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Vol. 1: Getting started

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Introduction

Dear User - welcome to WAsP, a World of creating regional wind atlases and making optimal siting of wind turbines. For newcomers this world may look complicated and dangerously full of pitfalls. And indeed it is so, therefore one of the main purposes of WAsP is to guide you as safely as possible from data to regional wind resources and annual wind turbine productions. This is no easy task, it requires many powerful tools for a wide range of situations. WAsP is a complete toolbox at your disposal, dedicated to the task. A toolbox which contains tools you do not even need to know the existence of, or how they were made and how they function. They are simply there doing the work for you, often through complicated and intriguing calculations. What you need to do is to input your wind data, wind turbine data, and topographical information to WAsP. Then you can begin to ask questions like: what if I place the turbine at the foot or on top of the hill? ... or perhaps move the turbine closer to the sea-shore instead? Or move it to somewhere else in the region or change the hub height or use another type of wind turbine?

WAsP has a very flexible and general in- and output system for data and this is the reason why the User's Guide at a first glance may look complicated and inaccessible. May we suggest that the first thing you do is to get acquainted with WAsP by going through the comprehensive examples in Chapters 3 and 4 of *Getting Started* and read the general description in Chapter 2 of the *User's Guide*. This will enable you to perform most of the siting calculations that occur in practice. The next step will quite naturally be to do a WAsP session on your own data following the procedure given in the examples. If the format of your wind data differs from the example, you will have to consult Chapter 6 and for input information on terrain roughness, hills and shelter also Chapters 3, 4, and 5. How to store the results on disk files is described in Chapter 10 which also explains the facilities for printing and plotting the results of a WAsP session.

If you are in the category of users whose ambition it is to become the company expert on wind resources and siting you must take the time necessary to study the entire manual. Only by doing this will you experience the full power of WAsP. Further, we strongly recommend you to read through the text of the European Wind Atlas (Troen and Petersen, 1989) which was created by and together with WAsP.

A few words of warning. The reliability of the results of a WAsP session will never exceed the reliability of the input data. Especially important is the accuracy of the wind information, the terrain height information, and the power curve of the wind turbine. A discussion of how uncertainties on these quantities affect the significance of the calculated power production is given in the European Wind Atlas, which also discusses the limitations of the methodology employed by WAsP. One basic constraint on the wind information is that it should be climatologically representative, which means that the data must cover several years, but not necessarily a 30-year standard climatological period. Short periods give high uncertainties and the use of periods of less than one year should be avoided.

The largest expected errors in results produced by WAsP are related to the calculation of flow in complex terrain. Empirically, the orographic model is found to work well for the prediction of flow perturbations over not too steep hills and ridges. The typical model-induced error is of the order of 10% in estimates of relative increase of wind speed on top of a hill which has horizontal dimensions of less than 1-2 km and slopes less than 30%. For steeper hills and ridges the model will underpredict the degree of speed reduction in the lee of the hill (as will other

similar models). This effect becomes quite pronounced for steep hills where the flow behind the hills separates.

Larger scale orographic features render the model increasingly deficient because of the importance of the dynamics not present in the model. It is difficult to estimate the magnitude of typical errors, but for most common applications, where the wind conditions are estimated close to the point of measurement, results will be only marginally influenced by the details of flow on larger scales.

Always judge carefully the results obtained in hilly or mountainous terrain. And quite generally, never consider a result final before you have examined and critically evaluated all the steps that have lead to it. WAsP has several features which are helpful in this process, especially the graphics, but in the end nothing can replace experience and sound judgement.

The structure of WAsP

WAsP consists of four main calculation blocks:

Analysis of raw data This option enables an analysis of any time-series of wind measurements.

Generation of wind atlas data Analysed wind data can be converted into a wind atlas data set. In a wind atlas data set the wind observations have been "cleaned" with respect to site specific conditions and reduced to standard conditions.

Wind climate estimation Using a wind atlas data set calculated by WAsP or one obtained from another source - eg the European Wind Atlas - the program can estimate the wind climate at any particular point by performing the inverse calculation as is used to generate a wind atlas.

Estimation of wind power potential The total energy content of the mean wind is calculated by WAsP. Furthermore, an estimate of the actual, yearly mean power production of a wind turbine can be obtained by providing WAsP with the power curve of the turbine in question.

Figure 1 is a schematic presentation of the wind atlas methodology of WAsP. The program contains an *analysis* and an *application* part which may be summarized in the following way:

Analysis:

time-series of wind speeds and directions	→	wind statistics
wind statistics + site description	→	wind atlas data

Application:

wind atlas data + site description	→	estimated wind climate
estimated wind climate + power curve	→	estimated power production

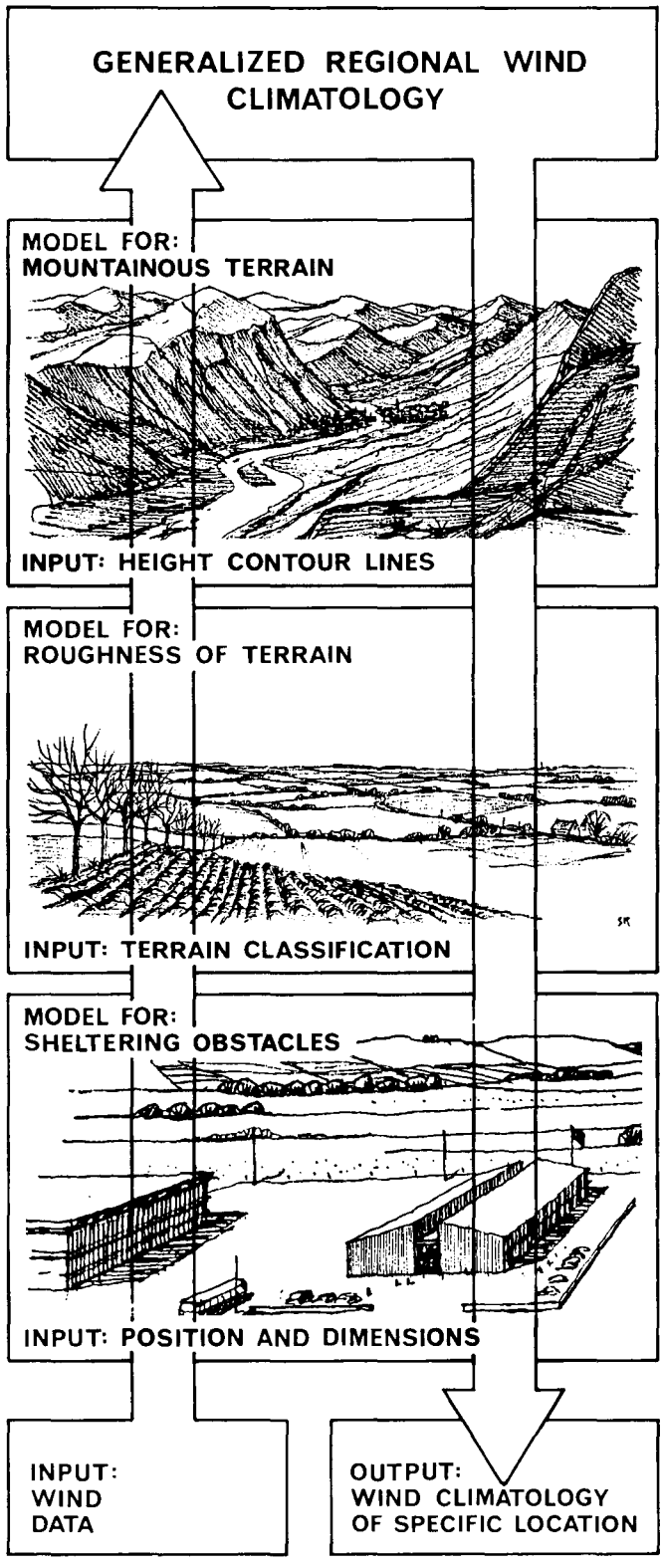

Figure 1. The wind atlas methodology of WASP. Meteorological models are used to calculate the regional wind climatologies from the raw data. In the reverse process - the application of wind atlas data - the wind climate at any specific site may be calculated from the regional climatology.

1 Before you begin

The complete WAsP package contains the following items:

1. WAsP - Getting Started (Vol. 1)
2. WAsP - User's Guide (Vol. 2)
3. *PARK* - User's Guide
4. WAsP and *PARK* installation diskette

The installation diskette contains a table of contents, `WASP41.TXT`, listing the files distributed on the diskette. The disk may also contain a `README.TXT` file with the latest information. You may also check `www.wasp.dk`.

1.1 Distribution and support

The WAsP package and User's Guides are distributed solely by:

Wind Energy and Atmospheric Physics Dept.	Phone:	(+45) 46 77 50 00
Risø National Laboratory, VEA-125	Fax:	(+45) 46 77 59 70
P.O. Box 49	e-mail:	gylling@risoe.dk
DK-4000 Roskilde		ole.rathmann@risoe.dk
Denmark		lars.landberg@risoe.dk
Web: www.risoe.dk/amv	Web:	www.wasp.dk

1.2 Hardware requirements

WAsP will run on IBM Personal Computers (PC, XT or AT) and IBM Personal System/2 and true compatible machines with the following characteristics:

- PC-DOS or MS-DOS operating system, version 2.0 or higher
- a double-sided floppy disk drive ($5\frac{1}{4}''$ or $3\frac{1}{2}''$)
- a hard disk drive
- at least 512 kbytes RAM-memory (WAsP occupies approximately 485 kbytes). However, a full 640 kbytes memory is strongly recommended.
- an 8087 or 80X87 mathematical co-processor. Note that all processors of type i486DX and above include the math coprocessor automatically.

Please verify that your machine fulfills these requirements before continuing.

Optional hardware

The following optional hardware is strongly recommended:

- a printer and/or a plotter with HP-GL emulation
- a digitizing tablet - preferably providing both binary and ASCII output

1.3 License Agreement for the use of WAsP

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The WAsP program and associated software has been developed by Risø National Laboratory and all rights belong to this organization. These rights cover every part and further developments of the program, associated software and written documentation. Unauthorized copying of the software and written documentation in any form or by any means is expressly forbidden.

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Distribution

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By opening the sealed disk package, you are agreeing to become bound by the terms of this license agreement.

2 Installing WAsP

The WASP program is furnished on the enclosed diskette, together with utility programs, data files, screen drivers, printer drivers, digitizer drivers as well as some sample data files. The diskette also contains the *PARK* program and associated files.

The WASP files on the diskette have been compressed in order to save space and must be extracted from the files INSTALL1.EXE, INSTALL2.EXE and INSTALLB.EXE. These executable files must be invoked from the directory where you want WASP to be installed. Hence, if you wish to install the program in the directory \WASP on your C: disk, the installation takes the following form:

```
C:\> md wasp
C:\> cd wasp
C:\WASP> a:install1
C:\WASP> a:install2
C:\WASP> a:installb
```

if the diskette is in drive A. The installation files can be copied to low-density diskettes if the PC is not equipped with a high-density diskette drive. Note, that one or more files can also be extracted from the packed files at a later stage, eg:

```
C:\WASP> a:install1 digit.par
C:\WASP> a:install2 *.dev
```

to extract DIGIT.PAR and all *.DEV files, respectively.

Before invoking WASP, the program may have to be tailored to your particular hardware configuration. This is done by changing some of the settings in the so-called *parameter files* using any ASCII text editor. The basic screen and window video modes are determined by parameters #48, #49 and #50 in the file WASP.PAR. Refer to Appendix B in the User's Guide for more information on parameter files.

2.1 Screen set-up

The graphics screen set-up is given in the file GRAPHICS.PAR. The following common graphics adapters are supported by device drivers included on the diskette:

Device name	Resolution	Driver file name	Mode
IBM Color Graphics, CGA	640 × 200	HALOIBMG.DEV	1
IBM Enhanced Graphics, Color EGA	640 × 350	HALOIBME.DEV	4
IBM Enhanced Graphics, Color VGA	640 × 480	HALOIBMV.DEV	7
Hercules Graphics Card*	720 × 348	HALOHERC.DEV	0
WYSE WY-700	1280 × 800	HALOWYSE.DEV	7
AT&T PC-6300 (Olivetti)	640 × 400	HALOINDA.DEV	6

* The Hercules graphics adapter must be initialized before running WASP by typing HGC FULL at the DOS prompt.

Parameters #1 and #2 in the file GRAPHICS.PAR should be set according to the values in the table above. If you cannot use any of the drivers listed, please report to Risø. The graphics screen video attributes (colours etc.) can also be chosen by changing parameters in the file GRAPHICS.PAR. This is particularly important with monochrome monitors as the default modes in GRAPHICS.PAR were chosen with a colour display in mind, see Appendix B in the User's Guide.

Having set up the screen you are now able to run WASP. For a brief demonstration session type:

```
C:\WASP> demo
```

2.2 Printer set-up

It is possible to make a screen-dump on a side printer of eg the orographic map by pressing the >-key while in graphics mode. In order to accomplish this you must enable printing by changing parameter #18 to 1 in GRAPHICS.PAR and install the right printer driver in line 1 of the file PRINT.PAR. The following printers are supported by the inclusion of printer drivers on the diskette:

Printer	Driver file name
Canon LBP-8A2	HALOCNA2.PRN
Epson MX-80, MX-100, FX-80, FX-100, LX-80, IBM graphics	HALOEPSN.PRN
HP LaserJet+ & Series II	HALOLJTP.PRN
HP PaintJet	HALOPJET.PRN
HP ThinkJet	HALOTJET.PRN
Kyocera F-1010 Compact Laser	HALOKLSR.PRN
NEC Pinwriter P5XL, Fujitsu DL2400	HALOFUSU.PRN
Okidata Microline 192+ & 193+	HALOOKIP.PRN
Okidata Microline 292, 293 & 294+	HALOO290.PRN
Okidata Microline 392C, 393C & 394C	HALOO390.PRN

Appendix B in the User's Guide contains additional information on setting up the printer.

Alternatively, the map may be plotted on a plotter with HP-GL emulation or through the use of the SURFER plotting program. For this purpose WASP is capable of making either an HP-GL file (.HPG) or a SURFER file (.PLT) by invoking the Plot option in the map display menu. The file type is determined by parameter #12 in GRAPHICS.PAR.

2.3 Digitizer set-up

Input of map data - height contour lines or roughness change lines - can be done directly from WASP through INPUT in the MAPDATA menu. Parameters #16 and #17 in GRAPHICS.PAR are set according to the type of digitizing tablet in question. The following digitizer pads, as well as any digitizer providing ASCII output, are supported:

Digitizer	Driver file name
Bit Pad One & compatibles	HALOBPOI.COM
GTCO Digi-Pad & compatibles	HALOGTCI.COM
Houston Instrument HIPAD & PCPAD	HALOHIPI.COM
Keyboard Locator Devices	HALOKBDI.COM
Summagraphics MM1201 & MM961 and compatibles	HALOSDTI.COM
ASCII output (CalComp 2000 ASCII and others)	DIGIT.PAR

HALO digitizer driver

Parameter #16 in GRAPHICS.PAR is set equal to 1 in order to invoke the HALO digitizer driver. The proper Halo driver is subsequently installed by typing its name and any options at the DOS prompt, before invoking WASP, eg:

```
C:\WASP> mode com1:96,n,8,1
C:\WASP> halosdti -i8 -x9000 -y9000 -b235 -l-1 -m-1 -r-1
C:\WASP> wasp
```

where i8 means interrupt number 8 - this should correspond to parameter #17 in GRAPHICS.PAR. WASP can then be started by typing wasp at the DOS prompt. This installation procedure is further described in Appendix B, Section B.4.

ASCII digitizer driver

With some digitizing tablets you may experience problems using the HALO digitizer drivers as described above. In such cases we suggest that you use the following procedure:

If parameter #16 is set equal to 3 the WASP internal driver is automatically installed. The set-up of this ASCII driver is specified in the file DIGIT.PAR. The file shipped with the program is valid for a CalComp DrawingBoard emulating 2000 ASCII, but any tablet providing ASCII output can be emulated. Appendix B explains in detail how to specify the digitizer output format.

2.4 Installing the PARK program

The *PARK* program is also furnished in compressed form and should be installed in a similar way as described above:

```
C:\> md park
C:\> cd park
C:\PARK> a:installp
```

if the diskette is in drive A: and the files should reside in C:\PARK. This program detects automatically the graphics card in your computer and you should thus be able to run it right away.

3 Getting acquainted ...

Once you have installed WAsP and chosen the proper graphics driver as described above, you may start the program by typing its name at the DOS prompt followed by pressing the ⟨*Enter*⟩ or ⟨*Return*⟩ key:

```
C:\WASP> wasp
```

A 'front page' or logo screen is then displayed for a few seconds while the program is loaded into the memory of the computer.

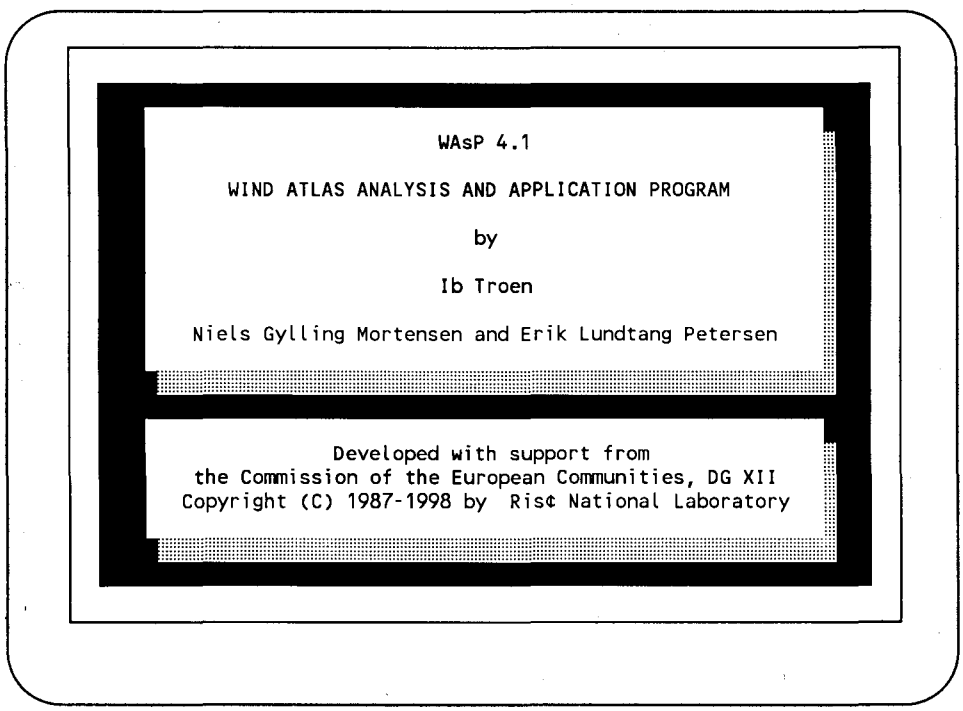

Figure 2. The WAsP logo screen.

Next, the so-called status screen is displayed, the importance of which will become apparent in a short while. At this point you should only note that the program starts out with "Default Wind Atlas Data" and a "Default Site Description", see Fig. 3. The main menu is shown below the status display.

Pressing the ⟨*Return*⟩-key now invokes the entire set of WAsP models and the program calculates the wind climate using the default data mentioned above. When the calculations are done the results are shown in tabular form in the so-called result display, see Fig. 4.

3.1 The world according to WAsP

Since no meteorological or topographical data has been loaded so far, WAsP assumes a simple default set-up. In this world the wind rose is uniform, ie the frequency of occurrence is 8.3 per cent in each of the twelve sectors (the %-column in the result display). The distribution of wind speeds is also the same in all sectors; given by Weibull A and k parameters of 5.2 ms^{-1} and 1.90, respectively. This is calculated for a height of 10 meters above ground level, see Fig. 4. To obtain a graphic display of the wind rose, type `DIS` (for `DISPLAY`) at the `WAsP`-prompt, followed by the ⟨*Return*⟩-key. Next, press any key on the keyboard to see the wind

```
ATLAS
                                        :Default Wind Atlas Data
                                        :

OROGRAPHY
                                        :
                                        :
ROUGHNESS
                                        :
                                        :Default Site Description
OBSTACLE
                                        :
                                        :

DATA                                    WECS

                                        Path C:\WASP\
                                        Dump C:\WASP\WASP.DMP
  DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
  DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WAsP>_
```

Figure 3. The WAsP status display.

speed distribution. Press ⟨*Esc*⟩ to leave graphics mode again. The overall mean wind speed (4.6 ms^{-1}), mean energy density (121 Wm^{-2}) and Weibull A and k parameters are given in the bottom line of the table.

Default terrain

The default terrain is a very simple one: a flat, horizontal plain (0% and 0° in the `Orography` columns), no sheltering obstacles (0% in the `Obstacle` column), and a uniform land surface (0 roughness changes in the `Rch` column). The roughness length of the surface is 0.03 meters: type `ROU` (for `ROUGHNESS`) at the `WAsP`-prompt, followed by the ⟨*Return*⟩-key, and then `EDI` followed by the ⟨*Return*⟩-key to see the roughness lengths. As in the result display the twelve sectors are specified by their center azimuth angles. Press the ⟨*Return*⟩-key twice to return to the main menu.

3.2 Erecting your first wind turbine

A wind turbine can be 'erected' and its power production estimated by loading the power curve of the wind turbine. Type `WEC` at the `WAsP`-prompt (for `WECS`: Wind Energy Conversion System) to load a power curve. When WAsP asks

```
Name of power curve file [.POW] ?
```

respond with an asterisk (*) to see all the power curves (stored in `*.POW` files). Choose one by typing eg `WECS251`. A question mark is now displayed by WAsP in the lower right-hand corner of the result display. This indicates that calculations have not been updated with the current set-up. Press ⟨*Return*⟩ to execute the models and calculate the power production. The height has now been changed to the hub height of the turbine (30.5 m) and the power production is shown in the bottom line of the table: P = 327.9 $MWh\,y^{-1}$. Evidently, the parameters of the wind speed distributions have also changed, by virtue of the new height, to A = 6.2 ms^{-1} and k = 1.90.

```
Default Wind Atlas Data                                          11/ 6/98 14:34

                                                        Height:   10.0 m a.g.l.
 Sect  Rch      Input      Obstacle   Orography          A    k     %    E%
 ----------------------------------------------------------------------------
   0:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
  30:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
  60:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
  90:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 120:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 150:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 180:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 210:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 240:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 270:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 300:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 330:   0   0.0%   0°   0.0%   0.0%   0°  :   5.2  1.90  8.3  8.3
 ----------------------------------------------------------------------------
 M=  4.6 m/s    E=  121. W/m²                          5.2  1.90
 ----------------------------------------------------------------------------
  DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
  DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WAsP>_
```

Figure 4. The WASP result display.

The hub height of the wind turbine was read by WASP in the power curve file WECS251.POW. To estimate the power production for another hub height, type HEI (for HEIGHT) and enter a new height, eg 40 for 40 meters. Press ⟨*Return*⟩ to execute the models again and calculate the power production for this height: P = 365.7 MWh y^{-1} (12% more than for the 30.5 m tower).

To confirm which wind turbine was used for the calculations above, press the ⟨*Return*⟩-key one more time, to switch to the status display. The answer is in the WECS box in the lower right-hand corner of the display:

```
C:\WASP\WECS251.POW
Micon M530 (250 kW)
```

ie we have used the power curve for a 250-kW Micon turbine, loaded from the file C:\WASP\WECS251.POW.

Before proceeding you should change the height to 30.5 m again and switch to the result display.

3.3 When the going get's rough ... or smooth

Next, we'll make some simple changes to the (rather boring) default landscape. Suppose we moved the wind turbine to an off-shore location. What would the power production be then? Type ROU to enter the ROUGHNESS menu and EDI to see the roughness rose. Then, at the EDIT prompt, type:

```
EDIT> 0-360:0.0
```

A roughness length of 0 (zero) meters tells WASP that we're dealing with a water surface. Press ⟨*Return*⟩ to go back to the ROUGHNESS menu, press ⟨*Return*⟩ once more to get to the main menu, and press ⟨*Return*⟩ to execute the models and estimate the wind climate and power production over water: P = 620.3 MWh y^{-1} (89% more than for the land site).

An off-shore location may not be feasible. How about a coastal site? Type ROU to enter the ROUGHNESS menu and EDI to see the roughness rose. Then, at the EDIT prompt, type:

```
EDIT> 0-150:0.03
```

Now we have introduced a land surface in the sectors 0 to 150, ie from 345 through 165 degrees clockwise while the sectors 180 to 330 remain set to 0, ie the roughness length of water. Press the ⟨*Return*⟩-key three times to calculate the wind climate and power production at the coastline: P = 480.7 MWh y^{-1} (47% more than for the inland site).

3.4 Moulding the terrain surface

As shown above, the wind climate and power production of a wind turbine is strongly dependent on the distribution and size of roughness changes. Another important influence from the terrain comes from the orography, ie the geometry or height variations of the terrain. Suppose we erected the wind turbine on top of a simple hill - what power production could we expect then?

First, change the land surface to a uniform plain with a roughness length of 0.03 m and then return to the main menu, ie:

```
WAsP> ROU
ROUGHNESS> EDI
EDIT> 0-360:0.03
EDIT> <Return>
ROUGHNESS> <Return>
```

Next, type ORO to enter the OROGRAPHY menu and then HIL to generate a simple bell-shaped hill. The next four questions concern the dimensions and orientation of the hill; answer them as follows:

```
Height of hill (m) ?   25
Location of hill center (x,y) ?   0,0
Orientation of major axis ?   165
Half-widths in metres ?   100,200
```

In this case we have specified a 25-meter high elongated hill with the major axis oriented in the direction 165-345°. The half-widths are defined here as the distances from hill center to points halfway to the base of hill in the direction of the major and minor axis. With half-widths of 100 and 200 meters, respectively, the 'footprint' of the hill is thus approx. 400 × 800 m^2.

When the hill has been specified you're back in the OROGRAPHY menu. Type SIT to tell WAsP where the turbine should be located on the hill. WAsP will now display a contour map of the hill with a cross indicating the position of the turbine. Press ⟨*Shift*⟩⟨*S*⟩ to chose the top of the hill and ⟨*Return*⟩ to run the WAsP models and calculate the wind climate and power production at the top of the hill: P = 461.6 MWh y^{-1} (41% more than for the uniform land site).

Try the same exercise with a 50-m hill having the same horizontal dimensions and orientation as above. However, instead of pressing ⟨*Shift*⟩⟨*S*⟩ to chose the location of the site, press ⟨*Esc*⟩ when the map is displayed. WAsP will then inquire for the coordinates of the site and you may enter 0, 0 to specify the top of the hill. Run the models again by pressing ⟨*Return*⟩ and get the power production for the hill: P = 599.9 MWh y^{-1} (83% more than for the uniform site).

The result display shows the sector-wise changes of the wind speed and direction compared to the flow over flat terrain. Note that the wind rose is no longer uniform, because of the turning of the wind induced by the terrain.

The table below summarizes the results of our calculations so far. It is evident that the changes we've made to the default landscape has had a pronounced influence on the wind climate and power production.

Hub height [m]	Roughness [m]	Orography	Mean wind [ms^{-1}]	Production [$MWh\,y^{-1}$]	Relative prod.
30.5	0.03	plain	5.5	327.9	1.00
40.0	0.03	plain	5.7	365.7	1.12
30.5	0.0	sea	7.1	620.3	1.89
30.5	0.0/0.03	sea/plain	6.3	480.7	1.47
30.5	0.03	25-m hill	6.2	461.6	1.41
30.5	0.03	50-m hill	7.0	599.9	1.83

Real landscapes are, of course, much more complicated than the simple situations we've looked at here. The distribution of areas of different roughness and the geometry of the terrain are conveniently represented in topographical maps. WASP therefore contains tools to input, display, edit, merge, store and retrieve the information stored in such maps. The example in Section 4 below is based on a digital map rather than the sector-wise descriptions employed above.

3.5 Winds in the real world

So far we've only made changes to the default terrain or site description. By doing so we get information on the influence of different terrain features and it is possible to evaluate the terrain effects at different sites. However, in order to estimate the actual power production at one or more sites, and to rank possible sites with respect to their wind energy potential, we need information on the actual wind climate. This information is contained in a so-called wind atlas.

Type `ATL` at the `WAsP`-prompt to enter the `ATLAS` menu; then `REL` to retrieve an existing wind atlas data set. WASP then asks

```
Name of wind atlas file [.LIB] ?
```

Respond with an asterisk (*) to see all the wind atlas data stored in `*.LIB` files. Choose a wind atlas file by typing eg `WASPDALE` followed by pressing the ⟨*Return*⟩ key. Re-analyzing the examples above with this 'real-world' data set leads to the following results, cf the table above:

Hub height [m]	Roughness [m]	Orography	Mean wind [ms^{-1}]	Production [$MWh\,y^{-1}$]	Relative prod.
30.5	0.03	plain	4.8	158.4	1.00
40.0	0.03	plain	5.1	190.6	1.20
30.5	0.0	sea	6.1	359.3	2.27
30.5	0.0/0.03	sea/plain	5.7	311.3	1.97
30.5	0.03	25-m hill	5.5	268.3	1.69
30.5	0.03	50-m hill	6.2	400.2	2.53

Note, that while the terrain corrections have not changed, the relative productions differ from the numbers given above because of the non-uniform, sector-wise distribution of the wind.

4 Carrying on . . .

In this chapter a complete siting using WASP will be carried out. The individual steps will be described. The entire demonstration can be run automatically, by changing the current directory to the directory where all the WASP files reside, and then typing:

```
demo
```

or you may choose to run WASP in interactive mode as described below.

4.1 Description of the problem

The company *Friends of Wind Energy, Waspdale Ltd.* has asked you to calculate the expected power output from a 600 kW wind turbine, situated at the summit of Waspdale Hill, see Figure 5. There are no meteorological measurements at the site, but you have been provided with a time series of wind speed and direction from the nearby Waspdale Airport, situated to the east of Waspdale Lake (file name: `RAWDATA.DAT` or `RAWDATA.BIN`).

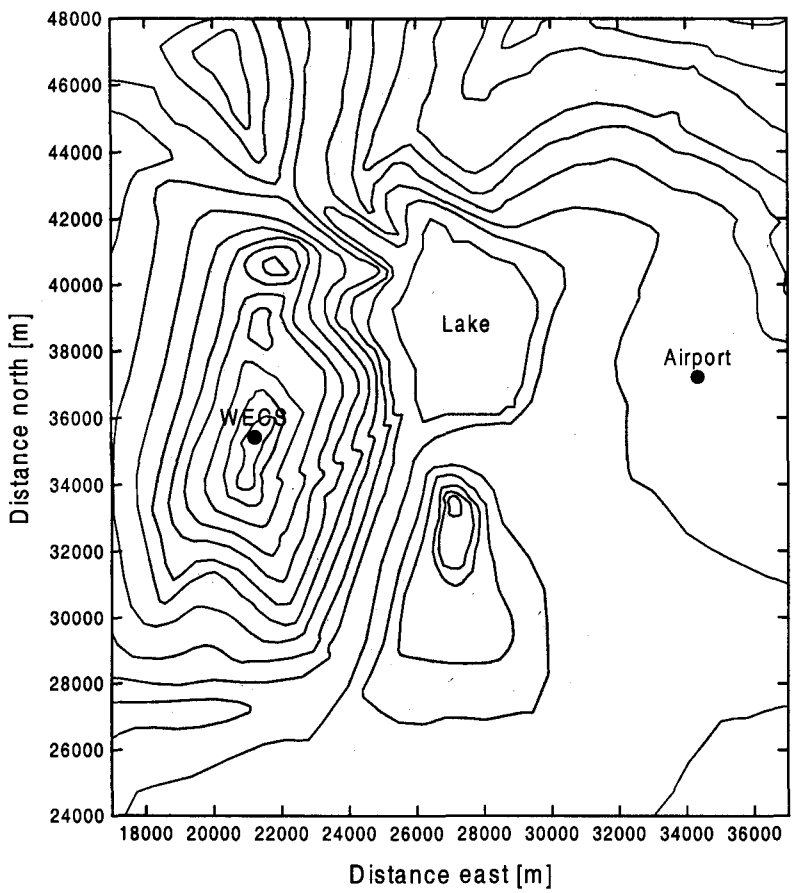

Figure 5. Waspdale with Waspdale Lake and Waspdale Hill. The coordinates of the mast in the airport are (34348 m E, 37233 m N) and of the turbine site (21229 m E, 35423 m N).

4.2 Solution to the problem

Since the meteorological measurements are affected by the local characteristics of the measurement site, it is necessary to 'clean' the data for these local effects before they are used at a new site. These effects are: shelter from nearby obstacles, such as houses, hangars, shelter belts etc; the effect of roughness, and the effect of the orography (height variations of the terrain). To quantify these effects you need:

- Description of the dimensions and location of near-by obstacles.
- Description of the roughness of the surrounding area.
- Digitized height contour map of the site.

These items will be looked into in more detail in the following.

Obstacles

From a visit to the site you have found that the meteorological mast might be affected by the shelter of 8 obstacles, see Figure 6. To model the sheltering effects, information about the following quantities is needed: the position relative to the mast (in the form of the angle (from north) and the distance of the two nearest corners), the height, the depth, and the porosity (ie the amount of empty space of the obstacle relative to the space that the obstacle takes up; a house has the porosity 0.0 (all solid)). These quantities for the 3 identified obstacles are as follows:

	α_1	r_1	α_2	r_2	h	d	P	
1	11	134	26	120	6	30	0.0	hangar
2	26	120	43	110	6	60	0.0	house
3	112	500	146	74	5	16	0.4	row of trees, dense
4	200	90	248	76	4	26	0.0	house
5	215	154	237	144	6	46	0.0	house
6	278	116	352	150	6	6	0.7	row of trees, thin
7	295	150	345	196	6	6	0.7	row of trees, thin
8	305	196	341	250	6	6	0.7	row of trees, thin

This information can be found in the ASCII file `AIRPORT.OBS`.

Roughness

Looking at the map of Waspdale (Figure 5) it can be seen that there are only two types of roughness: land and water. Since the land is very open with only a few buildings, all land areas are assigned the roughness length 0.03 m. The lake (water) is assigned a roughness length of 0 m.[1]

Orography

From Waspdale Geological Survey you have been provided with a 1:25 000 scale digital map of the area, this map also contains the borderlines of the roughness areas.

[1] Actually water has a roughness length of approx. 10^{-4} m, but in order to signal to WAsP that it is water and not a very smooth land surface (with different stability properties) water areas are assigned the roughness length 0.0 m.

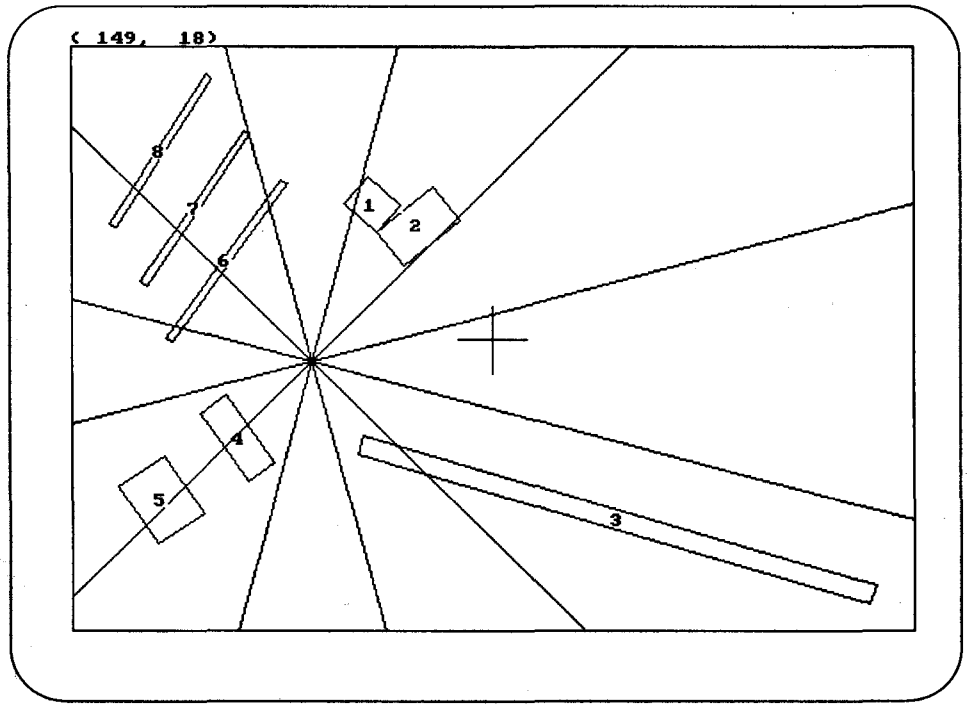

Figure 6. Obstacles close to the meteorological mast at Waspdale Airport.

The power curve

In order to be able to calculate the expected power production of the turbine a *power curve* (ie a curve with the power output of the turbine plotted versus the wind speed) is needed. Waspdale Wind Turbines Ltd. have provided you with this (file `V39_600.POW`).

4.3 The WAsP analysis

Since all the input data are now lined up, the WAsP program can be used to calculate the expected power production.

To start the program, the current disk and directory must be set to the directory where the WAsP files reside, this could look like:

```
CD WASP
```

When in the WAsP directory the program is started by typing:

```
WASP
```

The start up screen will be displayed for a few seconds while the program is loaded. When this is completed the status screen and the main menu are displayed.

The key words listed in the main menu are the possible options from this menu; to load meteorological data you select the DATA menu by typing[2]

```
DAT
```

The data menu is now displayed instead of the main menu:

```
RAWDATA TABLE DISPLAY
DOS HELP RETURN
```

[2]All commands can be abbreviated to their three first letters.

Since the data provided are in the form of a time series, the RAWDATA entry is selected by typing:

```
RAW
```

You are now prompted for the name of the file containing the meteorological data. To get a list of all files with the extension DAT we type:

```
*
```

From this list we select the data file containing the data in question by typing[3]:

```
RAWDATA
```

You are now asked to specify the data format. Since in this case the data are ASCII with the first number in the record being the date/time, the second the wind speed and the third the wind direction, the format is as follows:

```
* 2 3
```

Next you are asked for the minimum and maximum wind speed (and also for the calm threshold), the default is from 0 to 90. This option can be used to exclude missing data (marked with eg 999.9). In this case the default values can be accepted, this is done by pressing

⟨*Return*⟩

The next question is about the minimum and maximum values for the wind direction, here we also choose the default values (ie from 0 to 360), so we press

⟨*Return*⟩

Since all units in WAsP must be SI-units, the wind speed must be given in ms^{-1} and the direction in degrees. If this is not the case you must enter the scale factor and offset for the wind speed at the next question and the two parameters for the wind direction at the following question. It is possible at any point during the WAsP session to get context-specific help. This is done by entering:

```
?
```

In this case different conversion factors are displayed. Press

⟨*Return*⟩

to leave the help screen, and get back to the prompt. In our case the wind speed is in ms^{-1}, so we accept the default by pressing

⟨*Return*⟩

and the wind direction is given in degrees, which is the default, therefore we press

⟨*Return*⟩

Finally, you are asked to specify the discretisation widths for wind speed and direction. This is used to tell WAsP that the resolution of your measuring device or the data you have acquired is poorer than 0.1 ms^{-1} and 1 degree for speed and direction, respectively. Again, our data have a discretization of 0.1 ms^{-1} for speed and 1 degree for direction, we therefore accept the default by pressing

⟨*Return*⟩

Now that the data window and the scaling of the data have been determined, the time series is displayed, 4000 records at a time. This very handy display can be

[3] If no extension is given, the extension in brackets is used, here: .DAT.

used to check the quality of the data. Using the arrow keys it is possible to move the cursor checking the individual values. By pressing

W

it is possible to zoom in on a part of the series. The window can be moved by using the left and right keys and expanded by the up and down keys. By pressing the space bar

<SPACE>

a scatter plot (ie a plot where the u- and v-components of the part of the time-series displayed are plotted along the x- and y-axis, respectively) is displayed. Using the arrow-keys makes you step through the time series: If you press

⟨*Return*⟩

the next 4000 records will be displayed, and so on until you reach the end of the file.

When the last data record has been read, you will be prompted as to whether you want to read more data (from another file, eg data from the following month) into the program or whether this is the end of the time series. Since the latter is the case, we press

⟨*Return*⟩

to accept the default. (we could also have typed E and then ⟨*Return*⟩). The result of the raw data analysis is now displayed:

```
Summary of data in file : C:\WASP\RAWDATA.DAT                          [per mille]
Number of observations  :    8760      Observations skipped:   246
Number of reading errors:       0      Wind speed bin width:   1.0 m/s
```

Sect	Freq	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A	k
0:	2.0	48	174	311	144	168	132	24	0	0	0	0	0	0	0	3.5	2.08
30:	4.4	32	90	201	241	169	122	48	66	21	11	0	0	0	0	4.4	2.00
60:	5.6	23	159	251	263	138	73	44	27	13	10	0	0	0	0	3.9	1.86
90:	7.5	34	113	226	235	213	125	38	13	3	0	0	0	0	0	4.1	2.65
120:	6.2	28	113	202	218	211	149	38	24	13	4	0	0	0	0	4.3	2.49
150:	5.3	42	80	171	247	216	153	44	18	9	18	2	0	0	0	4.5	2.32
180:	7.8	24	47	130	214	226	181	84	29	24	35	8	0	0	0	5.1	2.23
210:	8.4	21	59	122	166	129	140	133	98	64	48	20	1	0	0	5.9	2.27
240:	12.2	11	25	57	99	152	156	153	132	89	105	20	3	0	0	6.9	2.73
270:	15.7	13	32	61	133	132	141	152	102	78	110	38	6	2	2	6.9	2.33
300:	16.8	10	52	84	136	137	172	165	87	59	73	17	2	1	3	6.4	2.34
330:	8.1	12	82	198	201	157	127	98	51	35	32	7	0	0	0	4.9	1.97
Total		20	68	135	175	162	145	108	69	46	54	14	2	1	1	5.5	2.00

```
Number of calms (included):      0          Mean wind speed:   4.9 m/s  (   0%)
                                          Mean energy density:   135 W/m²  (   2%)
  DISPLAY DUMP DOS RETURN
RAWDATA>_
```

Figure 7. Summary display of the measured time-series.

We now want to store this histogram table on a disk file. This is done by typing

DUM

and then specifying a file name. In our case we type

```
RAWDATA
```

to store the file as RAWDATA.TAB. You are asked to enter some text describing the histogram, here we type

```
Waspdale Airport 1983-85. Runway NW anemometer.
```

Finally you are asked to give the latitude, longitude, and the height of the anemometer, we type

```
-55.7 -167.9 12
```

We have now loaded the data into the program and we want to 'clean' them for the effects of the surrounding topography. This is done by introducing the files representing the different local effects (shelter from obstacles, the different effects of the roughness, and the effect of the orography) in order for WASP to calculate the effects.

First of all we want to return to the main menu, and we press

⟨*Return*⟩

Next, we introduce the *obstacles* - choosing the OBSTACLE menu by typing

```
OBS
```

in the main menu. Since we already have a file containing the obstacle descriptions we type

```
REL
```

to reload the file. We are asked for the name of the file, and we type

```
AIRPORT
```

to get the file AIRPORT.OBS. The obstacles have now been loaded and they are displayed by typing

```
DIS
```

in the OBSTACLE menu, see Fig. 6. Here it is possible to check if the position and dimensions of the different obstacles are as expected. Furthermore, a window can be made to zoom in on parts of the map. By pressing

⟨*Esc*⟩

we leave the obstacle display.

We now want to return to the main menu so that we can load the roughness description. This is done by pressing

⟨*Return*⟩

To select the roughness menu we type

```
ROU
```

at the main menu, and the roughness menu is displayed

```
MAPDATA SITE EDIT TEXT DUMP RELOAD
DOS HELP RETURN
```

Since the roughness description is in the form of a roughness map we select the MAPDATA option, by typing

```
MAP
```

From the mapdata menu we want to reload the roughness map and we type

```
REL
```

We are then asked to enter the name of the file:

```
WASPDALE
```

The file containing the digitized roughness lines (and also the height contours) has now been loaded, cf the status screen. To check the map, we type

```
EDI
```

The map is now displayed. It is possible here to move the cross-hair around by using the arrow keys. The coordinates of the cross-hair are shown in the upper left corner of the screen. By pointing at a line with the cross-hair, and pressing

```
V
```

the value of the line will be displayed. It is possible to zoom in on an area by moving the cross-hair to the area and press

```
W
```

The window size can be adjusted using the arrow-keys; when the window is as wanted press

⟨*Return*⟩

to display the selected area. The EDIT screen is left by pressing

⟨*Esc*⟩

Since this file contains roughness information as well as information on the orography (altitudes), we now have all the data the program needs to calculate the local effects.

We must do one final thing, however, which is to tell the program where on the map the meteorological mast is situated. This is done by pressing

⟨*Return*⟩

to go to the roughness menu, and then

```
SIT
```

The map is now displayed, and we have two options: one is to move the cross-hair (by using the arrows) to the site and then press S; or we can press ⟨*Esc*⟩ to leave the map display, we are then asked to enter the coordinates. We choose the last option, so we press

⟨*Esc*⟩

and then we enter the coordinates of the meteorological mast:[4]

```
34348,37233
```

WASP now performs the terrain effects calculations, and determines the roughness rose. The roughness rose can be inspected in the roughness menu

```
ROU
```

In the roughness menu select the EDIT option, to look at the roughness rose, by typing

[4]It is generally a good idea to check that the coordinates of the site correspond to the expected location on the map. This is done by moving the cross-hair to the position of the site, and checking the coordinates displayed in the upper left corner, before pressing ⟨*Esc*⟩.

EDI

The roughness rose is now displayed. At this point it is possible to correct the values in the rose, but since we judge the rose to be correct we just press

⟨*Return*⟩

to get back to the roughness menu and

⟨*Return*⟩

to get back to the main menu.

Now we want to calculate the generalized wind climate or *wind atlas*, that is, the distribution of wind speeds and directions corrected for the local effects (shelter, roughness and orography). This is done by choosing the ATLAS menu in the main menu by typing

ATL

To calculate the atlas we type

GEN

the program now performs the calculations. To save the wind atlas data set we type

DUM

in the ATLAS menu. You are asked to enter the name of the wind atlas file (*.LIB), type

WASP-AIR

to remind you that the data are from Waspdale Airport. In order to get an idea of the accuracy of the model calculations, it is now possible to predict the stations wind climate. This is done using the clean data generated from the the original data. By pressing

⟨*Return*⟩

we go to the main menu. Pressing

⟨*Return*⟩

again, the station is predicted using its own data. Note that the height is 10 m - for comparison with the original measurements (Fig. 7) the height needs to be set to 12 m. This is done by typing

HEI

and then,

12

to set the height to the new value. In the lower right-hand corner a question mark is now displayed, this is to indicate that the values on the screen do not reflect the current set-up (in our case we have changed the height). To recalculate all we have to do is to press:

⟨*Return*⟩

The prediction of the stations wind climate is now displayed, see Fig. 8. This should be compared to the measured data, Fig. 7.

Waspdale Airport 1983-85. Runway NW anemometer. 11/ 6/98 14:40

+ WASPDALE, CARTESIAN COORDINATES (UTM) Height: 12.0 m a.g.l.

Sect	Rch	Input		Obstacle	Orography			A	k	%	E%
0:	0	0.0%	0°	-4.0%	-1.5%	-1°	:	3.9	2.00	2.3	0.8
30:	0	0.0%	0°	-13.2%	-2.7%	0°	:	4.4	2.06	4.4	2.3
60:	0	0.0%	0°	-1.4%	-1.4%	1°	:	3.9	1.90	5.6	2.2
90:	0	0.0%	0°	0.0%	0.9%	1°	:	4.1	2.56	7.4	2.5
120:	0	0.0%	0°	-3.9%	2.0%	0°	:	4.3	2.48	6.3	2.6
150:	0	0.0%	0°	-4.0%	0.8%	-1°	:	4.5	2.32	5.4	2.6
180:	0	0.0%	0°	-0.1%	-1.5%	-1°	:	5.1	2.22	7.7	5.7
210:	0	0.0%	0°	-8.5%	-2.7%	0°	:	5.9	2.26	8.5	9.6
240:	0	0.0%	0°	-9.7%	-1.4%	1°	:	6.9	2.71	12.3	19.0
270:	4	0.0%	0°	-1.2%	0.9%	1°	:	6.8	2.35	15.5	25.6
300:	2	0.0%	0°	-8.1%	1.9%	0°	:	6.3	2.40	16.5	21.0
330:	0	0.0%	0°	-10.3%	0.8%	-1°	:	5.0	1.97	8.1	6.2
M= 4.9 m/s		E= 134. W/m²						5.6	2.09		

DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WAsP>_

Figure 8. The estimated wind climate at the meteorological mast, predicted using the wind atlas generated from the measured data.

The calculated wind atlas can be used to predict the wind climate at a different location within some distance from the mast. This distance is dependent on the conditions at the specific site: the existence and characteristics of any local wind regimes and the complexity of the surrounding topography.

When the wind atlas is to be applied at a new site the local effects of this site must be taken into account, that is the effect of shelter from obstacles, roughness, and orography. The procedure is shown in the following section.

Finally, return to the status screen by pressing ⟨*Return*⟩.

4.4 The WAsP application

We will now use the generated wind atlas to estimate the wind climate at the proposed wind turbine site. This is done by repeating the procedure we just have carried out in the opposite order:

First of all we want to enter the map of the terrain. This is done by choosing the OROGRAPHY menu by typing

```
ORO
```

in the main menu. To use digital maps we select MAPDATA by typing

```
MAP
```

and to reload the map we type

```
REL
```

We are now prompted for the name of the file, and we type

```
WASPDALE
```

to load the file WASPDALE.MAP. Since the proposed wind turbine site is on the same map as the meteorological mast, and we have already reloaded that map to calculate the effect of the terrain at the mast site, it is actually not necessary to repeat the reloading. However, since it is often the case that the map of the mast and the map of the proposed site is not the same, the procedure has been repeated here for completeness.

Press

⟨*Return*⟩

to get to the OROGRAPHY menu and

⟨*Return*⟩

to get back to the main menu.

We now need to enter the roughness, but since the roughness map is imbedded in the orographic map, this is already done. All we must do is to tell the program where on the map the site is located, this is done by entering the ROUGHNESS (or OROGRAPHY) menu by typing

```
ROU
```

in the main menu. Typing

```
SIT
```

the map of the area is now displayed. Since we know the coordinates of the wind turbine site we press

⟨*Esc*⟩

to leave the map display screen. Then the coordinates are entered at the prompt, by typing

```
21229,35423
```

The effect of the terrain at the new position is now calculated together with the roughness rose.

Since there are no obstacles at the new site (and they certainly are not the same as the ones at the mast site) we must type

```
-OBS
```

to remove the obstacles from the calculations. Notice that the obstacle file name disappears from the OBSTACLE box.

Finally, we want to calculate the production of the 600 kW turbine, this is done by choosing the WECS option at the main menu by typing

```
WEC
```

We are now asked for the name of the file with the power curve of the turbine, and we type

```
V39-600
```

to reload the file V39_600.POW.

Everything is now lined up to perform the calculations and your status display should be as shown in Fig. 9.

```
ATLAS
                                        :Waspdale Airport 1983-85. Runway NW anemometer.
C:\WASP\WASP-AIR.LIB                    :Waspdale Airport 1983-85. Runway NW anemometer.

OROGRAPHY
C:\WASP\WASPDALE.MAP                    :+ WASPDALE, CARTESIAN COORDINATES (UTM)
(    21229,    35423),      350)        : dr,  R  :    5.3    30000.
ROUGHNESS
C:\WASP\WASPDALE.MAP                    :+ WASPDALE, CARTESIAN COORDINATES (UTM)
(    21229,    35423)                    :
OBSTACLE
-                                       :-
                                        :

RAWDATA-(12 m a.g.l.)                   WECS
C:\WASP\RAWDATA.DAT                     C:\WASP\V39_600.POW
                                        Vestas V39 (600 kW)
C:\WASP\RAWDATA.TAB
Waspdale Airport 1983-85. Runway NW an  Path C:\WASP\
                                        Dump C:\WASP\WASP.DMP
  DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
  DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WAsP>_
```

Figure 9. Status display for the WECS site.

To calculate the production of the turbine, we just need to press

⟨*Return*⟩

After a short while the screen shown in Fig. 10 (the result display) is displayed. Here you can see (on the bottom line) that the expected yearly power production is 1590 MWh and the mean wind 7.5 ms^{-1}. On the far right the Weibull A and k parameters are shown for each sector. The magnitude of the different local effects are shown in the middle of the table.

```
Waspdale Airport 1983-85. Runway NW anemometer.                11/ 6/98 14:43

+ WASPDALE, CARTESIAN COORDINATES (UTM)                Height:   40.5 m a.g.l.
```

Sect	Rch	Input		Obstacle	Orography			A	k	%	P%
0:	0	0.0%	0°	0.0%	6.4%	-2°	:	5.5	2.31	2.1	0.6
30:	0	0.0%	0°	0.0%	5.6%	2°	:	7.1	2.38	4.2	2.7
60:	3	0.0%	0°	0.0%	10.5%	3°	:	5.9	2.36	5.7	2.1
90:	2	0.0%	0°	0.0%	17.1%	2°	:	6.1	2.95	7.7	2.7
120:	0	0.0%	0°	0.0%	18.2%	-1°	:	6.6	2.85	6.5	3.1
150:	0	0.0%	0°	0.0%	12.8%	-3°	:	6.7	2.67	5.5	2.8
180:	0	0.0%	0°	0.0%	6.4%	-2°	:	7.1	2.57	7.2	4.4
210:	0	0.0%	0°	0.0%	5.6%	2°	:	8.9	2.56	8.1	8.9
240:	0	0.0%	0°	0.0%	11.3%	4°	:	10.7	2.96	12.1	19.3
270:	4	0.0%	0°	0.0%	16.5%	2°	:	10.0	2.65	16.2	23.0
300:	2	0.0%	0°	0.0%	17.7%	-1°	:	10.0	2.74	16.9	23.8
330:	0	0.0%	0°	0.0%	12.8%	-3°	:	7.9	2.26	7.7	6.6

```
M=  7.5 m/s    E=  442. W/m²    P= 1.590 GWh/y      8.5  2.29

  DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
  DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WAsP>_
```

Figure 10. Result display for the WECS site.

To dump the results to a file, we first have to open the dump file by typing

```
:demo
```

this will open the file DEMO.DMP for input, and then type

```
>
```

to dump an exact copy of the result screen. For documentation it is also a good idea to include the status screen, this is done by typing

```
>
```

to dump this screen.

We have now completed the calculation of the estimated energy production. To terminate the WAsP session we type

```
STO
```

To get a hard-copy of the results, all you have to do is to type

```
PRINT DEMO.DMP
```

at the DOS prompt.

Recommended reading

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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 two-volume User's Guide. Volume 1 is an introduction to the program, including a description of the hardware requirements and installation procedure. Volume 2 is the program reference and User's Guide.

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COMPUTER PROGRAM DOCUMENTATION; DATA ANALYSIS; MAPS; RESOURCE ASSESSMENT; SITE CHARACTERIZATION; W CODES; WIND; WIND POWER

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