elevation of the height contours - which is what WASP uses as input - or as the spot heights of nodes in a rectangular grid. While the latter type may be convenient for some purposes, this type of height data cannot be used directly with WASP. The problem therefore arises of how to transform gridded height information into height contour data. The program `grd2map` aims at solving this problem.

The program transforms a Surfer grid (`grd`) file into a WASP map (`MAP`) file that can be imported directly by WASP. Both the grid file and the map file are in ASCII format and the grid must be regular, ie  $\Delta x = \Delta y$ . The format of a Surfer grid file is described in Chapter 11. An example of the map contours generated by Surfer and `grd2map`, respectively, is given in Fig. 14 below.

Compared to the original map, the contour lines in the lower two panels of Fig. 14 are somewhat smoother. This is so because the height information was first gridded and then contoured again - resulting in some loss of information. It also appears that the contouring routines in Surfer and `grd2map` in this case produce very similar results. In practice, the contour map obtained by running `grd2map` could be verified and detailed close to the sites of interest by digitization.

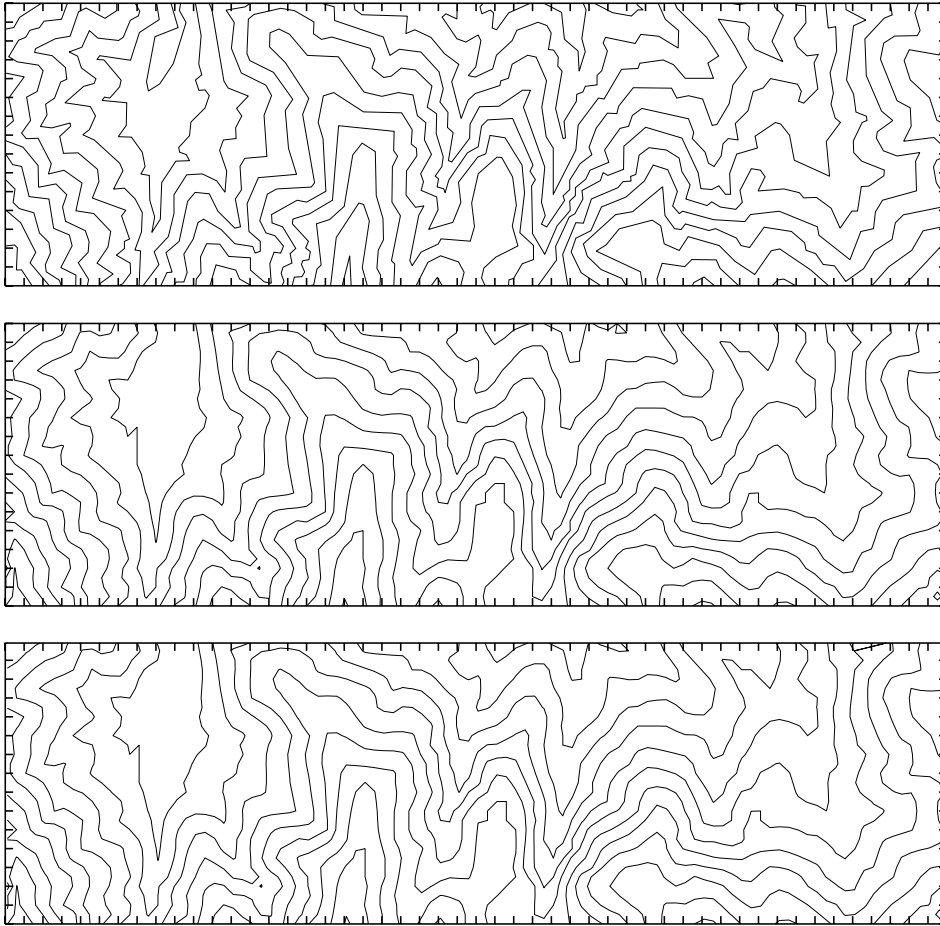
The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the grid file as command line argument:

```
grd2map [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[*<ext>*] specifies the grid file. The default *<ext>* is `grd`. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '`grd2map -?`'. The program can be invoked with the following options in the command line:

- e Extract specified subgrid (-w option) to separate grid file only. The contours are not calculated with this option.
- f Convert the grid point heights from feet to meters, ie the grid point values of the `grd`-file are multiplied by 0.3048 to get a metric map file.
- i# Vertical contour line interval in meters, ie only contours which are multiples of the specified interval value are calculated.
- u User-specified contour line levels.
- r#1,#2 Elevation range for extracted contours, ie only contours with height values between #1 and #2 are calculated and written in the map file.
- w#1,#2,#3,#4 Corner coordinates for subgrid, where the four arguments correspond to  $x_{\min}$ ,  $y_{\min}$ ,  $x_{\max}$ , and  $y_{\max}$ , respectively.

The output file is a WASP map file in ASCII format - with the same *<filespec>* as the input file, but with the extension `map`. Existing files with the same specification(s) will be overwritten. During execution, the program displays a brief summary of the grid and map files.



*Figure 14. Example of the map contours generated by Surfer (middle panel) and grd2map (lower panel). The grid file used as input was derived from the original 50-m contour map (upper panel) - which was obtained by digitization of a standard topographical map. The grid point spacing is 100 m; equal to the distance between tick-marks in the figures above.*

### **Using DEM data with WASP**

Investigations in the mountains of Northern Portugal (Mortensen and Petersen, 1998) indicate that the WASP prediction errors are large when maps are based on grids with large grid cell sizes ( $\geq 75$  m), and decrease with decreasing grid cell size for the finer grids ( $\leq 75$  m). With a grid cell size of about 50 m or less the prediction errors were found to be identical to the errors obtained with an original, 20-m contour, digitized map. A combination of a 2 by 2 km hand-digitized map around the site with any of the nine maps used for the study (based on DEM's of 10, 25, 50, 75, 100, 125, 150, 200 and 250 m grid size) gave results that were as accurate as using the original digitized map. Thus, if a digital elevation model is available only, the grid size should preferably be less than about 50 m. However, the grid cell size seems not to be critical if the terrain within 1 km of the site is digitized in detail.

## **7.2 From map to grid**

WASP 4/5 is furnished with an interface program to Surfer, a general viewing and plotting program for surface data. The interface program `wgrid.exe` on

the WASP 4/5 diskette transforms a map file in WASP format into a grid file that can be used directly as input to Surfer - or, with slight modifications, to other such programs. Furthermore, `wgrid` can generate a second file in Surfer format with the original digitized contour lines. Subsequently, contour maps or 3-D surface plots of the digitized terrain can be created. The map and 3-D surface can be viewed and plotted on most standard PC equipment. The `wgrid` program, however, is restricted to rather small map and grid files and runs interactively only. The program `map2grid` is a command line utility - developed from `wgrid` - that can process much larger maps and grids.

The program transforms a WASP map file into a grid file that can be imported directly by Surfer. The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the map-file as command line argument:

```
map2grid [<filespec>] [<options>]
```

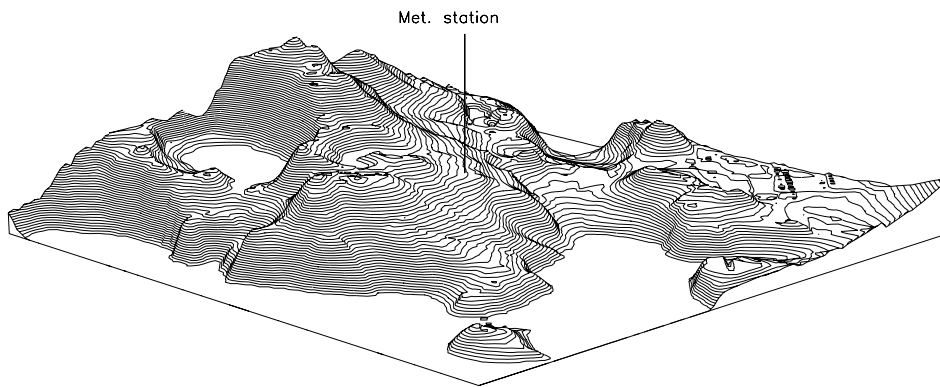
where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[*<ext>*] specifies the map file. The default *<ext>* is `map`. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '`map2grid -?`'. The program can be invoked with the following options in the command line:

- b Write Surfer boundary line file in addition to the grid file.
- d# Grid spacing in meters. The grid is considered regular, ie  $\Delta x = \Delta y = \#$ .
- f Convert contour line values from feet to meters, ie the values of the MAP-file are multiplied by 0.3048 to get a metric grid file.
- w#1, #2, #3, #4 Corner coordinates for subgrid, where the four arguments correspond to  $x_{\min}$ ,  $y_{\min}$ ,  $x_{\max}$ , and  $y_{\max}$ , respectively.
- r# The *resolution level*, which determines the number of 'rays' or directions examined by `map2grid` at each grid point. The larger the value the smoother the gridded surface; however, at the expense of a fast processing time. The default value of 3 is adequate in most cases. Use a value of 2 (or 1) for faster grid generation or in case of internal memory overflow (which will result in wrong grid point values).
- i# The power, *WP*, used for weighting along the different rays or directions. The grid point height is evaluated using contour line heights along the rays weighted with  $1/(|\sin \alpha|)^{WP}$ , where  $\alpha$  is the angle between the line from the grid point to the crossing of the ray with the contour line and the tangent to the contour line. The default value of 1 works satisfactorily in most cases.

`map2grid` produces an ASCII grid file (`.grid`) on basis of the input given in the command line and this file can be used directly with Surfer. All or some of the original contour lines of the input file can be dumped to a boundary line file (`.b1n`) which may also be viewed and plotted using Surfer. Hence, the `map2grid` utility and Surfer enable you to check your digitized maps as well as to produce high quality plots for documentation and illustration purposes. An example is shown in Fig. 15.

The grid produced by `map2grid` can also be used as input for wind flow models that require elevation information in a Cartesian grid.

The Surfer program can be used to analyze, view and plot most surface-type data - whether the information is available at irregularly spaced points or in a regular grid. The results stored in the WASP resource file (`.rsf`) are



*Figure 15. Perspective plot of the orographical setting of a meteorological station in Greenland. The plot covers an area of 2.5 by 2.5 km<sup>2</sup> and the grid spacing is 25 m. The vertical scale is exaggerated by a factor of 3. The plot was generated by Surfer.*

particularly well suited for this kind of analysis, and illustration of eg the speed-up/retardation of the wind speed or the distribution of power production over an area can readily be produced, see Chapter 11.



## 8 The ruggedness of ‘complex terrain’

The somewhat indeterminate term ‘complex terrain’ is often used in connection with the orographic characteristics of a landscape; primarily for hilly and mountainous terrain consisting of a ‘complex’ mixture of several (steep) hills or mountains. While most people have an idea of the general meaning of this term – albeit somewhat biased because of differences in experience – there exist no widely accepted measure of terrain complexity to which we can all refer, like eg terrain elevation (m a.s.l.) or the steepness of a winding, mountain road (%).

Even in the field of wind-flow modelling, it is not clear what ‘complex’ means. One well-known measure of terrain complexity (or steepness) is *relative relief*, ie the difference between the highest and lowest level within unit areas of eg 100 km<sup>2</sup> (Rutkis, 1971; William-Olsson, 1974). This was used as a means for judging the influence of the mountains and thereby the degree of reliability of the results presented in the European Wind Atlas (Troen and Petersen, 1989). However, maps of relative relief generally do not show the effects of local topography.

One objective measure of the steepness or ruggedness of the terrain around a site is the so-called *ruggedness index* or RIX (Bowen and Mortensen, 1996), defined as the percentage fraction of the terrain within a certain distance from a specific site which is steeper than some critical slope, say 0.3 (Wood, 1995). This index was proposed as a coarse measure of the extent of flow separation and thereby the extent to which the terrain violates the requirements of linearized flow models.

The ruggedness index has also been used to develop an orographic *performance indicator* for WASP-predictions in complex terrain (Bowen and Mortensen, 1996; Mortensen and Petersen, 1997) – where the indicator is defined as the difference in the percentage fractions ( $\Delta$ RIX) between the predicted and the reference site. This indicator may provide the sign and approximate magnitude of the prediction error for situations where one or both of the sites are situated in terrain *well outside* the recommended operational envelope.

### 8.1 The ruggedness index (RIX)

In practice, the ruggedness index is calculated for each of a number of radii originating at the site (meteorological station or wind turbine). A flat site will then have a RIX of 0%, a very complex (steep) site an index of, say, 30% – meaning that about one third of the terrain is steeper than our critical slope.

The value of the index defined above will of course depend on the size of the area we are looking at (the radius) and the threshold slope; however, the study indicates that these should be chosen within fairly narrow limits, see below. Given these values, the index is easy to calculate, providing a site-specific measure of terrain ruggedness, and seems to show rather well the effects of local topography on the accuracy of WASP predictions (Bowen and Mortensen, 1996 and 1997).

The purpose of the RIX program is to calculate the ruggedness index of a specific site. In addition to the overall index, the program also calculates indices for each of a number of user-specified sectors. The program is invoked from the directory \WASP\UTIL by typing its name at the DOS prompt with

*The RIX program*

the name of a WASP map file and the site coordinates as arguments:

```
RIX <mapfile> xsite ysite [(options)]
```

where <mapfile> = [(drive)][(path)]<filename>[.(ext)] specifies the WASP map file, which must be in ASCII (text) format. The default <ext> is MAP and the site coordinates must be positive and given in meters. A summary of command line arguments is shown if the program is started with a question mark 'RIX -?'. Ruggedness indices for each of a number of sites in a wind farm can be calculated by specifying the name of a WASP resource file which contains the site coordinates:

```
RIX <mapfile> <rsffile> [(options)]
```

where <rsffile> = [(drive)][(path)]<filename>[.(ext)] specifies an existing WASP resource file; the default <ext> of which is RSF.

The default configuration of the program is given in the text file RIX.CFG:

*RIX configuration file*

```
%  
% rix configuration file  
% sets up default values  
%  
radius = 3500  
threshold = 0.3  
sectors = 12  
subsectors = 6  
verbose = no  
display_sectors = yes  
skip_flat_center = yes
```

With this configuration, the program then takes the terrain within 3500 m of the site into account, the threshold slope is 0.3, and indices are calculated for 12 sectors based on six profiles in each sector. The number of sectors and azimuthal resolution correspond to the default values used by WASP in calculating the orographic corrections; ie parameters #1 and #42 in WASP.PAR. The radius 3500 m and threshold slope 0.3 are the values used by Bowen and Mortensen (1996, 1997).

The program can also be invoked with one or more options in the command line:

*Command-line options*

- r# sets the size (radius) of the terrain for which the RIX is calculated. The default value is 3500 m.
- t# sets the threshold slope for calculation of the RIX value. The default value is 0.3.
- s# sets the number of sectors for which the RIX values are calculated and displayed. The default value is 12.
- u# sets the number of subsectors (terrain profiles) used for the RIX calculations. The default value is 6.
- o(<filespec>) specifies an output (text) file containing the results. Results are shown on screen as default.
- v verbose mode. Default is 'no' (-nv).
- d display sector-wise RIX values. Default is 'yes'.

`-skip` skip flat center of map. Default is 'yes'.

Options which do not take an argument can be negated by putting an 'n' between the hyphen and the option letter(s).

For a single site (eg a meteorological station) the command line could look like this: *Examples*

```
RIX \wasp\project\mymap.asc 317070 6176091
```

where the results would then be shown directly on the screen. Calculating RIX for several sites (eg the wind turbine positions in a wind farm) the command line could look like this:

```
RIX \wasp\project\mymap.asc \wasp\project\park.rsfc -Opark.rix
```

where the results would then be calculated for the positions specified in `park.rsfc` and written to the file `park.rix`.

## 8.2 Using the ruggedness index

The ruggedness index is described in some detail by Bowen and Mortensen (1996, 1997) and Mortensen and Petersen (1997). The main conclusions of the studies are:

- If the RIX is  $\approx 0\%$  the slopes of the terrain are less steep than 0.3 and the flow is likely to be attached, ie follow the terrain surface. This situation is generally within the performance envelope of WAsP.
- If the RIX is  $> 0\%$  parts of the terrain are steeper than 0.3 and flow separation may occur in some sectors. This situation is generally outside the performance envelope of WAsP and prediction errors may be expected. Large RIX values will lead to large errors in the flow modelling. The accuracy of the prediction, however, will depend on the relation between the two sites:
  - If the predictor (meteorological station) and predicted (wind turbine) sites are equally rugged, ie have approximately the same RIX value, the modelling errors are significant but similar in magnitude. The overall prediction should still be accurate as the two errors would tend to cancel each other out. Such a situation obviously occurs for the self prediction at any category of site. However, it may also occur for two neighbouring sites in rugged terrain which have similar orography and orientation. This represents an important application involving the prediction of the wind speeds and energy at adjacent sites along a steep ridge in a wind farm.
  - If the predictor site is rugged and the predicted site less rugged, ie the RIX value of the reference site is larger than that of the predicted site, the modelling errors are significant and unequal. The overall prediction will be underestimated with a significant negative error.
  - If the predictor site is smooth or less rugged than the complex predicted site, ie the RIX value of the reference site is smaller than that of the predicted site, the modelling errors are significant and unequal. The overall prediction will be overestimated with a significant positive error.

## 9 Interpolation of wind atlas data

The technique of the European Wind Atlas and WASP program is to predict the local wind energy potential from the regional wind climatology after corrections for terrain height variations, surface roughness and sheltering obstacles. Regional wind climatologies are stored in Wind Atlas data files and also prepared by WASP in a similar reverse calculation whereby the statistics of measured meteorological time-series are corrected for local effects. The standard WASP prediction procedure is to apply the nearest climatology or otherwise most representative one.

As part of the project *Wind Resource Atlas for Denmark* we developed the LIB Interpolator program, for smooth spatial interpolation within an irregular grid of \*.lib files, see Fig. 20. The program was designed for wind atlas mapping rather than site development. Directional distributions are interpolated by Fourier splines and properties independent of direction are interpolated by Bezier surfaces. Extrapolation beyond the grid boundaries is done slightly different, producing less surface curvature while maintaining continuity at the boundary. There has been some external interest in the LIB Interpolator. External users would however need additional administrative routines, e.g. related to the grid-definition, and as an intermediate step, we decided to program the simplified LIB Interpolator LT (Light).

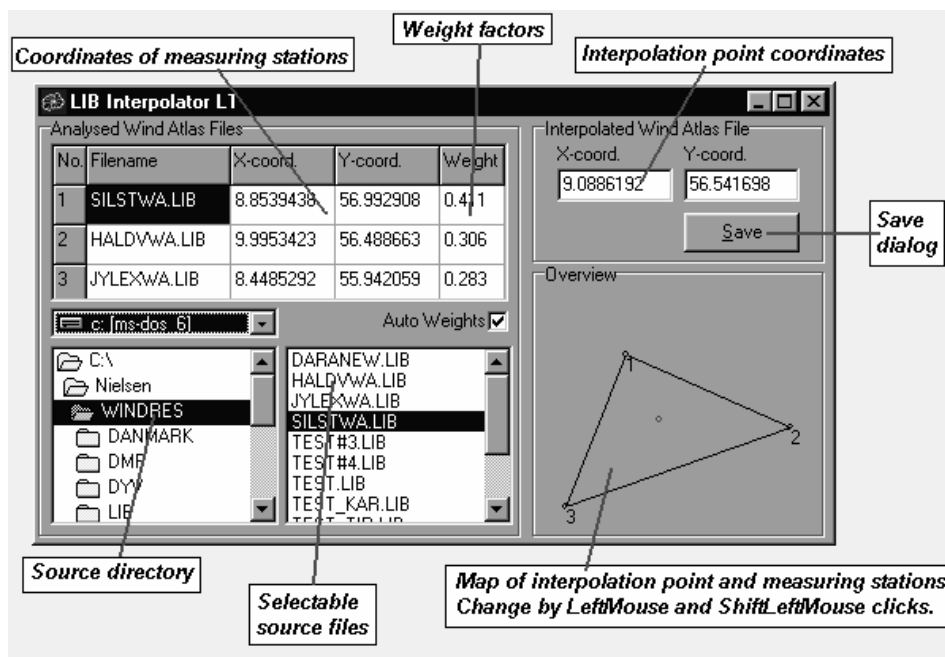


Figure 20. User interface of the LIBintLT program.

### 9.1 The LIB-file interpolator

The purpose of the program LIBintLT is to estimate an artificial WASP wind atlas files by spatial interpolation.

The grid is reduced to three measuring stations only. Properties independent of direction are predicted by linear interpolation rather than by third-

order Bezier polynomials. The special interpolation algorithm is removed and the graphics is reduced. The results should be equivalent to running the original LIB Interpolator with a minimal grid with three measuring stations only.

## 9.2 User interface

Input data files (\*.lib) are selected from the file list, see Fig. 19. The user then specifies the coordinates of the three measuring stations by direct editing in the string table to the top left, and the edit boxes to the top right defines the position of the interpolation point. The coordinate system is arbitrary. An alternative, less precise way, is to click on the overview map on the bottom right. An ordinary left-button mouse click on the map will change the interpolation point while a left-button mouse click with the Shift key of the keyboard pressed will change the position of the nearest measuring station. Weighting factors are either calculated automatically by the program or specified by the user. Click on the Save-button to save the calculated results.

## 9.3 Options

The options are stored in the LibIntLT.ini file and read at the start of the next section. Changing the last line from 'N' to 'Y' would make the program execute in batch mode without displaying the user interface.

## 10 Plotting the power curve

The purpose of the program `pow2dat` is to transform a WAsP power curve (`pow`) file into a data file that can be used to plot the power and power coefficient curves of the wind turbine. The plots can be made using either the Grapher files (`*.grf` generated or any other general purpose plotting program for  $x$ - $y$  graphs.

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the POW-file as argument:

```
pow2dat [[{filespec}] [{options}]
```

where  $\langle filespec \rangle = [\langle drive \rangle][\langle path \rangle]\langle filename \rangle[\langle ext \rangle]$  specifies the `pow`-file. The main result is an ASCII file containing the data to be plotted; ie the wind speed in  $\text{ms}^{-1}$ , the power output in kW and the power coefficient,  $C_p$ .

### 10.1 The power curve

Start the Grapher program and load the `grf` file. Press  $\langle F2 \rangle$  to view the graph. The  $x$ -axis covers the wind speed interval 0-25  $\text{ms}^{-1}$ ; the  $y$ -axis covers an interval from 0 to  $P_x$ , where  $P_x$  is at least 110% of the maximum power. The power is plotted in kW.

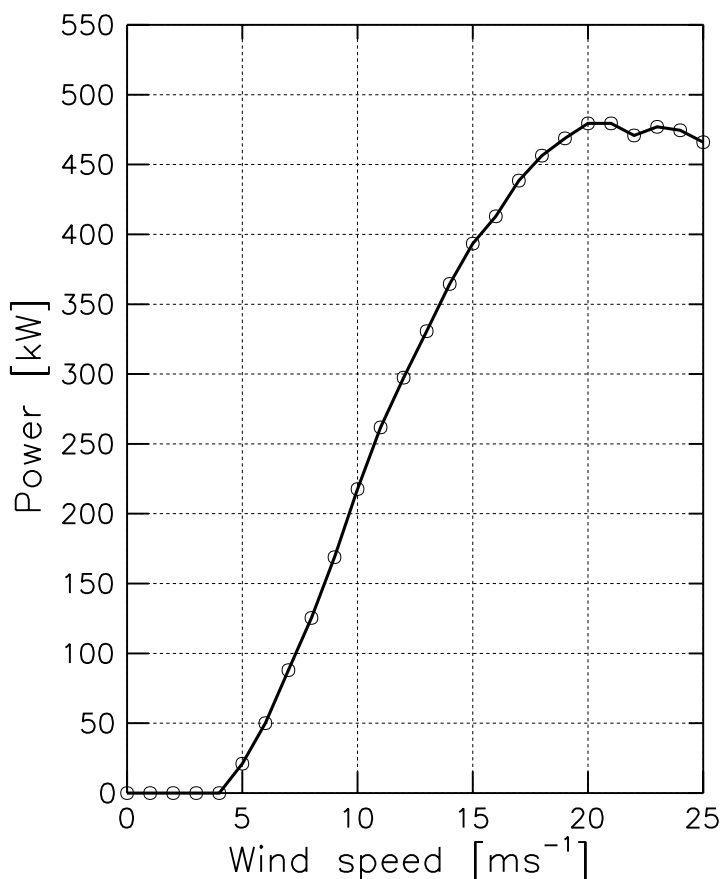


Figure 21. Measured power curve of a 450-kW wind turbine. The power curve is plotted as a piecewise linear curve with nodes for every  $1 \text{ ms}^{-1}$ . The graph was plotted using the Grapher program.

## 10.2 The power coefficient curve

The power coefficient,  $C_p$ , is the ratio of the net generated power to the wind power of the undisturbed flow through the rotor swept area (Frandsen and Pedersen, 1990). Given the WAsP power curve file and the rotor diameter, the power coefficient can be calculated as:

$$C_p = \frac{P}{\frac{1}{2}\rho AV^3} = \frac{8P}{\pi\rho d^2 V^3}$$

where  $P$  is the power,  $\rho$  is the air density ( $1.225 \text{ kg m}^{-3}$ ),  $A$  is the rotor swept area,  $d$  the rotor diameter and  $V$  is the wind speed at hub height. An example of a  $C_p$ -curve is given below.

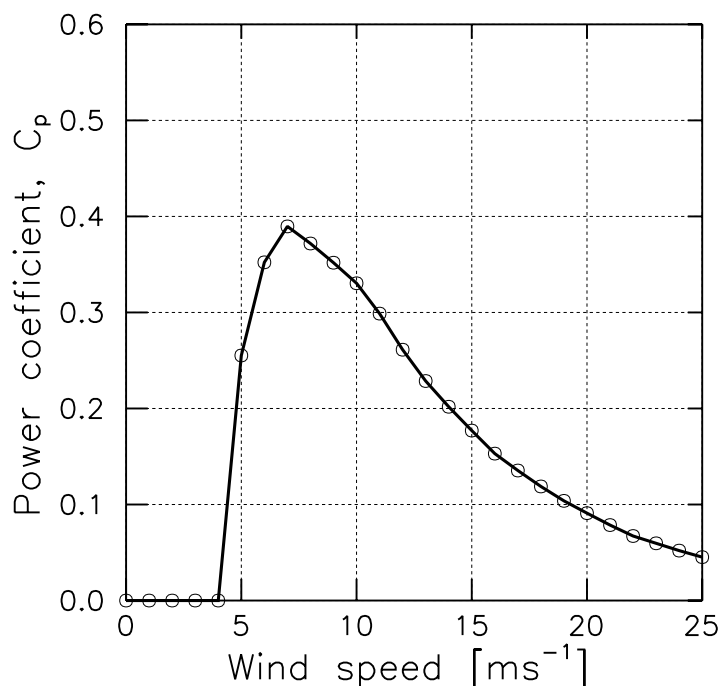


Figure 22. The power coefficient curve of a 450-kW wind turbine. The power coefficient curve is plotted as a piecewise linear curve with nodes for every  $1 \text{ ms}^{-1}$ . The graph was plotted using the Grapher program.

If the rotor diameter is written as the second value in line 2 of the power curve file, pow2dat will automatically calculate the  $C_p$  values and generate this plot file. Alternatively, the diameter can be specified in the command line, see below. If the rotor diameter is not known to WAsP, the  $C_p$  values cannot be calculated and the plot will not be generated. Note, that the power curve files included in WAsP now contains the rotor diameter as described above.

## 10.3 Options

The pow2dat program can be invoked with one or more options - separated by blank characters or spaces - in the command line:

- c Combine the power curve and power coefficient plots into one plot, see Fig. 23.

- d# Rotor diameter (in meters) of the wind turbine. If the diameter is already specified in the power curve file, the diameter specified in the command line will be used.
- p# The Grapher pen numbers used for the plots. Default values are pens 1, 3 and 5, corresponding to -p1, 3, 5. The three pen numbers must be separated by commas.
- " Add text heading to plot(s). If the opening quotation mark is specified only, eg "-", a default heading is used, corresponding to the text in the first line of the power curve file. If a closing quotation mark is specified as well, eg "-Vestas V39", the text between the quotation marks is used as heading.

The slash may be used instead of the hyphen, eg /C, /d37.0, /p2,4,8 and /"Bonus MkIII 450 kW" are valid options. If only one pen number is specified all pens will be assigned this value.

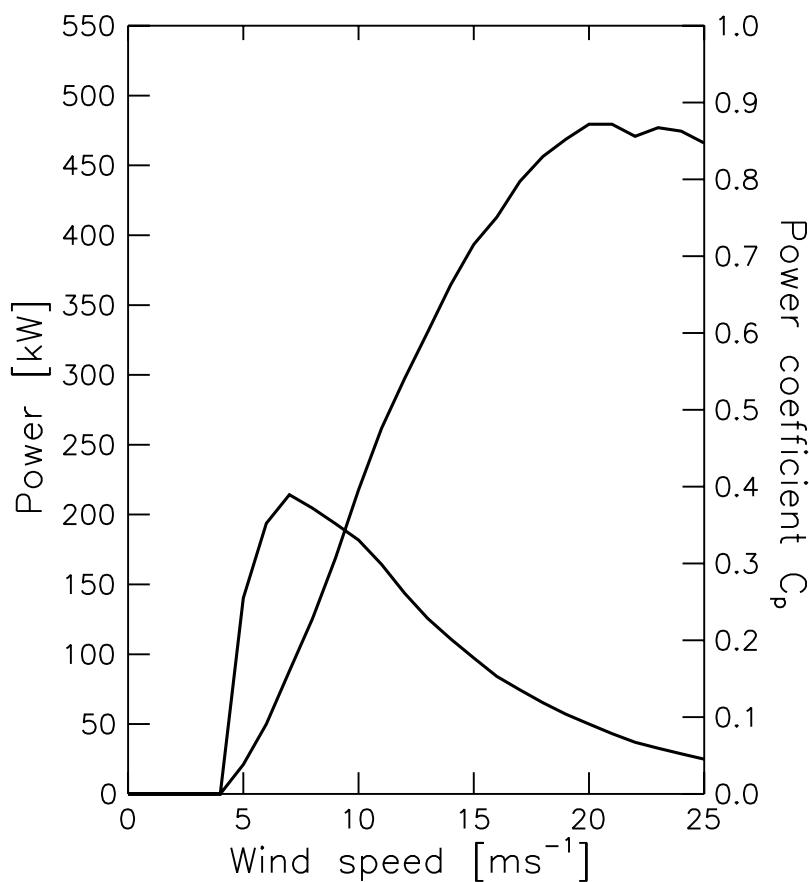


Figure 23. Combined power curve and power coefficient plot for a 450-kW wind turbine.

Most of the power curves published by the European Commission (1995) in the *European Wind Turbine Catalogue* have been transferred to WASP power curve files and are included in the package.

## 10.4 Output files

The result of a program run is an ASCII file with the same *filespec* as the input file - except the extension of the output file(s) is dat. Existing files with



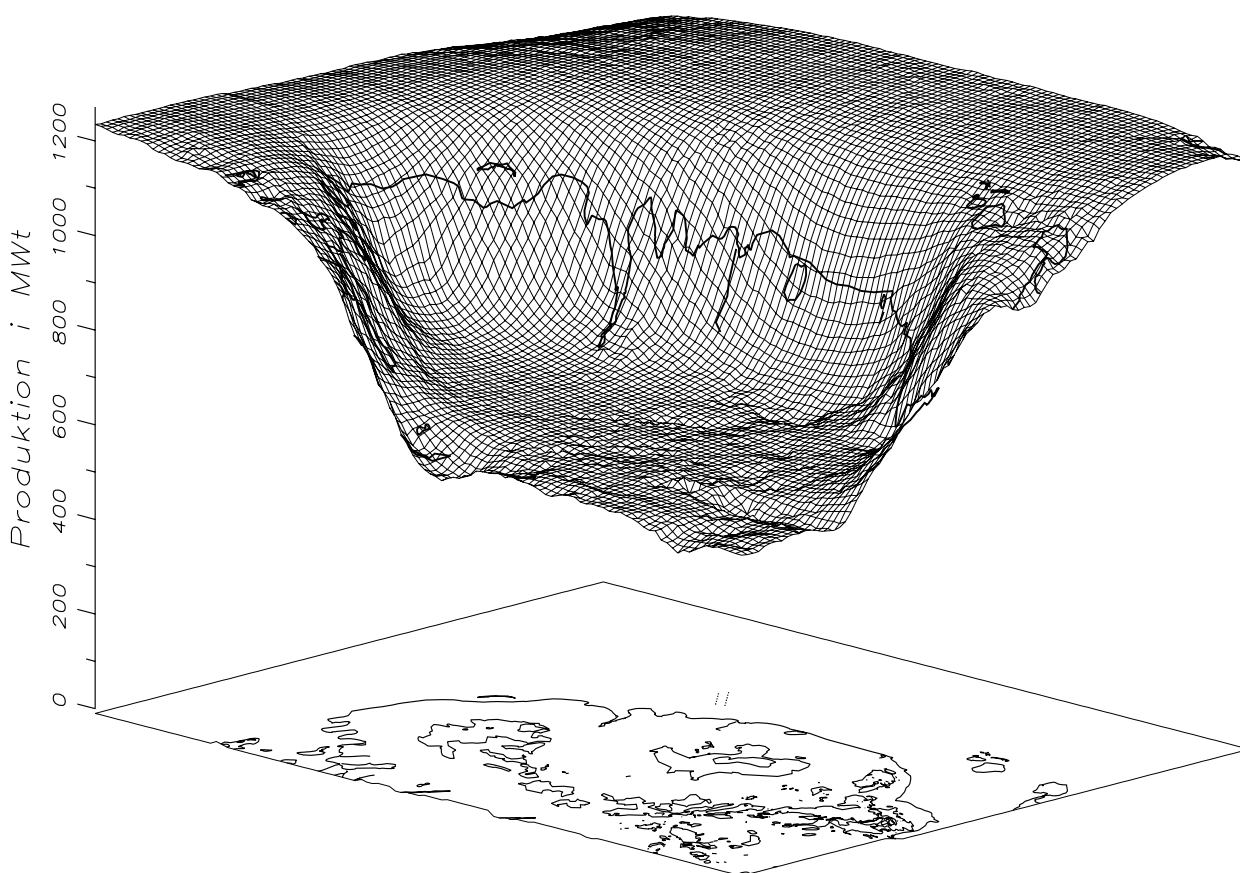
the same specification(s) will be overwritten.

The dat file contains the data to be plotted. Column one is the wind speed in  $\text{ms}^{-1}$ , column two is the power output in kW and column three, if present, is the power coefficient,  $C_p$ . Column four contains the power coefficients scaled such that they can be plotted in the combined power curve/power coefficient plot.

## 11 Resource to grid files

The purpose of the program `rsf2grd` is to transform a WASP 4/5 resource file or a WASP 6/8 resource grid into a Surfer grid file in ASCII format. The grid point values may be Weibull  $A$ - or  $k$ -parameters, mean wind speeds, mean power densities or wind turbine power productions. Grid files of the same quantities normalized with the grid-averaged value of the quantity in question - or any user-specified number - can also be calculated. Optionally, a grid file with the elevations of the resource file sites can be made too.

The output files can be imported and processed directly by the Surfer program, see below, and can also - with little or no modification - be used with most other plotting programs for surface data.



*Figure 24. Sample plot showing the wind power production of a 450-kW wind turbine in a coastal area. The 250-meter grid values were extracted from a resource file using `rsf2grd` and plotted using the Surfer program.*

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the `rsf`- or `wrg`-file as argument:

```
rsf2grd [<filespec>] [<type>] [<options>]
```

If no *<filespec>*, *<type>* or *<options>* are given the program will run interactively. A summary of command line arguments and options is shown if the program is started with a question mark in the command line: '`rsf2grd -?`'. The order of *<type>*, *<options>* and *<filespec>* in the command line is not signifi-

cant. The resource file is read twice to find the mean, maximum and minimum values of the grid.

## 11.1 Grid file types

Five different *types* of grid files can be made from the WASP resource file. The type is determined from the following command line arguments:

- a Grid file of Weibull *A*-parameters [ $\text{ms}^{-1}$ ]
- k Grid file of Weibull *k*-parameters
- u Grid file of mean wind speeds [ $\text{ms}^{-1}$ ]
- e Grid file of mean power densities [ $\text{Wm}^{-2}$ ] or wind turbine power productions [ $\text{Wh y}^{-1}$ ]
- x Grid file of terrain heights above sea level [m]

Only one type can be invoked in one program run. A grid of mean wind speeds is the default if no type is specified. The type specification must be surrounded by one or more blank characters (spaces) and the slash may be used instead of the hyphen: /A, /k, /U, /e and /x are valid type specifications.

## 11.2 Options

The program can be invoked with one or more options - separated by blank characters - in the command line:

- n The grid values are normalized (divided by) with the grid-averaged value of the type in question. The mean value of the *normalized* grid is then 1.0, and values of eg 0.8 and 1.2 mean that the grid point values are 20% lower or higher, respectively, than the mean value of the grid. The resource file is read twice to find the mean, maximum and minimum values.
- v# The grid values are normalized by a user-specified value, eg -e -v1.0E+6 to convert from  $\text{Wh y}^{-1}$  to  $\text{MWh y}^{-1}$ .
- r The input resource file was generated with the *Random points* option (WASP 4/5) rather than the (default) *Grid* option, or the input resource file was exported from a wind farm member (WASP 6/8).
- s# The grid values are calculated for one sector only, eg -u -s10 to obtain a grid of the mean wind speeds in the W-sector. This option is not valid with type -e or -x.
- z In addition to the grid file of wind or energy results a grid file of terrain elevation in [m] above sea level is also made.
- c The output file(s) are written as records of (*x, y, z*) coordinates rather than in the *Surfer* grid file format. The *x*- and *y*-values are the map coordinates and the *z*-value corresponds to any of the types listed above. This option facilitates import of the results to other programs than *Surfer*.

The slash may be used instead of the hyphen: /n, /v100.0, /S7, /Z, /c are all valid options.

## 11.3 Input file

The input file is a WASP 4/5 resource file generated with the RESOURCEFILE option in the main menu, a WASP 6/8 resource grid or wind farm exported from the right-click menu, or using a utility script. The *<filespec>* takes the following form:

$$\langle filespec \rangle = [ \langle drive \rangle ] [ \langle path \rangle ] \langle filename \rangle [ . \langle ext \rangle ]$$

where square brackets enclose optional specifiers. The default file extension is *rsf* or you can specify *wrg* for WASP 6/8 files.

The total and sector-wise Weibull *A*- and *k*-parameters are given in the *\*.rsf* and *\*.wrg* resource files. From these, the mean speeds are calculated as  $A \cdot \Gamma(1 + 1/k)$ , where  $\Gamma(x)$  is the gamma function.

## 11.4 Output files

The result of a program run is one or two ASCII grid files with the same *<filespec>* as the input file - except the extension of the output file(s) is *grd* and/or *alt* (for altitude or elevation). Existing files with the same specification(s) will be overwritten.

### Surfer grid file format

The format of a Surfer ASCII *\*.grd*-file is explained in the Surfer User's Guide, a summary is given in Fig. 25 below.

Line	Contents
1	File ID: DSAA for ASCII grid file
2	$n_x$ : number of grid lines along <i>x</i> -axis (columns) $n_y$ : number of grid lines along <i>y</i> -axis (rows)
3	$x_{\min}$ : minimum <i>x</i> -coordinate of grid $x_{\max}$ : maximum <i>x</i> -coordinate of grid
4	$y_{\min}$ : minimum <i>y</i> -coordinate of grid $y_{\max}$ : maximum <i>y</i> -coordinate of grid
5	$z_{\min}$ : minimum <i>z</i> -value of grid $z_{\max}$ : maximum <i>z</i> -value of grid
6-	Grid row 1: $z_{11}, z_{12}, z_{13}, \dots$ Grid row 2: $z_{21}, z_{22}, z_{23}, \dots$ Grid row 3: $z_{31}, z_{32}, z_{33}, \dots$ etc.

Figure 25. The *z*-values are organized row-wise in the Surfer grid file. Each row has the same *y*-coordinate, from  $y_{\min}$  (row 1) to  $y_{\max}$  (last row). The *x*-coordinates in each row starts with  $x_{\min}$  and ends with  $x_{\max}$ . The node  $z_{11}$  thus corresponds to the lower left corner of the grid.

### Alternative output file format

Invoking the *-c* option, the output file is written as records of (*x*, *y*, *z*) coordinates rather than in the Surfer grid file format:

```
19000.0  39000.0  3.81
21000.0  39000.0  4.34
23000.0  39000.0  3.90
```

```
19000.0  41000.0  3.81
21000.0  41000.0  4.16
23000.0  41000.0  4.07
19000.0  43000.0  3.81
...
```

The  $x$ - and  $y$ -values are the map coordinates (in meters) and the  $z$ -value corresponds to any of the types listed above. This file format is automatically invoked if the input file was generated with the `Random points` option (`-r`), i.e. corresponding to a wind farm.

## 12 Reporting

### 12.1 Printing the wind atlas

The purpose of the program `lib2txt` is to transform a WASP wind atlas (`lib`) file into a (human-readable) text file that can be viewed, printed or included in a document. Furthermore, the overall mean wind speeds [ $\text{ms}^{-1}$ ] and power densities [ $\text{Wm}^{-2}$ ] for the standard heights and roughness lengths given in the wind atlas file are calculated and printed.

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the wind atlas file as argument:

```
lib2txt [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[*<ext>*] specifies the wind atlas file. The default *<ext>* is `lib`. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '`lib2txt -?`'.

The default output is a simple ASCII text file which corresponds exactly to the right-hand page of the station statistics given in the European Wind Atlas, see Fig. 26. The program can be invoked with one option only in the command line:

`-l` Write the output in  $\text{\LaTeX}$  format for inclusion in a  $\text{\LaTeX}$  document. The formatting of the tables is given in the file `wasp.sty`, see Section 12.3.

The slash may be used instead of the hyphen and the program is not case-sensitive, so `/l` and `-L` are both valid options.

### 12.2 Finding the PostScript bounding box

The purpose of the `bbox` program is to find the so-called *bounding box* of a Grapher/Surfer PostScript file, ie the coordinates of the lower left and upper right corners of a box just enclosing the graphic. These coordinates are given in PostScript units (1/72 inch) with respect to the lower left corner of the paper. The bounding box coordinates are (sometimes) needed when including PostScript graphics in a document, but the DOS versions of Grapher/Surfer do not write a bounding box comment in the PostScript output file.

The program is invoked by typing its name at the prompt in a Command Prompt window, with the name of the PostScript file as argument:

```
bbox [<filespec>] [<options>]
```

where *<filespec>* = [*<drive>*][*<path>*]*<filename>*[*<ext>*] specifies the PostScript file. The default *<ext>* is `out`. If neither *<filespec>* nor *<options>* are given the program will run interactively. A summary of command line arguments is shown if the program is started with a question mark '`bbox -?`'.

The default action is to find and display the size of the bounding box only, but the program can be invoked with one option in the command line:

`-f` Write a new PostScript file in which the bounding box comment is included. The default extension of this file is `eps`. Note, that the original PostScript file is *not* deleted.

The slash may be used instead of the hyphen and the program is not sensitive to case, so `/f` and `-F` are both valid options.

Wind atlas: Sprogøe 1985-94, 70 m a.g.l. 12 sectors.

Roughness Class 0 (0.0002 m)												
z	0	30	60	90	120	150	180	210	240	270	300	330 Total
10	6.18	6.22	5.96	6.56	8.04	7.46	7.59	7.63	7.96	8.21	7.57	6.73 7.45
	1.78	1.90	1.93	2.03	2.60	2.30	2.08	2.28	2.28	2.26	2.16	1.90 2.13
25	6.77	6.82	6.53	7.18	8.79	8.16	8.31	8.35	8.71	8.99	8.29	7.37 8.16
	1.83	1.96	1.99	2.09	2.68	2.37	2.15	2.35	2.36	2.33	2.22	1.96 2.20
50	7.28	7.33	7.02	7.71	9.43	8.76	8.92	8.97	9.35	9.64	8.90	7.93 8.76
	1.88	2.01	2.04	2.14	2.75	2.43	2.20	2.42	2.42	2.39	2.29	2.01 2.26
100	7.89	7.94	7.60	8.36	10.24	9.51	9.67	9.73	10.15	10.45	9.64	8.59 9.50
	1.82	1.95	1.98	2.08	2.67	2.35	2.13	2.34	2.34	2.32	2.21	1.94 2.19
200	8.69	8.76	8.39	9.23	11.34	10.51	10.69	10.76	11.22	11.53	10.65	9.47 10.49
	1.73	1.85	1.87	1.96	2.52	2.23	2.02	2.21	2.22	2.20	2.10	1.84 2.08
Freq	5.4	4.5	4.1	5.5	8.3	7.9	7.7	11.2	13.5	14.5	11.5	6.0
Roughness Class 1 (0.0300 m)												
z	0	30	60	90	120	150	180	210	240	270	300	330 Total
10	4.29	4.36	4.26	4.76	5.54	5.20	5.39	5.35	5.57	5.70	5.14	4.55 5.19
	1.52	1.62	1.65	1.80	2.12	1.87	1.80	1.92	1.91	1.89	1.77	1.58 1.81
25	5.17	5.24	5.12	5.72	6.63	6.24	6.46	6.41	6.67	6.83	6.17	5.48 6.22
	1.64	1.75	1.77	1.94	2.28	2.02	1.95	2.08	2.06	2.03	1.92	1.70 1.94
50	6.02	6.10	5.95	6.62	7.65	7.22	7.49	7.42	7.71	7.88	7.15	6.37 7.21
	1.84	1.97	1.99	2.19	2.57	2.27	2.19	2.33	2.31	2.27	2.15	1.91 2.18
100	7.16	7.24	7.07	7.86	9.07	8.57	8.89	8.80	9.14	9.32	8.49	7.58 8.55
	1.96	2.10	2.12	2.33	2.73	2.42	2.33	2.48	2.46	2.42	2.30	2.03 2.31
200	8.89	9.00	8.79	9.78	11.29	10.66	11.06	10.95	11.36	11.53	10.56	9.41 10.62
	1.87	2.00	2.03	2.22	2.61	2.31	2.22	2.37	2.35	2.31	2.19	1.94 2.21
Freq	5.2	4.4	4.4	6.2	8.3	7.8	8.5	11.8	13.7	13.9	10.2	5.8
Roughness Class 2 (0.1000 m)												
z	0	30	60	90	120	150	180	210	240	270	300	330 Total
10	3.75	3.80	3.74	4.23	4.80	4.54	4.73	4.67	4.88	4.98	4.44	3.92 4.53
	1.52	1.62	1.63	1.85	2.08	1.85	1.82	1.91	1.92	1.90	1.75	1.54 1.80
25	4.65	4.72	4.63	5.23	5.92	5.62	5.85	5.78	6.02	6.14	5.50	4.87 5.60
	1.63	1.73	1.74	1.98	2.23	1.98	1.95	2.05	2.05	2.03	1.87	1.65 1.92
50	5.49	5.56	5.46	6.14	6.93	6.60	6.87	6.78	7.06	7.19	6.46	5.74 6.57
	1.81	1.91	1.93	2.19	2.47	2.20	2.15	2.27	2.27	2.23	2.07	1.83 2.12
100	6.57	6.64	6.52	7.31	8.25	7.86	8.19	8.07	8.40	8.54	7.70	6.87 7.83
	1.98	2.10	2.12	2.41	2.71	2.41	2.37	2.49	2.49	2.45	2.28	2.01 2.33
200	8.10	8.19	8.04	9.03	10.19	9.70	10.10	9.96	10.35	10.50	9.50	8.46 9.66
	1.90	2.01	2.03	2.31	2.60	2.31	2.27	2.38	2.39	2.35	2.18	1.92 2.23
Freq	5.1	4.3	4.6	6.4	8.2	7.8	8.8	12.0	13.8	13.6	9.7	5.7
Roughness Class 3 (0.4000 m)												
z	0	30	60	90	120	150	180	210	240	270	300	330 Total
10	2.95	3.01	3.01	3.40	3.73	3.59	3.76	3.70	3.86	3.91	3.46	3.07 3.57
	1.52	1.62	1.66	1.89	2.03	1.84	1.85	1.91	1.92	1.87	1.73	1.54 1.80
25	3.91	3.98	3.98	4.48	4.92	4.73	4.96	4.88	5.09	5.15	4.57	4.07 4.72
	1.62	1.72	1.76	2.00	2.15	1.95	1.96	2.03	2.03	1.97	1.83	1.63 1.90
50	4.75	4.83	4.82	5.42	5.93	5.72	5.99	5.89	6.14	6.21	5.53	4.94 5.70
	1.76	1.87	1.91	2.17	2.34	2.12	2.12	2.20	2.20	2.13	1.99	1.77 2.06
100	5.76	5.85	5.83	6.53	7.14	6.90	7.22	7.10	7.39	7.47	6.68	5.99 6.87
	2.00	2.13	2.17	2.48	2.67	2.41	2.42	2.51	2.50	2.42	2.26	2.02 2.34
200	7.03	7.14	7.12	7.98	8.73	8.43	8.83	8.68	9.02	9.09	8.16	7.30 8.39
	1.92	2.05	2.09	2.39	2.57	2.32	2.33	2.42	2.41	2.34	2.18	1.95 2.26
Freq	5.0	4.3	4.7	6.8	8.2	7.8	9.3	12.3	13.9	13.2	9.0	5.7

z	Class 0		Class 1		Class 2		Class 3	
m	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>
10	6.6	315	4.6	128	4.0	85	3.2	42
25	7.2	403	5.5	202	5.0	149	4.2	90
50	7.8	488	6.4	280	5.8	218	5.0	146
100	8.4	639	7.6	445	6.9	341	6.1	229
200	9.3	905	9.4	886	8.6	661	7.4	430

Figure 26. Sample Wind Atlas file printed as a standard text file.

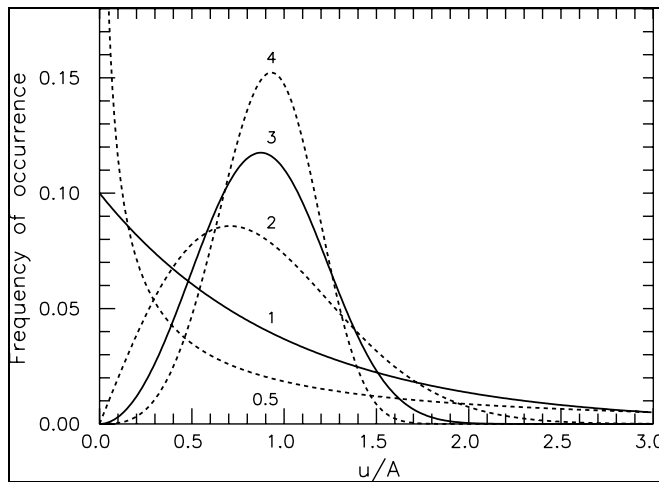


Figure 27. The Postscript BoundingBox is specified by the coordinates of the lower left and upper right corners of a box just enclosing the graphic.

### 12.3 Sample station description

In the European Wind Atlas, the climatological data and measuring conditions for each station were presented in a number of standard tables and graphs: The station description, a summary of the raw data, and the wind atlas tables (calculated regional Weibull parameters) were printed on a pair of facing pages; and the raw data and some derived quantities were shown graphically in wind climatological fingerprints at the end of each country section.

As an example of the use of the WASP Utility Programs, we present below an extended version of such a station description. Each station summary is here given on two pairs of facing pages. The first opening contains

- the station description
- the station topography
- the topographical model corrections
- several raw data summaries

and the second opening gives

- the wind climatological fingerprint
- the calculated regional Weibull parameters
- the calculated regional mean wind speeds and energies

A style file, `wasp.sty`, is further provided for processing files in LaTeX format.



# Sprogø

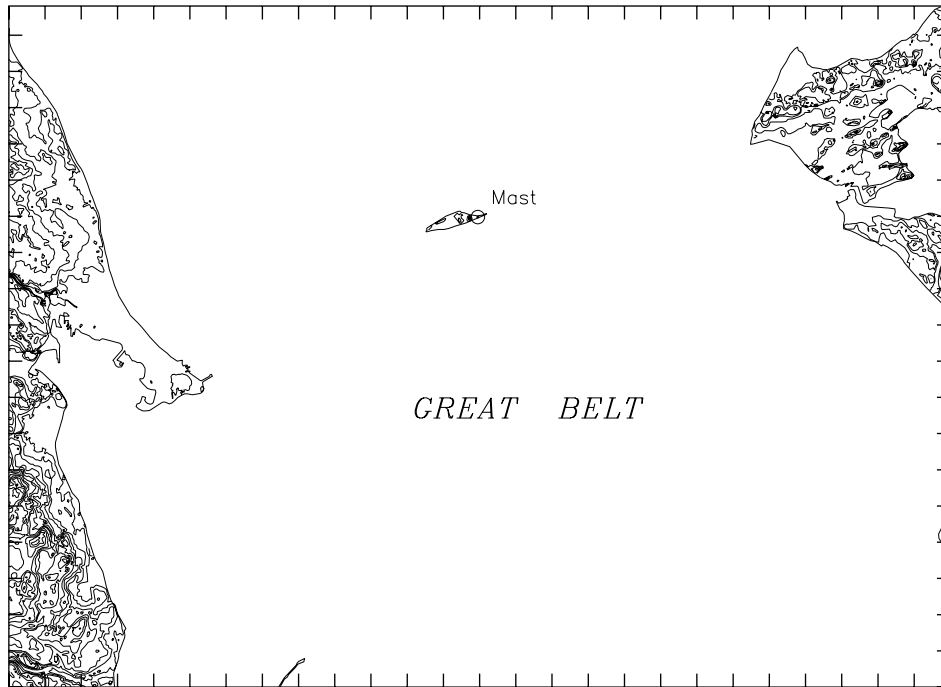
# Denmark

55° 19' 53'' N	10° 58' 27'' E	E 625 242 m	N 6 133 579 m	1 m
----------------	----------------	-------------	---------------	-----

The mast is situated on the small island of Sprogø in the middle of Storebælt (Great Belt). The mast stands on a long narrow spit of land only 50 m wide and extending 300 m east of the island proper. Except for the 240°-270° sector, the approach to the mast is over several kilometers of water. The distance to the islands of Sjælland to the east and Fyn to the west is approximately 10 km.

In recent years, the island has been completely changed and enlarged due to the construction of the Great Belt link. The data reported here were measured at 70 m a.g.l. - the lower levels on the mast should not be analyzed using the topographical information presently available.

On the map below, the height contour interval is 5 m and tick marks are shown for every kilometer.

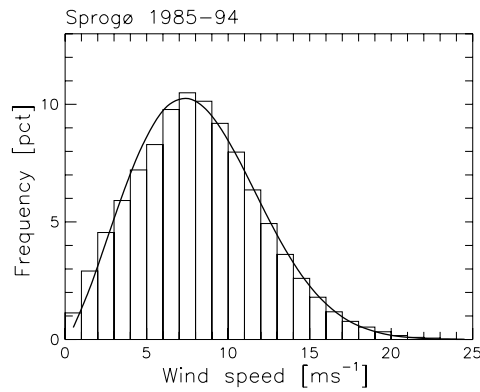
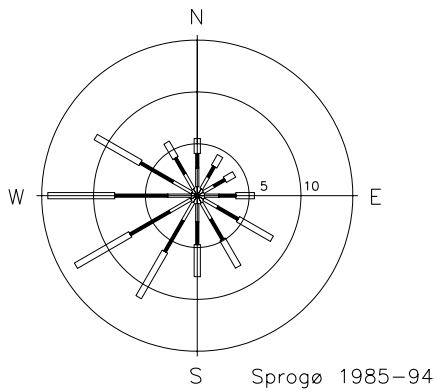


Sector	Input		Obstacles		Roughness		Orography		z <sub>0m</sub>
0	0.00	0.00	0.00	0.00	0.00	0.00	0.35	-0.30	0.0002
30	0.00	0.00	0.00	0.00	0.00	0.00	-0.34	-0.39	0.0002
60	0.00	0.00	0.00	0.00	1.08	0.00	-0.84	-0.09	0.0006
90	0.00	0.00	0.00	0.00	1.16	0.00	-0.82	-0.13	0.0006
120	0.00	0.00	0.00	0.00	0.00	0.00	-0.67	0.28	0.0002
150	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.40	0.0002
180	0.00	0.00	0.00	0.00	0.00	0.00	0.35	-0.30	0.0002
210	0.00	0.00	0.00	0.00	0.38	0.00	-0.35	-0.40	0.0003
240	0.00	0.00	0.00	0.00	3.22	0.00	-0.87	-0.09	0.0019
270	0.00	0.00	0.00	0.00	4.30	0.00	-0.85	-0.13	0.0043
300	0.00	0.00	0.00	0.00	0.44	0.00	-0.69	0.28	0.0003
330	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.40	0.0002

Height of anemometer: 70.0 m a.g.l.

198501010005-199412312355

Sect	Freq	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A	k
0	5.5	17	49	89	105	113	111	95	84	77	122	66	46	18	8	7.6	1.86
30	4.4	26	57	91	104	99	93	100	92	74	135	76	33	15	4	7.6	2.01
60	4.1	28	57	77	90	100	101	109	97	87	127	79	31	9	6	7.7	2.09
90	5.5	20	45	61	72	89	97	104	101	88	143	98	59	18	7	8.4	2.18
120	8.3	14	30	40	54	63	69	79	96	101	187	154	70	32	10	9.8	2.73
150	7.9	14	34	52	68	83	83	90	97	96	167	121	59	25	11	9.1	2.40
180	7.8	11	33	54	67	76	85	96	93	90	158	108	67	37	26	9.3	2.17
210	11.3	9	23	35	44	61	74	91	107	106	190	122	72	37	28	9.9	2.43
240	13.5	6	18	27	41	58	78	98	112	114	195	124	69	35	25	9.9	2.48
270	14.4	4	13	22	36	51	72	105	127	122	201	122	65	34	25	9.9	2.47
300	11.3	6	18	30	44	62	79	100	109	110	178	119	77	36	32	9.9	2.29
330	5.9	13	40	72	89	95	102	114	100	83	131	81	42	23	13	8.1	1.97
Total	100.0	11	29	46	59	72	83	98	105	101	172	113	62	30	20	9.3	2.33

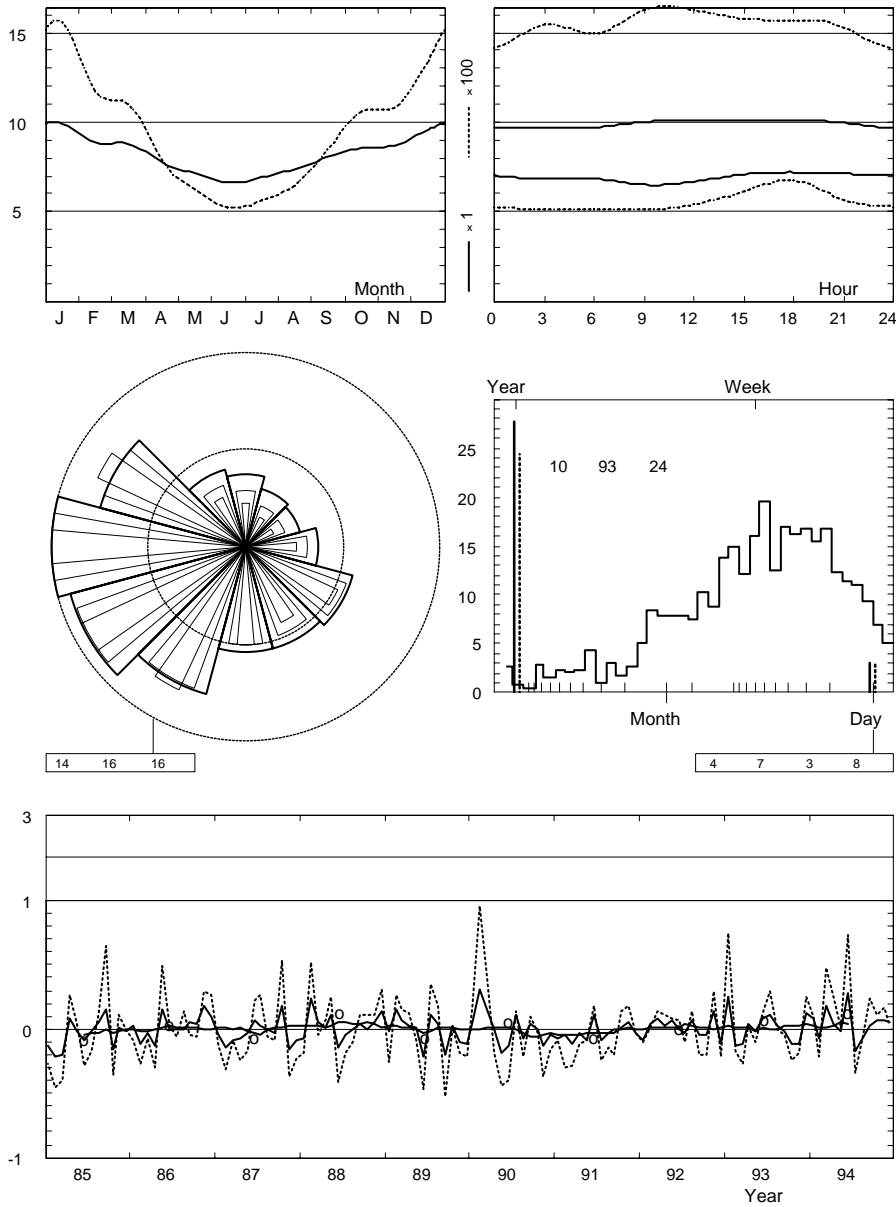


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
0	9.7	9.0	8.6	7.7	7.2	6.8	7.0	7.5	8.0	8.7	8.7	9.6	8.2
1	9.7	8.9	8.5	7.6	7.3	6.7	6.8	7.5	8.0	8.7	8.6	9.5	8.2
2	9.7	8.8	8.5	7.5	7.2	6.8	6.8	7.4	7.9	8.6	8.7	9.6	8.1
3	9.7	8.9	8.5	7.6	7.1	6.7	6.8	7.3	7.8	8.5	8.7	9.7	8.1
4	9.7	8.8	8.6	7.6	7.0	6.7	6.8	7.3	7.8	8.5	8.8	9.6	8.1
5	9.7	8.8	8.7	7.6	7.0	6.7	6.8	7.2	7.8	8.4	8.7	9.5	8.1
6	9.7	8.8	8.7	7.7	7.0	6.6	6.8	7.2	7.8	8.4	8.7	9.5	8.1
7	9.8	8.8	8.8	7.7	6.9	6.5	6.7	7.2	7.9	8.5	8.8	9.4	8.1
8	9.9	8.9	8.9	7.7	6.8	6.4	6.6	7.1	7.9	8.5	8.8	9.5	8.1
9	10.0	8.9	8.9	7.6	6.6	6.3	6.5	7.1	7.7	8.6	8.8	9.4	8.0
10	10.0	8.8	9.0	7.6	6.6	6.2	6.5	7.2	7.9	8.6	8.8	9.4	8.0
11	10.1	8.8	8.9	7.6	6.6	6.3	6.6	7.2	8.0	8.5	8.7	9.4	8.0
12	10.1	8.8	8.9	7.7	6.9	6.5	6.7	7.3	8.0	8.5	8.7	9.4	8.1
13	10.2	8.8	8.9	7.9	7.1	6.7	6.9	7.4	8.1	8.4	8.7	9.5	8.2
14	10.1	8.9	8.9	7.9	7.3	6.8	7.1	7.5	8.2	8.4	8.7	9.6	8.3
15	10.1	8.9	8.9	8.0	7.3	6.9	7.1	7.6	8.3	8.6	8.6	9.7	8.3
16	10.1	8.9	8.9	8.1	7.4	6.7	7.2	7.7	8.3	8.6	8.5	9.6	8.3
17	10.1	8.8	8.9	8.0	7.4	6.7	7.1	7.7	8.3	8.6	8.5	9.6	8.3
18	10.1	8.9	8.9	8.1	7.5	6.6	7.2	7.7	8.1	8.6	8.7	9.7	8.3
19	10.1	9.1	8.9	7.9	7.4	6.7	7.2	7.6	8.2	8.6	8.7	9.8	8.3
20	10.0	9.0	8.8	7.9	7.3	6.6	7.1	7.5	8.3	8.7	8.7	9.7	8.3
21	10.0	9.0	8.8	7.8	7.4	6.6	7.1	7.4	8.3	8.7	8.6	9.7	8.3
22	9.9	8.9	8.8	7.8	7.5	6.8	7.2	7.4	8.3	8.8	8.7	9.6	8.3
23	9.8	9.0	8.7	7.8	7.4	6.9	7.2	7.5	8.2	8.6	8.7	9.7	8.3
Mean	9.9	8.9	8.8	7.8	7.1	6.6	6.9	7.4	8.1	8.6	8.7	9.6	8.2

Sprogøe, Denmark

1985-94

70.0 m agl, mean 8.2 m/s, st dev 3.9 m/s, cube 944. m<sup>3</sup>/s<sup>3</sup>



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1985	8.6	7.0	7.1	8.4	7.1	6.0	6.8	7.8	9.3	7.2	8.8	9.4	7.8
1986	10.1	7.8	8.5	6.8	8.2	6.6	6.9	7.3	8.5	8.9	10.2	10.5	8.4
1987	9.4	7.6	8.0	7.2	6.9	7.0	7.1	7.4	7.8	10.2	7.4	8.7	7.9
1988	9.2	11.0	9.2	7.8	7.9	5.7	6.6	7.3	8.4	8.5	9.1	10.9	8.6
1989	9.7	10.2	9.4	8.0	7.2	5.2	7.7	7.7	6.5	8.8	7.8	8.5	8.0
1990	10.5	11.6	10.2	7.8	5.8	5.8	7.6	6.9	8.3	8.6	7.6	9.1	8.3
1991	9.2	8.5	7.8	7.5	6.6	7.4	6.3	7.1	7.7	8.7	9.2	9.3	7.9
1992	9.1	9.2	9.5	7.9	7.6	6.6	6.7	7.9	7.7	8.2	10.0	8.5	8.2
1993	12.4	7.8	7.8	8.0	7.0	7.1	7.7	7.6	7.9	7.5	7.7	10.8	8.3
1994	10.8	8.2	10.4	8.1	7.0	8.4	5.8	6.9	8.3	9.1	9.3	10.1	8.5
Mean	9.9	8.9	8.8	7.8	7.1	6.6	6.9	7.4	8.1	8.6	8.7	9.6	8.2

**Roughness Class 0 ( $z_0 = 0.0002$  m)**

$z$	0	30	60	90	120	150	180	210	240	270	300	330	Total
10	6.2	6.2	6.0	6.6	8.0	7.5	7.6	7.6	8.0	8.2	7.6	6.7	7.5
	1.78	1.90	1.93	2.03	2.60	2.30	2.08	2.28	2.28	2.26	2.16	1.90	2.13
25	6.8	6.8	6.5	7.2	8.8	8.2	8.3	8.4	8.7	9.0	8.3	7.4	8.2
	1.83	1.96	1.99	2.09	2.68	2.37	2.15	2.35	2.36	2.33	2.22	1.96	2.20
50	7.3	7.3	7.0	7.7	9.4	8.8	8.9	9.0	9.4	9.6	8.9	7.9	8.8
	1.88	2.01	2.04	2.14	2.75	2.43	2.20	2.42	2.42	2.39	2.29	2.01	2.26
100	7.9	7.9	7.6	8.4	10.2	9.5	9.7	9.7	10.1	10.4	9.6	8.6	9.5
	1.82	1.95	1.98	2.08	2.67	2.35	2.13	2.34	2.34	2.32	2.21	1.94	2.19
200	8.7	8.8	8.4	9.2	11.3	10.5	10.7	10.8	11.2	11.5	10.6	9.5	10.5
	1.73	1.85	1.87	1.96	2.52	2.23	2.02	2.21	2.22	2.20	2.10	1.84	2.08
Freq.	5.4	4.5	4.1	5.5	8.3	7.9	7.7	11.2	13.5	14.5	11.5	6.0	100.0

**Roughness Class 1 ( $z_0 = 0.0300$  m)**

$z$	0	30	60	90	120	150	180	210	240	270	300	330	Total
10	4.3	4.4	4.3	4.8	5.5	5.2	5.4	5.3	5.6	5.7	5.1	4.6	5.2
	1.52	1.62	1.65	1.80	2.12	1.87	1.80	1.92	1.91	1.89	1.77	1.58	1.81
25	5.2	5.2	5.1	5.7	6.6	6.2	6.5	6.4	6.7	6.8	6.2	5.5	6.2
	1.64	1.75	1.77	1.94	2.28	2.02	1.95	2.08	2.06	2.03	1.92	1.70	1.94
50	6.0	6.1	5.9	6.6	7.7	7.2	7.5	7.4	7.7	7.9	7.2	6.4	7.2
	1.84	1.97	1.99	2.19	2.57	2.27	2.19	2.33	2.31	2.27	2.15	1.91	2.18
100	7.2	7.2	7.1	7.9	9.1	8.6	8.9	8.8	9.1	9.3	8.5	7.6	8.5
	1.96	2.10	2.12	2.33	2.73	2.42	2.33	2.48	2.46	2.42	2.30	2.03	2.31
200	8.9	9.0	8.8	9.8	11.3	10.7	11.1	10.9	11.4	11.5	10.6	9.4	10.6
	1.87	2.00	2.03	2.22	2.61	2.31	2.22	2.37	2.35	2.31	2.19	1.94	2.21
Freq.	5.2	4.4	4.4	6.2	8.3	7.8	8.5	11.8	13.7	13.9	10.2	5.8	100.0

**Roughness Class 2 ( $z_0 = 0.1000$  m)**

$z$	0	30	60	90	120	150	180	210	240	270	300	330	Total
10	3.8	3.8	3.7	4.2	4.8	4.5	4.7	4.7	4.9	5.0	4.4	3.9	4.5
	1.52	1.62	1.63	1.85	2.08	1.85	1.82	1.91	1.92	1.90	1.75	1.54	1.80
25	4.7	4.7	4.6	5.2	5.9	5.6	5.8	5.8	6.0	6.1	5.5	4.9	5.6
	1.63	1.73	1.74	1.98	2.23	1.98	1.95	2.05	2.05	2.03	1.87	1.65	1.92
50	5.5	5.6	5.5	6.1	6.9	6.6	6.9	6.8	7.1	7.2	6.5	5.7	6.6
	1.81	1.91	1.93	2.19	2.47	2.20	2.15	2.27	2.27	2.23	2.07	1.83	2.12
100	6.6	6.6	6.5	7.3	8.3	7.9	8.2	8.1	8.4	8.5	7.7	6.9	7.8
	1.98	2.10	2.12	2.41	2.71	2.41	2.37	2.49	2.49	2.45	2.28	2.01	2.33
200	8.1	8.2	8.0	9.0	10.2	9.7	10.1	10.0	10.4	10.5	9.5	8.5	9.7
	1.90	2.01	2.03	2.31	2.60	2.31	2.27	2.38	2.39	2.35	2.18	1.92	2.23
Freq.	5.1	4.3	4.6	6.4	8.2	7.8	8.8	12.0	13.8	13.6	9.7	5.7	100.0

**Roughness Class 3 ( $z_0 = 0.4000$  m)**

$z$	0	30	60	90	120	150	180	210	240	270	300	330	Total
10	3.0	3.0	3.0	3.4	3.7	3.6	3.8	3.7	3.9	3.9	3.5	3.1	3.6
	1.52	1.62	1.66	1.89	2.03	1.84	1.85	1.91	1.92	1.87	1.73	1.54	1.80
25	3.9	4.0	4.0	4.5	4.9	4.7	5.0	4.9	5.1	5.2	4.6	4.1	4.7
	1.62	1.72	1.76	2.00	2.15	1.95	1.96	2.03	2.03	1.97	1.83	1.63	1.90
50	4.8	4.8	4.8	5.4	5.9	5.7	6.0	5.9	6.1	6.2	5.5	4.9	5.7
	1.76	1.87	1.91	2.17	2.34	2.12	2.12	2.20	2.20	2.13	1.99	1.77	2.06
100	5.8	5.8	5.8	6.5	7.1	6.9	7.2	7.1	7.4	7.5	6.7	6.0	6.9
	2.00	2.13	2.17	2.48	2.67	2.41	2.42	2.51	2.50	2.42	2.26	2.02	2.34
200	7.0	7.1	7.1	8.0	8.7	8.4	8.8	8.7	9.0	9.1	8.2	7.3	8.4
	1.92	2.05	2.09	2.39	2.57	2.32	2.33	2.42	2.41	2.34	2.18	1.95	2.26
Freq.	5.0	4.3	4.7	6.8	8.2	7.8	9.3	12.3	13.9	13.2	9.0	5.7	100.0

$z$ m	Class 0		Class 1		Class 2		Class 3	
	$\text{ms}^{-1}$	$\text{Wm}^{-2}$	$\text{ms}^{-1}$	$\text{Wm}^{-2}$	$\text{ms}^{-1}$	$\text{Wm}^{-2}$	$\text{ms}^{-1}$	$\text{Wm}^{-2}$
10	6.6	315	4.6	128	4.0	85	3.2	42
25	7.2	403	5.5	202	5.0	149	4.2	90
50	7.8	488	6.4	280	5.8	218	5.0	146
100	8.4	639	7.6	445	6.9	341	6.1	229
200	9.3	905	9.4	886	8.6	661	7.4	430

# Acknowledgements

Bent Nielsen transferred the code generating the wind climatological fingerprint from Risø's mainframe computer to the PC environment.

Several users made suggestions to - or pointed out flaws in - early versions of the WASP Utility Programs. These contributions are gratefully acknowledged.

# References

- Andersson, O. and K. Poder (1981). Koordinattransformationer ved Geodætisk Institut. *Landinspektøren* **9**, 552-571.
- Bowen, A.J. and N.G. Mortensen (1996). Exploring the limits of WASP: the Wind Atlas Analysis and Application Program. Proceedings of the *1996 European Union Wind Energy Conference*, Göteborg, Sweden, May 20-24, 584-587.
- Bowen, A.J. and N.G. Mortensen (1997). WASP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. In press.
- European Commission, DG XVII (1995). European Wind Turbine Catalogue. THERMIE Programme Action No. WE 15. Produced by Energy Centre Denmark, Copenhagen, for the European Commission, Directorate-General for Energy (DG XVII). 63 pp.
- Frandsen, S. and B.M. Pedersen (1990). Recommended practices for wind turbine testing. 1. Power performance testing. 2. edition. Available from B.M. Pedersen, Technical University of Denmark, Building 404, DK-2800 Lyngby, Denmark. 30 pp.
- Mortensen, N.G., L. Landberg, I. Troen and E.L. Petersen (1998). Wind Atlas Analysis and Application Program (WASP). Vol. 1: Getting Started. Risø-I-666(v.1)(ed.2)(EN). Risø National Laboratory, Roskilde. 30 pp.
- Mortensen, N.G., L. Landberg, I. Troen and E.L. Petersen (1993). Wind Atlas Analysis and Application Program (WASP). Vol. 2: User's Guide. Risø-I-666(v.2)(EN). Risø National Laboratory, Roskilde. 133 pp.
- Mortensen, N.G. and E.L. Petersen (1998). Influence of topographical input data on the accuracy of wind flow modelling in complex terrain. Proceedings of the *1997 European Wind Energy Conference*, Dublin, Ireland, October 6-9, 317-320.
- Rathmann, O., N.G. Mortensen, L. Landberg and A. Bowen (1996). Assessing the accuracy of WASP in non-simple terrain. Wind Energy Conversion 1996. Proceedings of the *18th British Wind Energy Association Conference*, Exeter, England, 25-27 September 1996, 413-418.
- Rutkis, J. (1971). Tables on relative relief in middle and western Europe. University of Uppsala, Department of Physical Geography, UNGI Rapport 9. 21 pp.
- Troen, I. and E.L. Petersen (1989). *European Wind Atlas*. Risø National Laboratory, Roskilde. 656 pp. ISBN 87-550-1482-8.
- William-Olsson, W. (1974). A map of the relative relief of the western half of Europe, 1:4 000 000. Esselte Map Service, Stockholm.
- Wood, N. (1995) The onset of separation in neutral, turbulent flow over hills. *Boundary-Layer Meteorology* **76**, 137-164.

*WAsP Utility Programs 3.0*

Copyright © 1993-2004 by Risø National Laboratory.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, without the express written permission of Risø National Laboratory. The information in this manual is subject to change without notice and does not represent a commitment on the part of Risø National Laboratory. The WAsP program and associated software is furnished under a license agreement and may be used or copied only in accordance with the terms of this agreement. The enclosed disk(s) may be copied solely for backup purposes.

Neither Risø National Laboratory nor any person acting on behalf of Risø is responsible for the use which might be made of the information presented in this publication.

## **Mission**

To promote an innovative and environmentally sustainable technological development within the areas of energy, industrial technology and bioproduction through research, innovation and advisory services.

## **Vision**

Risø's research shall **extend the boundaries** for the understanding of nature's processes and interactions right down to the molecular nanoscale.

The results obtained shall **set new trends** for the development of sustainable technologies within the fields of energy, industrial technology and biotechnology.

The efforts made shall **benefit** Danish society and lead to the development of new multi-billion industries.