

Wind Atlas Analysis and Application program (WAsP)

Vol. 2: User's guide

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

Publication date:
1993

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

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Citation (APA):
Mortensen, N. G., Landberg, L., Troen, I., & Lundtang Petersen, E. (1993). Wind Atlas Analysis and Application program (WAsP): Vol. 2: User's guide. Risø National Laboratory. (Risø-I; No. 666(v.2)(EN)).

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**Wind Atlas Analysis and
Application Program (WASP)
Vol. 2: User's Guide**

**Niels G. Mortensen, Lars Landberg, Ib Troen and
Erik L. Petersen**

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Erik L. Petersen

Risø National Laboratory, Roskilde, Denmark
January 1993

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Artistic drawings by Søren Rasmussen

ISBN 87-550-1789-4

Grafisk Service · Risø · 1993

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1 Running WASP

1.1 Interactive mode

Once WASP is installed on the hard disk, the program is started by typing WASP at the DOS prompt followed by *<Return>* or *<Enter>*. A 'frontpage' or logo screen is then displayed for a few seconds while the program is loaded into the memory of the computer. At this stage WASP also reads several support files: WASP.TXT, WASP.DAT, WASP.PAR, GRAPHICS.PAR and, possibly, PRINT.PAR and DIGIT.PAR. These files should therefore always be accessible when running the program, ie they must be in the same directory as the program.

The file WASP.TXT contains the menu commands and other text displayed during the WASP session; WASP.DAT contains numerical input to the complex terrain model and the *.PAR files contain parameters with which the program is initialized, see Section 1.3.

When the program and support files have been loaded, one of the main displays of WASP, the so-called *status display*, is shown – together with the main menu. The overall structure of the menus of WASP is shown in Fig. 1.

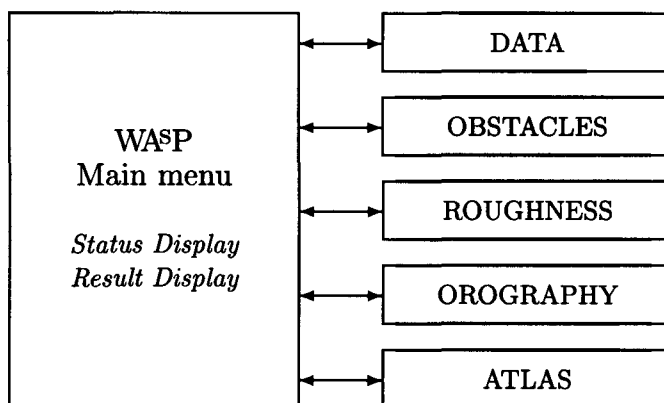


Figure 1. The menu structure of WASP, cf the Quick Reference Sheet in Appendix E.

The main menu contains commands or key-words to enter the 5 sub-menus shown in Fig. 1. The models accounting for roughness change, shelter and orography are executed by entering RETURN or simply pressing *<Return>*. This action also switches to the other main display of WASP: the *result display*.

The status display

The purpose of the status display is to provide an overview of the current status of the program. If all the facilities of WASP are exploited, up to 9 different kinds of files may have been connected to the program. Furthermore, some of the input data read from file may have been altered and/or new data may have been entered from the keyboard. The status display was devised to help the user keep track of all this information, as well as showing the status of the various models. The lay-out of this display is shown in Fig 2.

Each entry (box) in the display lists a file name if an input file has been entered (eg C:\WASP\WECSITE.RDS). An identifying text string (usually line 1 of the file) is shown in the right-hand side of the box or below the file name (DATA and WECS).

```

ATLAS-----
:WASP Airport 1983-85.
C:\WASP\WASPDAL.LIB      :Wasp Airport 1983-85.

OROGRAPHY-----
C:\WASP\WASPDAL.MAP      :+ WASPDAL, CARTESIAN COORDINATES (UTM)
( 27139, 33371), 220)    : dr, R : 4.9 27558.
ROUGHNESS-----
C:\WASP\WECSSITE.RDS     :WECSS site - Beeverly Hill
OBSTACLE-----
-                         :-
RAWDATA-(12 m a.g.l.)-----
C:\WASP\RAWDATA.DAT
WECS-----
C:\WASP\WECSS251.POW
Micon M530 (250 kW)
≡ C:\WASP
▶ C:\WASP\WECSSITE.DMP
DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT
DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP
WASP>_

```

Figure 2. The status display of WASP.

Apart from the OROGRAPHY entry, the file name and text of any dumped file is also shown (eg C:\WASP\WASPDAL.LIB). The OROGRAPHY entry states the coordinates (x, y) of the current site and – to the right – the height above sea level of this site, the radial grid size at the center of the model and the model radius, respectively. These numbers are all given in metres.

In the lower right-hand corner of the display the current drive and path are shown (in this case C:\WASP) and also the name of the dump file if one has been opened (C:\WASP\WECSSITE.DMP, see Chapter 10).

The main menu is shown below the status display. The first line lists the key-words for entering the sub-menus and – when employed from left to right – also leads the user through a complete WASP session. The second line contains several useful utilities. Key-words or commands are invoked by typing the first three – or more – letters of the key-word, followed by pressing the <Return>-key.

The result display

Switching to the other main display is done by invoking the RETURN option – equivalent to pressing <Return>. The result display shows the estimated wind climate in tabular form, calculated employing the current wind atlas data set and site description. Typically, the complete WASP ‘scenario’ could be set up in the status display before pressing <Return> to invoke the models and see the results, Fig. 3.

The calculations supply information on the overall mean wind speed (M), the total energy content of the wind (E), the mean power which is expected to be generated by the turbine (P) and on the Weibull distribution (A and k). Furthermore, for each of 12 azimuth sectors, the number of roughness changes (Rch), the effects of obstacles and the terrain, the resulting Weibull parameters (A and k) and the frequency of occurrence (%) are given. The effects of obstacles are given as the reduction in per cent of the wind speeds in each sector. The speed-up/retardation

| WASP Airport 1983-85. | | | | | | | 4/ 9/91 13:54 | | | | |
|--|-----|-------|----------|-----------|-------|-----|-----------------------|------|------|------|--|
| WECS site - Beverly Hill | | | | | | | Height: 30.5 m a.g.l. | | | | |
| Sect | Rch | Input | Obstacle | Orography | A | k | % | P% | | | |
| 0: | 3 | 0.0% | 0° | 0.0% | 6.8% | 1° | 5.3 | 2.39 | 2.0 | 0.7 | |
| 30: | 1 | 0.0% | 0° | 0.0% | 11.2% | 2° | 6.0 | 2.20 | 4.0 | 2.2 | |
| 60: | 0 | 0.0% | 0° | 0.0% | 14.7% | 1° | 5.8 | 2.04 | 5.9 | 3.2 | |
| 90: | 0 | 0.0% | 0° | 0.0% | 14.8% | -1° | 5.8 | 2.80 | 7.9 | 3.1 | |
| 120: | 0 | 0.0% | 0° | 0.0% | 11.0% | -2° | 6.2 | 2.66 | 6.3 | 3.4 | |
| 150: | 0 | 0.0% | 0° | 0.0% | 7.1% | -1° | 5.9 | 2.52 | 5.1 | 2.4 | |
| 180: | 0 | 0.0% | 0° | 0.0% | 7.0% | 1° | 7.1 | 2.42 | 7.3 | 6.7 | |
| 210: | 0 | 0.0% | 0° | 0.0% | 10.8% | 2° | 7.1 | 2.08 | 8.4 | 8.2 | |
| 240: | 0 | 0.0% | 0° | 0.0% | 14.7% | 1° | 9.4 | 2.86 | 12.7 | 23.6 | |
| 270: | 1 | 0.0% | 0° | 0.0% | 14.2% | -1° | 8.3 | 2.62 | 17.0 | 23.1 | |
| 300: | 1 | 0.0% | 0° | 0.0% | 10.6% | -2° | 7.9 | 2.63 | 15.9 | 19.2 | |
| 330: | 1 | 0.0% | 0° | 0.0% | 6.9% | -1° | 6.0 | 2.18 | 7.3 | 4.2 | |
| M= 6.5 m/s E= 280. W/m² P= 464.8 MWh/y | | | | | | | 7.3 2.28 | | | | |
| DATA OBSTACLE ROUGHNESS OROGRAPHY ATLAS WECS HEIGHT DISPLAY RESOURCEFILE FREQUENCY DOS HELP RETURN STOP WASP>_ | | | | | | | | | | | |

Figure 3. The result display of WASP.

and turning of the wind calculated by the complex terrain model are given in per cent and degrees, respectively. Hence, in the 0°-sector shown in Fig 3, the wind is 1.068 times higher and turned +1° compared to the undisturbed wind.

The right-most column in the result display gives the sector-wise distribution of the total energy content of the wind or the actual power production by a wind turbine, in per cent. The heading of the display shows the names of the wind atlas data set and site description employed, as well as the height for which the calculations are performed. Finally, the date and time the display was last updated are shown.

The main menu

WASP is primarily an interactive or menu-driven program and the various options of the program are chosen by invoking the commands or *key-words* shown in the menus. The key-words are invoked by typing the first three or more characters of the key-word in question, eg HEI for the HEIGHT option. The key-words of the main menu – shown in Fig. 2 and 3 – are described briefly below.

DATA The input and output routines to handle measured meteorological data (in the form of a time-series of wind speed and direction) and general climatological data (in the form of a climatological table) are collected in the DATA menu. The options of the DATA menu are described in detail in Chapter 6.

OBSTACLE Input and editing of the obstacle list for a specific site is taken care of by this menu. Typing -OBSTACLE – or just -OBS – in the main menu clears the obstacle list – the same list is reactivated by invoking the EDIT option in the OBSTACLE menu. The options of the OBSTACLE menu are described in detail in Chapter 5.

- ROUGHNESS** Input and editing of the surface roughness conditions for a specific site – and, optionally, input of local wind speed corrections and wind direction correction angles for each sector – is done in the **ROUGHNESS** menu. This menu also contains a path to the **MAPDATA** menu and commands for specifying the site on a map containing roughness and/or height contour lines. The options of the **ROUGHNESS** menu are described in detail in Chapter 3.
- OROGRAPHY** Input of a digitized map of the area or an idealized orography and initialization of the complex terrain model. Entering **-OROGRAPHY** removes the map from the set-up – the map is reactivated by invoking the **SITE** option in the **OROGRAPHY** menu. The options of the **OROGRAPHY** menu are described in detail in Chapter 4.
- ATLAS** Calculation, storage or retrieval of wind atlas data are the options in the **ATLAS** menu. The wind atlas calculation combines the meteorological data and the site description to obtain a regionally representative data set. The wind atlas *must* be generated for table or raw data to have any effect on the results (the estimated wind climate). The options of the **ATLAS** menu are described in detail in Chapter 8.
- WECS** Retrieval of a wind turbine power curve. When a power curve has been loaded the yearly power production of the wind turbine in question is shown in the main display and recalculated as the display is updated. The sector-wise distribution of the energy production is also shown. Typing **-WECS** removes the turbine from the set-up – blank input reactivates the same power curve. The **WECS** option is described in detail in Chapter 9.
- HEIGHT** Sets a new height above ground level (m a.g.l.) for which results are calculated, eg the wind turbine hub height.
- DISPLAY** Shows graphically the wind statistics resulting from the current **WASP** calculations: the sector-wise frequencies of occurrence in a wind rose (Fig. 4) and the Weibull distribution of the wind speeds, in total and sector-wise (Fig. 5). The **DISPLAY** option is described in detail in Chapter 6.
- RESOURCEFILE** The wind resources are calculated in several points which may be chosen at random or which describe a regular grid. The results are written in a so-called resource file (default extension **RSF**). Returning to the main menu the list of points is kept, and points may be appended to the list and/or the calculations executed later by returning to the **RESOURCEFILE** option. Points can be chosen on the graphics screen or input through a free-format file. The **RESOURCEFILE** option is described in detail in Chapter 9. – Entering **-RESOURCEFILE** (or **-RES**) closes relevant files and resets number of resource map points to zero.
- FREQUENCY** Calculates the probability that the wind occurs in a certain user-specified ‘window’ of wind speed and direction.
- DOS** Entering and returning from the Disk Operating System without terminating **WASP**. This allows the user to execute DOS commands while having a **WASP** session, eg check a directory on disk or edit a file before it is used as input to the program. In order to fully exploit this option, as much memory as possible should be free before invoking **WASP**.
- HELP** **WASP** is equipped with an on-line help function that offers a brief description of the menu key-words and their usage. The help function is invoked by the **HELP** option in the various menus. Furthermore, a question mark ‘?’ may be input anywhere

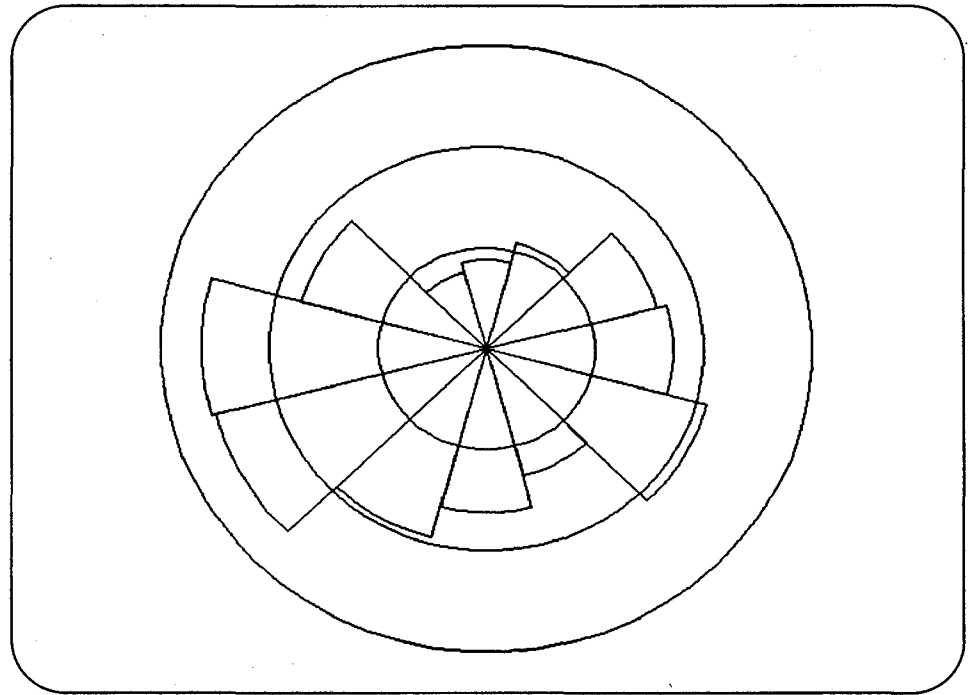


Figure 4. The estimated frequencies of occurrence shown as a wind rose. Invoke DISPLAY in the main menu to obtain this graphic.

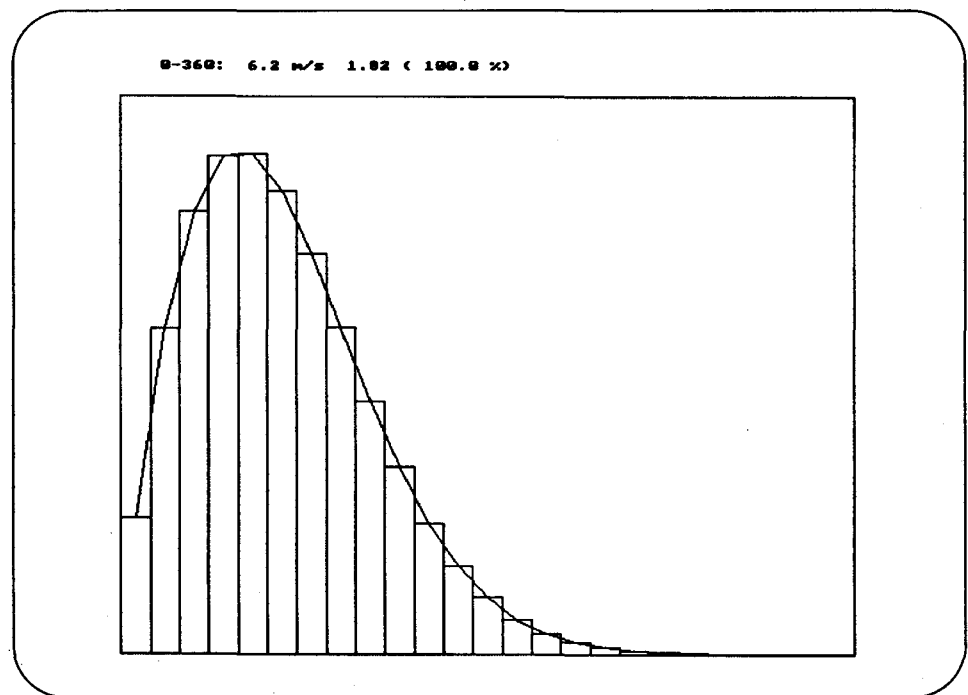


Figure 5. The estimated Weibull distribution of wind speeds. Invoke DISPLAY in the main menu and press any key to obtain this graphic.

(except in graphics mode) in the dialogue with WASP to obtain context-sensitive help. WASP will then display a short message, stating what type of input or action is required. The help messages are given in the language specified by the user, see Section 1.4.

- RETURN** Invokes the different models of WASP and updates the screen with the new results. Switches between the two main displays if calculations are already updated: the *status display* and the *result display*. RETURN or RET is equivalent to pressing the *<Return>*-key.
- STOP** Stops the execution of WASP. *Data and results not stored on disk files will be lost.*
- : and >** Dumping the results of a WASP session on an ASCII text file (default extension .DMP). *:filename.ext* opens the dump file. An exact copy of the alphanumeric screens can subsequently be dumped by pressing the 'greater-than' key (>), or a table of results suitable for further processing can be dumped by pressing the colon key (:). The format of this table is determined by parameter #63 in the file WASP.PAR, see Chapter 10.
- ?** A question mark may be used as input anywhere in the dialogue with WASP – except in graphics mode – to obtain context-sensitive help. WASP will then display a short message, stating what type of input or action is required. The help messages are given in the language specified by the user, see Section 1.4.

1.2 Batch mode operation

The interactive mode may sometimes seem inopportune, especially when analysing data from a great number of stations or running the models at many different sites and/or heights. Therefore, a batch-like mode has been implemented, allowing any number of WASP commands to be executed automatically.

In batch mode, the input to WASP comes from an ASCII disk file rather than the keyboard. This input file should contain commands and input data in exactly the same format and order as it would have been given in interactive mode. The batch or command file can only be employed at the beginning of a WASP session. For example,

```
WASP DEMO.ENG
```

loads and executes WASP, performing a demonstration session, using the WASP commands and other input of the file DEMO.ENG. It is a simple task to make a copy of eg DEMO.ENG and with a text editor tailor a command file to suit your particular needs. Another sample command file, SITING.CMD, is provided on the WASP diskette. It performs a wind turbine siting exercise on the basis of a previously calculated wind atlas data set. The exercise is invoked by typing:

```
WASP SITING.CMD
```

and the results are stored in the file SITING.DMP. – Notice, that control is transferred to the keyboard when the entire command file has been read and executed by WASP.

Recording a command file

A 'recording' feature is also provided, in order to make it simpler to establish command files. If the command file name is preceded by a colon, the sequence of commands and other input during the WASP session to follow is recorded in the file. Hence, the siting exercise mentioned above was recorded in a file by typing:

```
WASP :SITING.CMD
```

Notice, that the recording includes *all* commands, also the commands and cursor movements in graphics mode. Establishing or reusing a command file – eg by

changing the names of input files and/or site coordinates, but otherwise repeating the analysis – is generally easier without having to worry about the graphics commands. Graphics can be turned off by setting P_{69} in `WASP.PAR` equal to zero.

1.3 The parameter files

WASP is initialized with the parameters and constants of several parameter files. This offers the possibility of determining some of the specific conditions under which the program is running as well as how the results are displayed. The parameter files are ASCII text files and they may be typed, copied, printed and edited.

The `WASP.PAR` file

There are at present 74 parameters in this parameter file. About 15 parameters, like P_0 , P_{25} , P_{35} , P_{32} , P_{38} , P_{43} , P_{48} – P_{50} , P_{63} , P_{69} and P_{71} – P_{74} , are purely technical and have no effect on the meteorological data or models. Another 15 or so, like P_1 , P_{12} – P_{17} , P_{18} – P_{23} , P_{36} – P_{37} and P_{42} , affect the way meteorological data are analysed, but do not affect the models themselves. The remaining parameters have a profound influence on the meteorological models. These *may* be altered when special circumstances suggest so, and may in such cases lead to better results. However, it is generally advisable *not* to change these parameters. The complete parameter list is given in Appendix B, Section B.1, with a brief explanation as to the meaning of each.

On-line change of parameters

The parameters contained in the `WASP.PAR` file are used for initialization. Their setting can be altered by the command:

`n = <new value>`

This will set parameter number n , P_n , to the new value `<new value>`. If no new value is specified the current value will be displayed and a new value can then be typed. If blank input is entered, the current value is maintained. However, please note: *No checking of the parameter value is performed. Some parameters have only significance in the initialization or at the time of input of new files (eg number of sectors, standard levels etc). These parameters can be changed interactively but this will have no effect. Some physical parameters are used at different levels in the program, and if these parameters are changed in the middle of a session erroneous results may be produced. To avoid this, on-line change of the physical parameters should in general be avoided.*

Warning!

The `GRAPHICS.PAR` file

The graphics options of WASP defaults to active – but graphics can be turned off by changing parameter P_{69} in `WASP.PAR` to zero. When active, the graphics screen type and display characteristics are specified by the parameters in the file `GRAPHICS.PAR`. Enabling side printing and digitizing is also done by changing parameters in this file. The complete list of graphics parameters is given in Appendix B, Section B.2.

The `PRINT.PAR` file

It is possible to make a screen-dump of eg the orographic map or the resulting Weibull distribution by pressing the `>`-key while in graphics mode. In order to accomplish this printing must be enabled by changing parameter #18 to 1 in

GRAPHICS.PAR and the right printer driver must be installed in line 1 of the file PRINT.PAR. This file further contains 17 parameters (printer attributes) to set-up the printer correctly. Appendix B, Section B.3, explains the meaning of these 18 parameters and lists the printers supported by WASP.

The DIGIT.PAR file

Input of map data – height contour lines or roughness change lines – can be done directly from WASP by invoking the INPUT option of the MAPDATA menu. Digitizing is enabled by setting parameter P_{16} in the file GRAPHICS.PAR equal to either 1 or 3. If P_{16} is equal to 1 the HALO digitizer driver is invoked. The proper Halo driver must then be installed before running WASP. This installation procedure is described in Section B.4.

If P_{16} is equal to 3 the internal WASP digitizer driver is invoked. The specific set-up of this ASCII driver is specified in the file DIGIT.PAR. The default configuration given in this file is valid for a CalComp DrawingBoard emulating Calcomp 2000 ASCII. Appendix B, Section B.4, explains how to change the default configuration to one corresponding to any particular digitizing tablet providing ASCII output.

1.4 Choosing the language

The texts used in the menus and in the displays in general are read by WASP from the file WASP.TXT when the program is started. Since all the text displayed during a WASP session is collected in this file, a language option has been added to the program, providing the user with a choice of 8 different languages. Each language is supplied as a separate file on the WASP diskette. The files are named WASP.LAN, where the file extension LAN specify the language. The extension is simply the first three characters of the English name of the language.

Table 1. Optional languages of WASP. The default (and reference) language is English.

| <u>.LAN</u> | <u>Language</u> | <u>.LAN</u> | <u>Language</u> |
|-------------|-----------------|-------------|-----------------|
| .DAN | Danish | .GER | German |
| .DUT | Dutch | .ITA | Italian |
| .ENG | English | .POR | Portuguese |
| .FRE | French | .SPA | Spanish |

The default language is English, but by replacing the file WASP.TXT with another language file, the language of WASP is changed. Hence, if you, before invoking the WASP program, type

```
COPY WASP.DAN WASP.TXT
```

the default language is replaced by Danish. The texts displayed by WASP, as well as the communication between the user and WASP, will now be in Danish. Similarly, the English reference version is restored by typing:

```
COPY WASP.ENG WASP.TXT
```

Keyboard drivers

Notice, that the keyboard must have been set up with the proper keyboard driver when using Danish or German, enabling you to type the special characters of these alphabets. See your DOS User's Guide for information on national keyboard drivers. Further, you must use only *upper-case* letters when using these languages.

You may run WASP and exploit all its facilities in any of the languages mentioned above. However, they were all translated from the English version and there may occur slight differences in the meaning of eg the help texts. In addition, the rapid development of WASP render the updating of the various languages difficult. Consequently, the English version must be regarded as the reference, and this or the WASP User's Guide should be consulted in cases of doubt.

Having chosen a language as described above, a demonstration of WASP in this may be obtained by typing:

```
WASP DEMO.LAN
```

where LAN is substituted with the proper file name extension, see Table 1. Notice, that parameter #25 in WASP.PAR is changed to 3 seconds by the command file, to slow down the pace of WASP.

1.5 A few recommendations

It is advisable to keep the program and support files in a separate directory, eg `c:\wasp`, and create other directories for the user data files. Typing `DOS` in the main menu and then `cd\wasp\data`, changes from the current directory (`\wasp`) to this data directory.

This can conveniently be 'automated' by making a small command file for each data directory or project. For example, a command file `TEST` with the following commands

```
dos  
cd\wasp\testdata  
return
```

will change the current directory to `\wasp\testdata` when WASP is started in the following way:

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

It is also advisable to keep the default file name extensions suggested by WASP. When the data files corresponding to one particular site have the same name, but with different extensions, it is simple to overview and handle these data files.

Memory management

WASP is a rather memory-consuming program and if the program occasionally crashes, it is most likely due to shortage of internal memory. Therefore, you are advised to remove any RAM-resident programs, DOS shells, mouse drivers, printer spoolers, etc. from the conventional 640-kB memory.

By the same token, WASP will run smoothly under DOS 5.0. This version offers much more (> 20%) free memory compared to earlier versions of DOS. The size of the free memory can be checked by the DOS `CHKDSK`-command.

Finally, in the file `CONFIG.SYS`, set `FILES` and `BUFFERS` to at least 20.

2 General topographical concepts

Estimation of the wind resource ranges from overall estimates of the mean energy content of the wind over a large area – called *regional assessment* – to the prediction of the average yearly energy production of a specific wind turbine at a specific location – called *siting*. The information necessary for siting generally needs to be much more detailed than in the case of regional assessment. However, both applications make use of the general concepts of topography analysis and regional wind climatologies.

In order for WASP to calculate the effects of topography on the wind at a given place (“the site”) it is necessary to describe systematically the characteristics of the surroundings. The site may be a projected wind turbine site or a meteorological station.

Roughness The collective effect of the terrain surface and obstacles, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain. However, not all the topographical elements contribute to the roughness. Vegetation and houses are examples of roughness elements, whereas long smooth hills, for example, are not, because they do not themselves cause an increase in the turbulence of the flow.

Orography Orographic elements such as hills, cliffs, escarpments and ridges exert an additional influence on the wind. Near the summit or crest of these features the wind will accelerate while near the foot and in valleys it will decelerate.

Shelter Close to an obstacle such as a building the wind is strongly influenced by the presence of the obstacle. The effect extends vertically to approximately three times the height of the obstacle, and downstream to 30 to 40 times the height. If the point of interest is inside this zone, it is necessary to take the sheltering effects into account, whereas if the point is outside the zone the building should be treated as a roughness element.

For a given situation, there are thus three main effects of topography on the wind: roughness, orographic and shelter effects. In nature these effects are not entirely independent. The program takes this into account, but allows the user to specify the close-by sheltering obstacles, the roughness of the surrounding terrain, and the orography independently. How these terrain characteristics are obtained and entered to WASP is explained in Chapters 3–5.

Practical considerations When it comes to describing a site in practice it is recommended that the following material is available:

- a recently revised topographical map on a scale of 1:25 000 or 1:50 000 with height contour lines, an example is given in Fig. 6.
- a topographical map or sketch showing the distribution of areas with different roughness, eg forests, shelter belts (windbreaks), lakes, oceans, towns etc., see Fig. 7. If this is not at hand, a roughness rose (ie a sector-wise description of the roughness in eg 12 sectors) should be constructed.
- a map or sketch showing sheltering obstacles close to the point of interest.

Photographs of the surroundings of the site and/or aerial photographs may come in handy if a visit to the site(s) is not feasible.



Figure 6. Example of a topographical map.

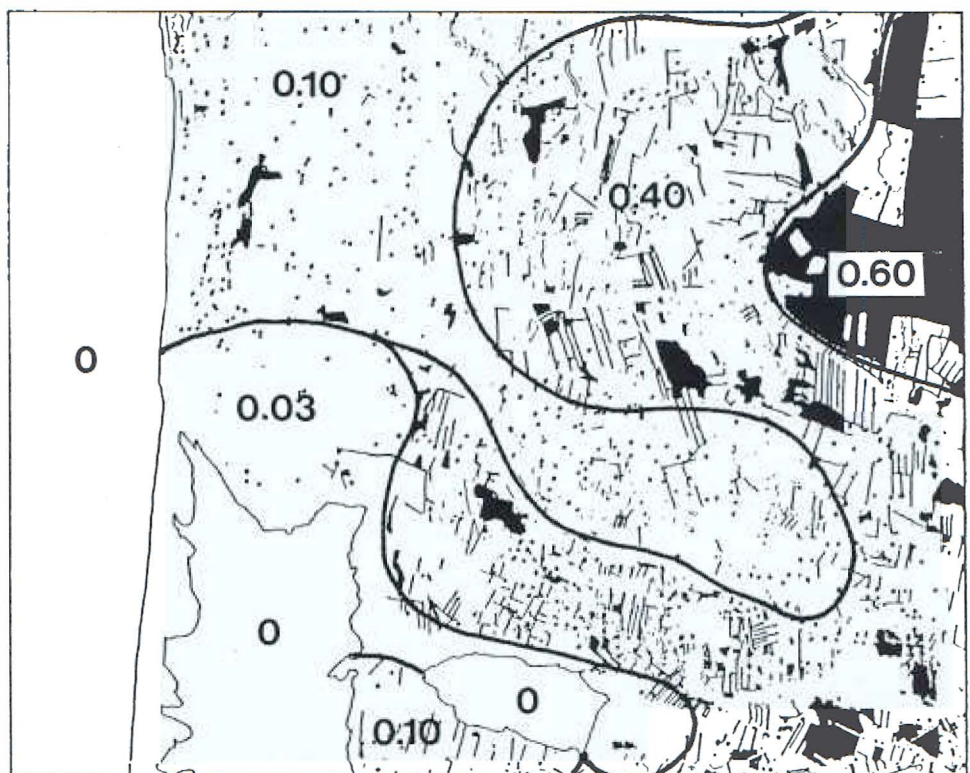


Figure 7. Sketch showing the different roughness areas around a site, cf Fig. 6.

2.1 The roughness of a terrain

The roughness of a particular surface area is determined by the size and distribution of the roughness elements it contains; for land surfaces these are typically vegetation, built-up areas and the soil surface. In the European Wind Atlas (Troen and Petersen, 1989) the different terrains have been divided into four types, each characterized by its roughness elements. Each terrain type is referred to as a *roughness class*. A description and illustration of these four roughness classes is given in Figs. 8–11 which furthermore give the relation between roughness length and roughness class, the former being the commonly used length scale to characterize the roughness of a terrain.

The roughness length

The roughness of a terrain is commonly parameterized by a length scale called the roughness length z_0 . Formally, z_0 is the height where the mean wind speed becomes zero, if the wind profile has a logarithmic variation with height. This usually occurs during moderate and strong wind conditions.

A simple empirical relation between the roughness elements and the roughness length has been given by Lettau (1969). A roughness element is characterized by its height h and the cross-section facing the wind S . Further, for a number of roughness elements distributed evenly over an area, the density can be described by the average horizontal area, A_H , available to each element. Then

$$z_0 = 0.5 \times \frac{h \times S}{A_H} \quad (1)$$

This relation gives reasonable estimates of z_0 when A_H is much larger than S . It tends to overestimate z_0 when A_H is of the order of S ; this is because, when the roughness elements are close together, the flow is “lifted” over them. Then only a fraction of S and h contributes to the roughness. Furthermore, the lifting of the flow requires measuring the height above ground from somewhere between the top of the roughness elements and half the height of the elements. This height is referred to as a *displacement length*. The displacement length must often be taken into account on sites with forests, cities, and tall vegetation. Finally, Eq. 1 assumes that the porosity is approximately zero, ie the roughness elements are solid. For porous roughness elements, z_0 from Eq. 1 must be reduced by a fraction equal to the porosity.

As an example, Eq. 1 can be applied to calculate the roughness length of a terrain with a large number of houses (eg a provincial town). The roughness is estimated from $h = 5$ m, $S = 100$ m² and $A_H = 1000$ m²:

$$z_0 = 0.5 \times 5 \times \frac{100}{1000} = 0.25 \text{ m}$$

The empirical relation may also be applied to windbreaks (shelter belts) by letting $S \sim hL$ and $A_H \sim \ell L$, where L is the length of windbreak and ℓ the distance between windbreaks. Hence, Eq. 1 becomes:

$$z_0 = 0.5 \times \frac{h^2}{\ell} \quad (2)$$

For a typical height of 10 m, the influence of ℓ on z_0 can be illustrated by the following table:

| | | | | |
|------------------------------------|-----|------|-----|------|
| Distance between windbreaks ℓ | [m] | 1000 | 500 | 200 |
| Roughness length z_0 | [m] | 0.05 | 0.1 | 0.25 |

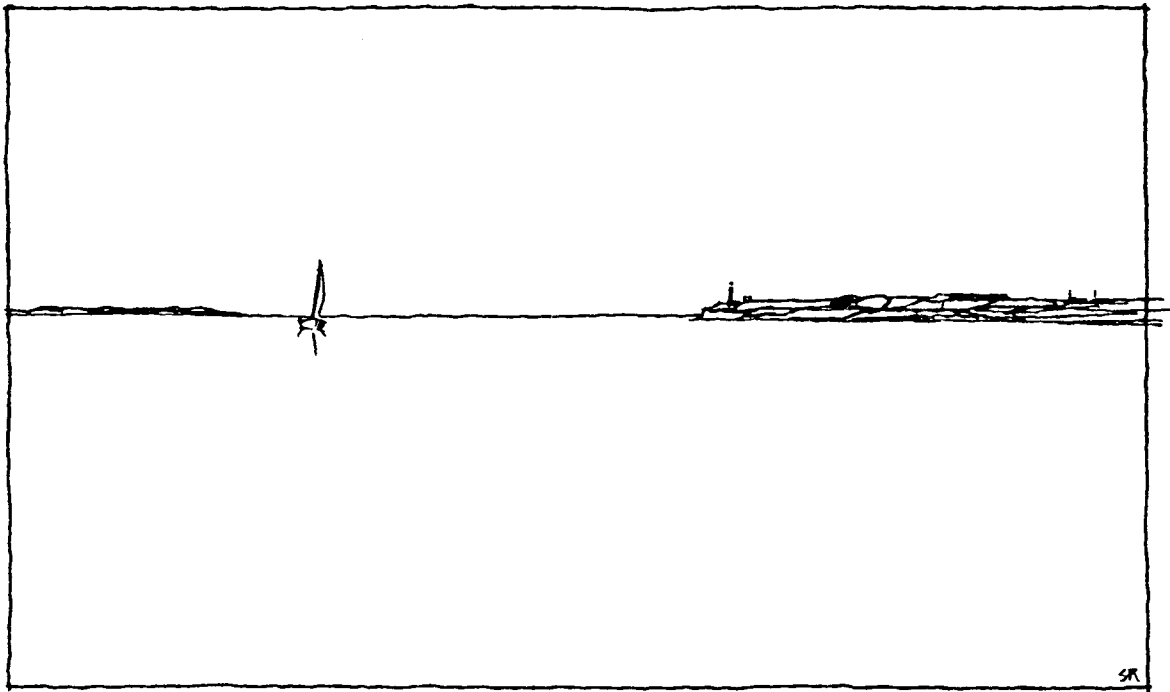


Figure 8. Example of terrain corresponding to roughness class 0: water areas ($z_0 = 0.0002$ m). This class comprises the sea, fjords, and lakes.

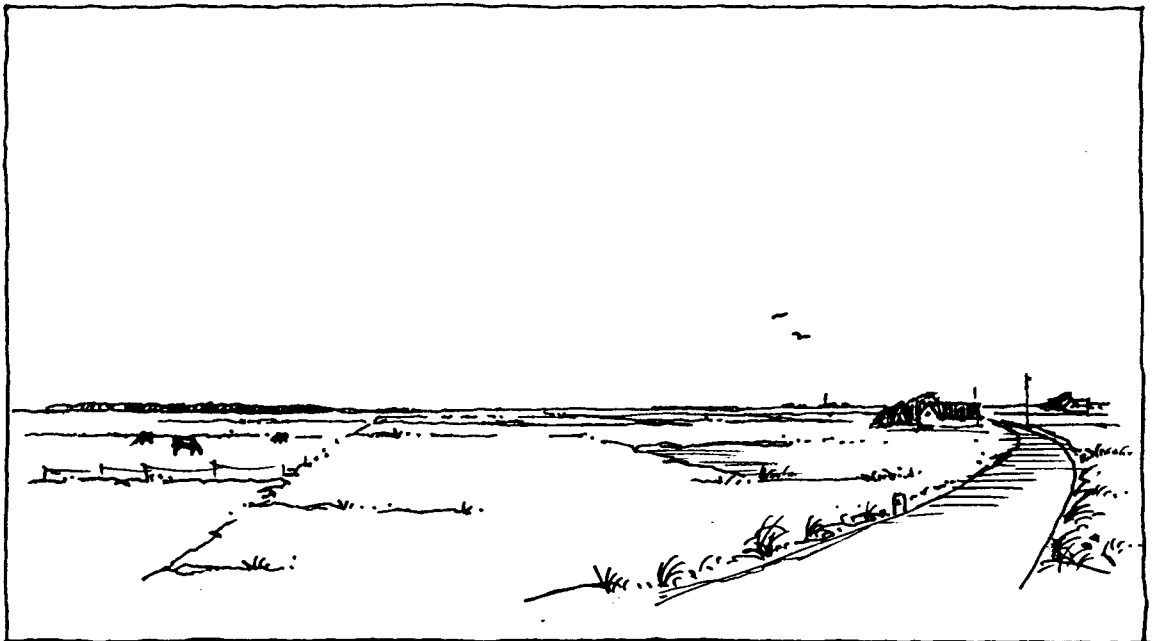


Figure 9. Example of terrain corresponding to roughness class 1: open areas with few windbreaks ($z_0 = 0.03$ m). The terrain appears to be very open and is flat or gently undulating. Single farms and stands of trees and bushes can be found.

It should be noted that the porosity was assumed to be zero in the above calculation. For windbreaks of trees and bushes, the porosity is approximately 0.5, which leads to a decrease in the distance ℓ between the windbreaks by a factor of two in order to give the same roughness.

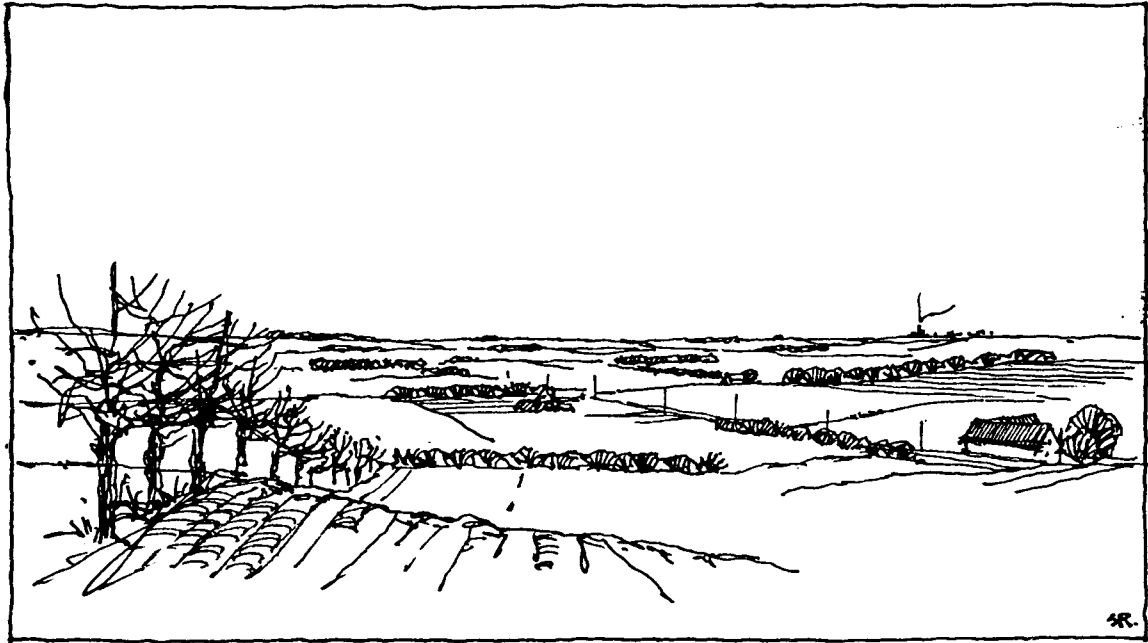


Figure 10. Example of terrain corresponding to roughness class 2: farm land with windbreaks, the mean separation of which exceeds 1000 m, and some scattered built-up areas ($z_0 = 0.10$ m). The terrain is characterized by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or undulating. There are many trees and buildings.

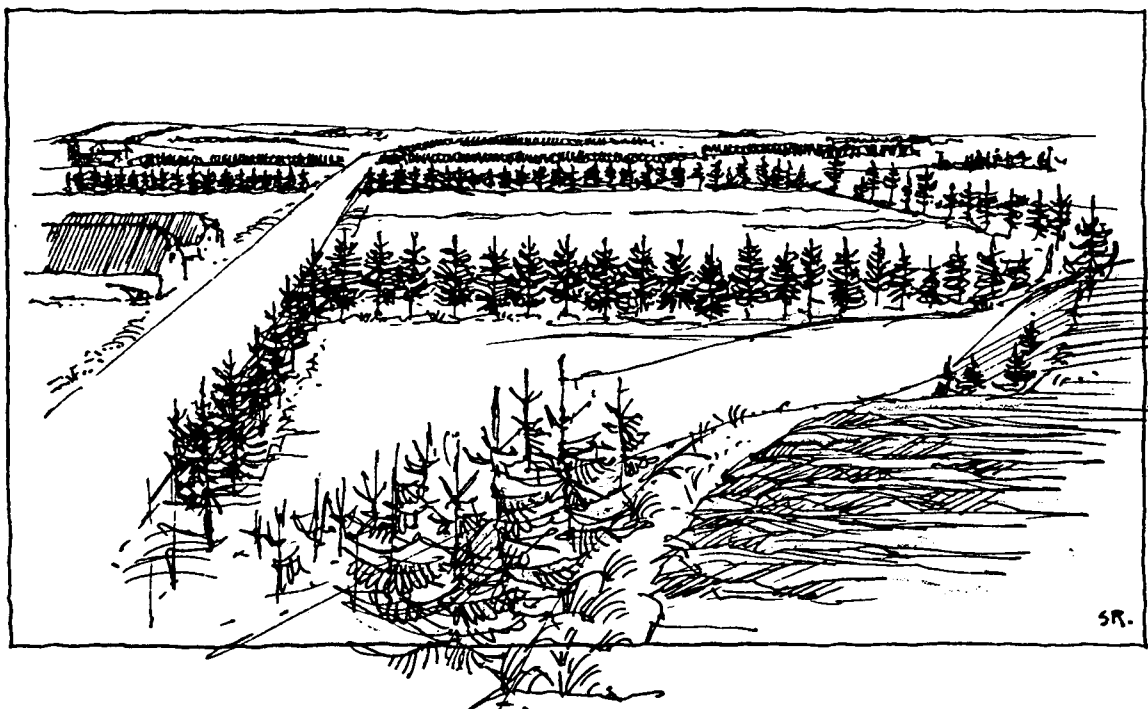


Figure 11. Example of terrain corresponding to roughness class 3: urban districts, forests, and farm land with many windbreaks ($z_0 = 0.40$ m). The farm land is characterized by the many closely spaced windbreaks, the average separation being a few hundred metres. Forest and urban areas also belong to this class.

Figure 12 indicates the relation between roughness length, terrain characteristics, and roughness class.

The roughness length of surfaces covered by vegetation may vary with the wind speed. For example, the bending of stalks by the wind can change the form of the surface. A similar phenomenon occurs for water waves where both the height and form of the waves are dependent on wind speed. From dimensional arguments, the following equation can be obtained for the roughness over water when viscous effects and the surface tension of the water are neglected (Charnock, 1955):

$$z_0 = b \frac{u_*^2}{g} \quad (3)$$

where b is a constant ($b \approx 0.014$), g the gravitational acceleration, and u_* the friction velocity.

*Roughness of water
in WASP*

During the development of WASP it was attempted to use both Eq. 3 and a fixed value for the roughness of water areas, roughness class 0. It turned out that a fixed value of 0.0002 m gave results as good as Eq. 3 for the moderate to high wind speeds of interest to wind energy applications, hence all calculations in WASP are obtained with this value. Notice, however, that *on input the roughness of water must be given as 0 (zero)*, in order for WASP to distinguish between water areas and very smooth land surfaces.

It should be noted that in general the roughness length as applied in WASP has to be considered as a climatological parameter because the roughness of an area changes with foliation, vegetation, snow cover and so on. The energy production of a wind turbine must be determined on the basis of climatology, primarily because of the variations of the weather; however, the seasonal variations in the local terrain characteristics can also have a profound influence.

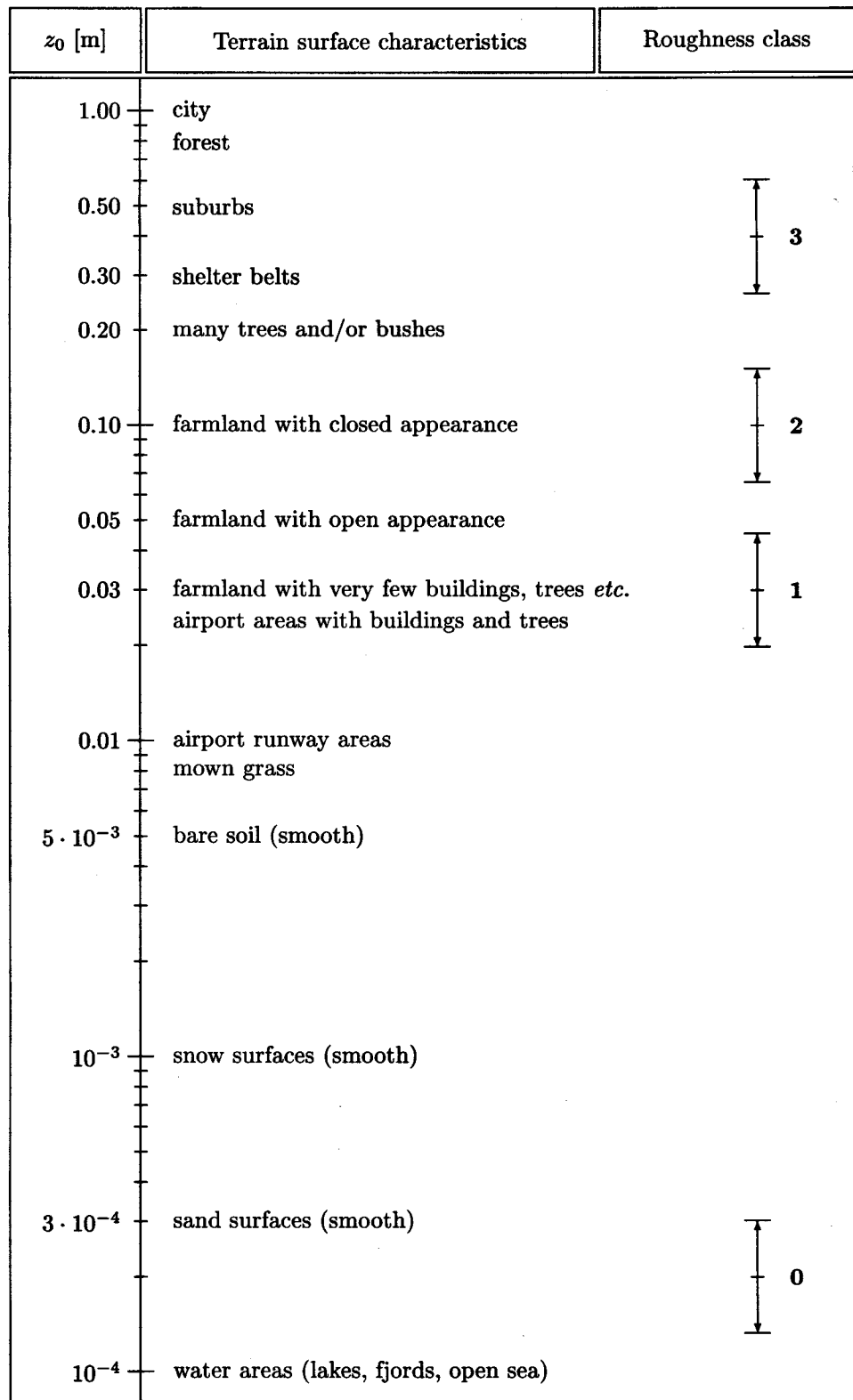


Figure 12. Roughness length, surface characteristics and roughness class (European Wind Atlas, 1989). The roughness classes are indicated by vertical bars. The central points give the reference values and the length of the bars indicates the typical range of uncertainty in roughness assessments.

2.2 The effect of height variations in the terrain

The effects of height variations in the terrain on the wind profile can most clearly be demonstrated by the results from the international field experiments at the Askervein hill on the Isle of South Uist in the Hebrides (Taylor and Teunissen, 1987; Salmon *et al.*, 1987). Figure 13 shows a perspective plot of the Askervein hill. The line along which measurements of wind speed and direction were recorded is indicated by the meteorological towers.

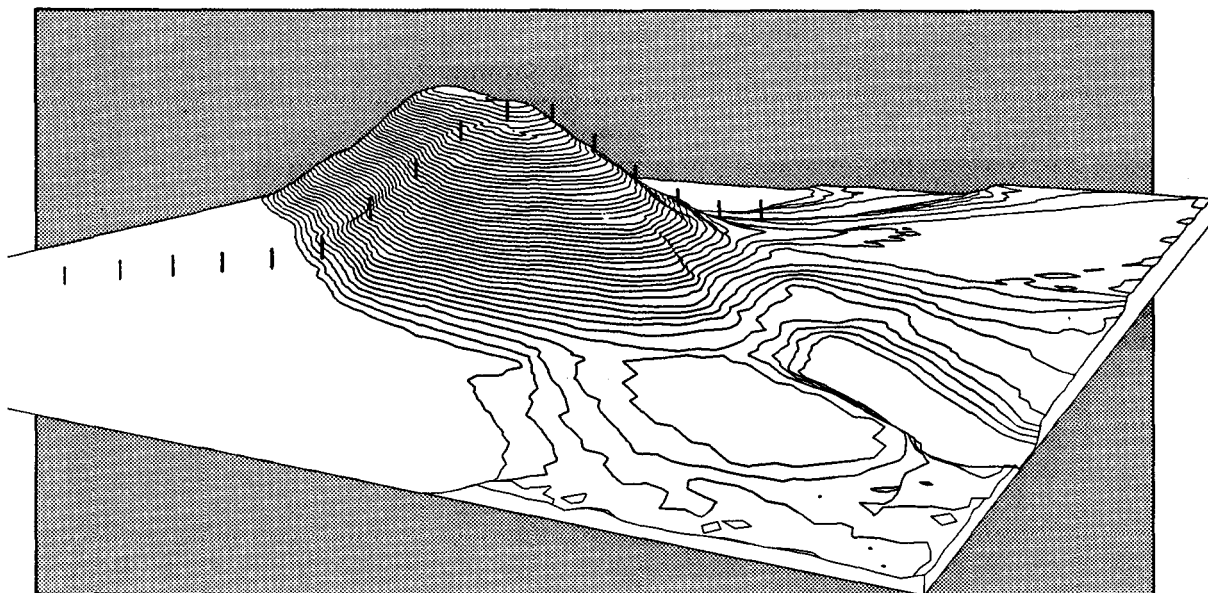


Figure 13. Perspective plot of the Askervein hill.

The experimental data are shown in Fig. 14 with the relative speed-up ΔS at 10 m a.g.l. plotted against the distance from the crest. The relative speed-up ΔS is defined as:

$$\Delta S = \frac{u_2 - u_1}{u_1} \quad (4)$$

where u_2 and u_1 are the wind speeds at the same height above ground level at the top of the hill and over the terrain upstream of the hill, respectively.

The data in Fig. 14 are obtained for a wind direction almost perpendicular to the orientation of the ridge. Also shown are the results from three numerical models: the BZ-model (Troen, 1990) used in WAsP and two other models (Beljaars *et al.*, 1987). Some noteworthy characteristics from Fig. 14 are:

- the speed-up at the crest is 80 per cent as compared with the undisturbed upstream mean wind speed
- the negative speed-up (speed-down) in the front and lee of the hill is 20 to 40 per cent as compared with the undisturbed upstream mean wind speed

Figure 16 shows wind profiles recorded simultaneously upstream and on top of the Askervein hill. Note that the upstream profile is logarithmic with height whereas the hill-top profile has a knee at the height ℓ , the height of maximum relative speed-up. The profile is constant with height above the knee until it matches with the upstream profile at the height $2L$ where L is a characteristic length of the hill, typically the half-width as shown in Fig. 15.

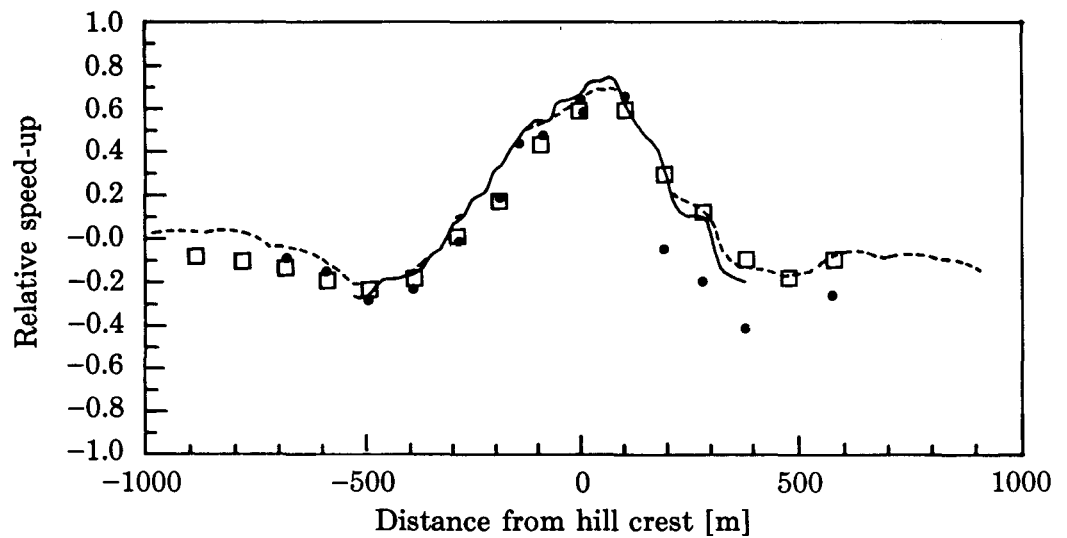


Figure 14. Relative speed-up ratios for flow over the Askervein hill at 10 m above ground level. Measurements are indicated by dots and results from the orographic model by squares. Results from two other numerical models are shown by a full and dashed line, respectively.

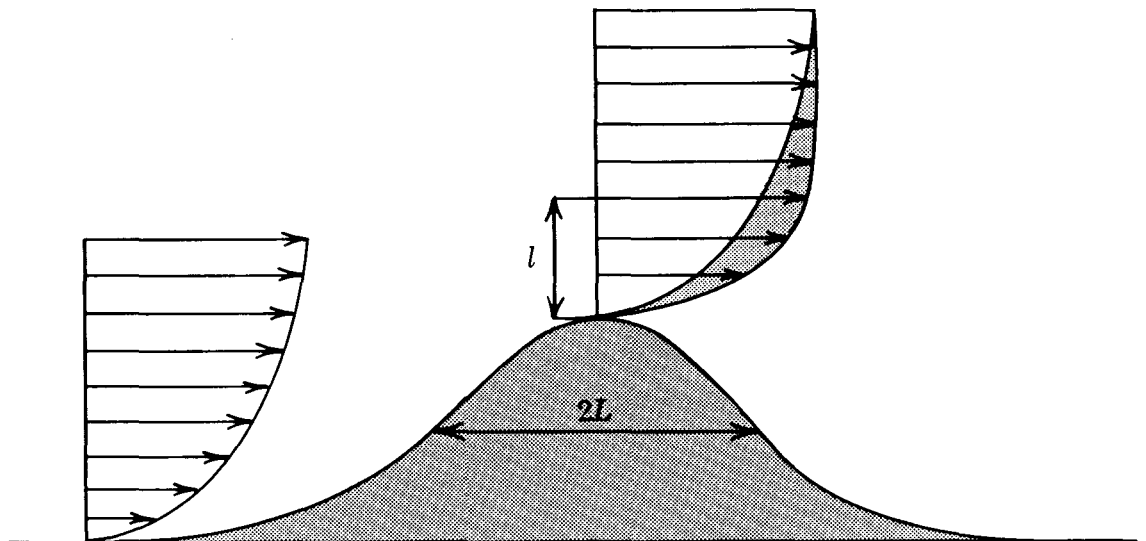


Figure 15. Flow over an idealized hill with upstream and hill-top wind profiles. The two length scales characterizing the flow are indicated: L is a characteristic length of the hill, here – following traditional nomenclature – the half width at the middle of the hill; l is the height of maximum relative speed-up.

It is evident that hills exert a profound influence on the flow, and this has to be taken into account as carefully as possible. But one should be aware that all the height changes in the terrain influence the flow: a 5% height increase can have a 5% impact on the mean wind speed – possibly at hub height – resulting in a 15% increase of the available power.

In certain situations the precise meaning of “height above the ground” is not quite clear. As an example, consider a wind turbine on a low hill: if the height of the hill is very small compared to the hub height and the sides slope steeply, the hill can be considered as a foundation for the turbine which adds to the hub height. But if the lateral and vertical dimensions of the hill are increased, the situation changes and the relevant height becomes the height above the hill top.

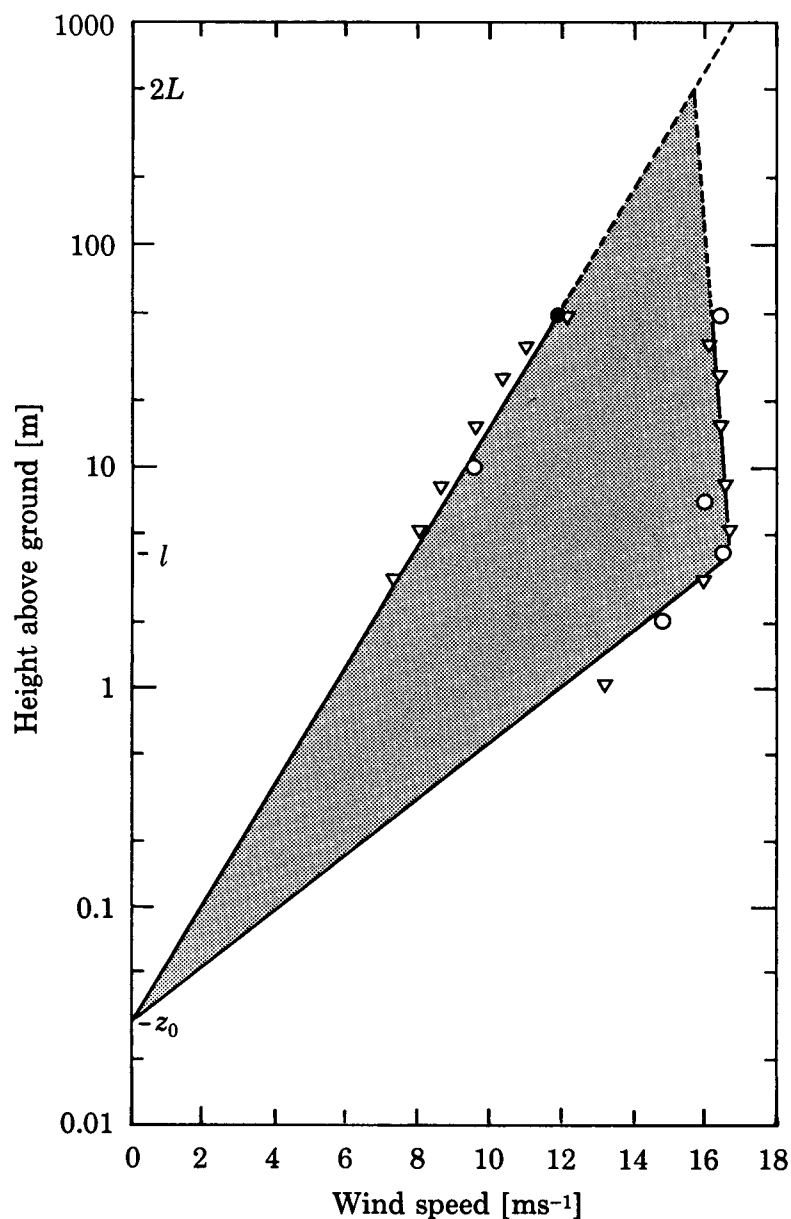


Figure 16. Wind profiles recorded simultaneously upstream and on top of the Askervein hill (Jensen et al., 1984). The symbols indicate wind speed measurements. Upstream profile is the straight line to the left; hill-top profile is the line to the right. The two length scales L and l are defined in Fig. 15.

2.3 Shelter behind obstacles

Shelter is defined as the relative decrease in wind speed caused by an obstacle in the terrain. Whether an obstacle provides shelter at the specific site depends upon:

- the distance from the obstacle to the site (x)
- the height of the obstacle (h)
- the height of the point of interest at the site (H)
- the length of the obstacle (L)
- the porosity of the obstacle (P)

Figure 17 shows the reduction of wind speed due to shelter from an infinitely long two-dimensional obstacle of zero porosity. The shelter decreases with diminishing length and increasing porosity of the obstacle.

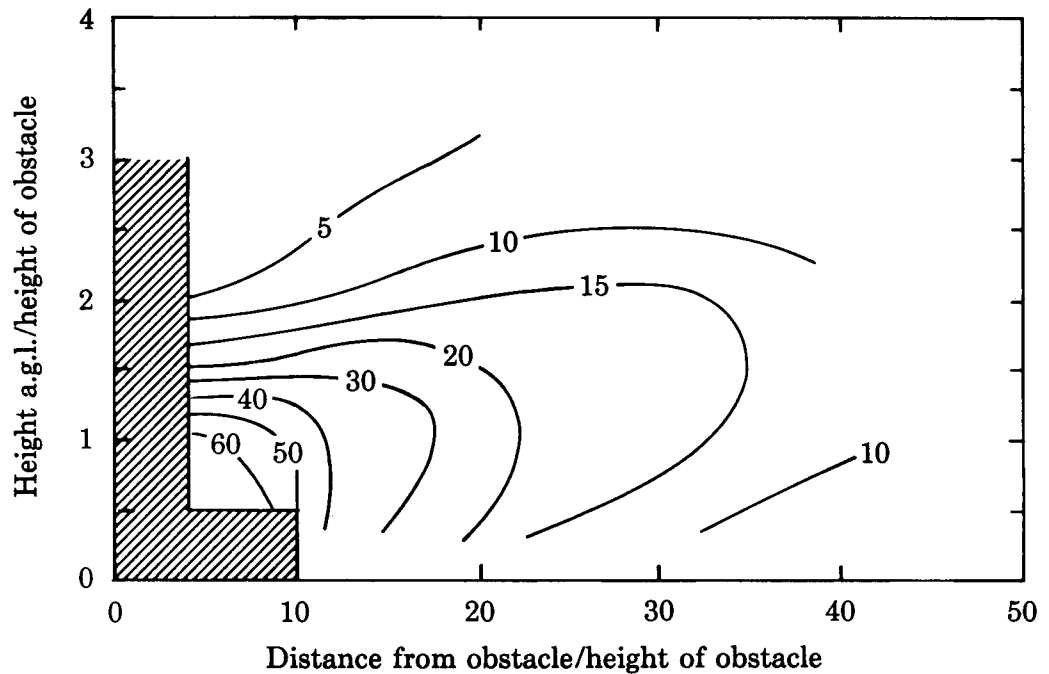


Figure 17. Reduction of wind speed (R_1) in per cent due to shelter by a two-dimensional obstacle based on the expressions given by Perera (1981). In the shaded area the sheltering is very dependent on the detailed geometry of the obstacle. In addition, wind speed is usually increased close to and above the obstacle – similar to the speed-up effects over hills.

As a general rule, the porosity can be set equal to zero for buildings and ≈ 0.5 for trees. A row of similar buildings with a separation between them of one third the length of a building will have a porosity of about 0.33. For windbreaks the characteristics listed in Table 2 may be applied. The porosity of trees changes with foliage, ie the time of year and like the roughness length, the porosity should be considered a climatological parameter.

Table 2. Porosity of windbreaks. The porosity is the ratio, expressed here as a fraction, of the area of the windbreaks 'pores', to its total area.

| Windbreak appearance | Porosity P |
|----------------------|--------------|
| Solid (wall) | 0 |
| Very dense | ≤ 0.35 |
| Dense | 0.35 - 0.50 |
| Open | ≥ 0.50 |

The PARK program The wind turbines in a wind park also 'shelter' each other, leading to a reduction in the overall power production. These wake effects and the park performance should be calculated using the *PARK* program.

The terrain roughness

There are two different ways of describing the roughness characteristics of the terrain surrounding a site:

- in the form of a digital map of *roughness-change lines*, ie lines separating areas of equal roughness (length). The roughness map describes the distribution of areas of equal roughness length and WASP is able to interpret the roughness conditions at any site within the map,
- or, in the form of a site-specific roughness description – also referred to as a roughness rose. In this case the roughness conditions at one site are described sector by sector, as ‘seen’ from the site, ie the description contains the distance to and magnitude of the roughness changes that occur in each sector.

In the first case, WASP calculates its own roughness rose from the roughness map, in the second case WASP uses the rose specified by the user directly. The input to the model accounting for roughness is thus in both cases a roughness rose.

The roughness map offers the greatest flexibility, because the site can be chosen freely within the area covered by the map. The roughness rose, on the other hand, generally offers greater accuracy in the roughness description of single sites.

3.1 The roughness map

Areas of different roughness are apparent on most topographical maps, see Fig. 18. Examples are: water areas (the sea, fjords, lakes), sand surfaces, bare soil, moor, open farmland, farmland with many shelter belts, forests, villages, and cities.

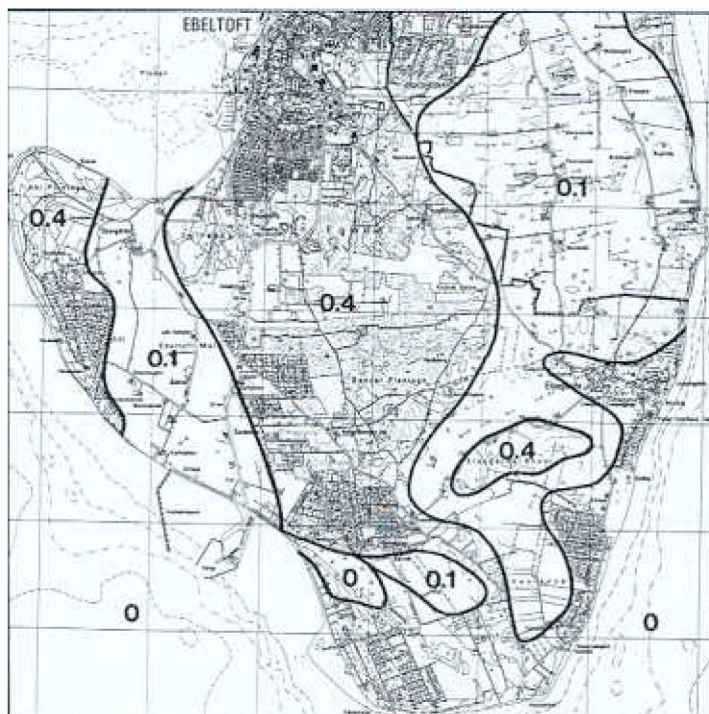


Figure 18. Example of a standard topographical map with areas of different roughness marked. Notice, that water areas are assigned a roughness length of “0” (zero). The roughness length values are given in metres.

The landscape can be classified into areas of similar roughness on basis of the information contained in the map, as well as any other information available, eg aerial photographs. This classification may be thought of as dividing the landscape into a number of terrain types or roughness classes – often in more detail than the classes mentioned in Section 2.1. When the classification has been done a roughness length z_0 can be assigned to each class – one possible relation between roughness class and roughness length was given in Fig. 12.

Roughness-change lines

The lines separating areas of different roughness are in this Guide referred to as roughness-change lines. Whereas the familiar height contour lines are assigned one value only, ie the height above mean sea level, roughness-change lines are assigned two values: the roughness lengths z_{0l} and z_{0r} found on either side of the line.

Furthermore, the starting point and end point of each roughness-change line must be specified. Tracing the line from the start to the end, the left- and right-hand sides of the line are unambiguously defined and the roughness lengths can be referred to as the left-hand z_{0l} and right-hand z_{0r} roughness lengths, respectively. Figure 19 illustrates the characteristics of roughness-change lines.

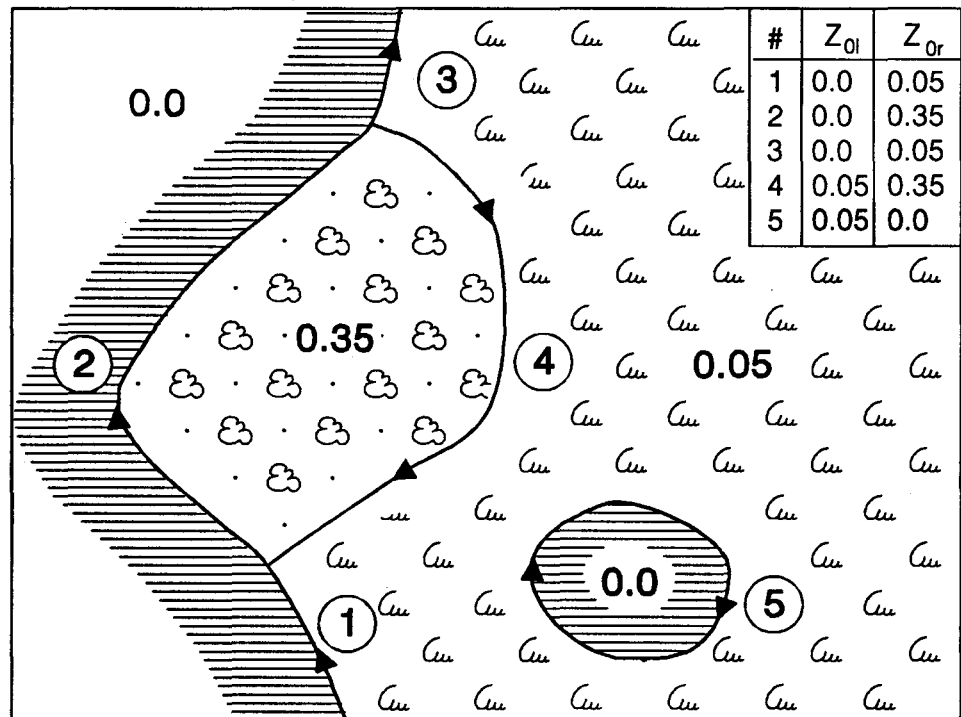


Figure 19. Example of roughness-change lines. Each line has a starting point and an end point, and two roughness length values are assigned to it. Water surfaces must be assigned a roughness length of 0 (zero) metres.

Providing the roughness map

Great care must be exercised when drawing and digitizing the roughness-change lines, so as to ensure a consistent roughness map. Like height contours, roughness-change lines should never cross each other; if they do, ambiguity in the roughness lengths will result, thereby creating wrong results.

Like height contour data, the roughness data are stored in a .MAP file containing



Figure 20. Example of a roughness map obtained by digitizing the roughness-change lines on a standard topographical map.

the values and coordinates of the roughness lines. The order of the coordinates in the file defines the start and end points of the lines. Height contour lines and roughness-change lines may be present in the same map file or may be stored in different files. Evidently, the coordinate systems must be the same in both cases.

Certain features in the landscape, first of all coast lines, represent both a height contour and a roughness-change line. Consequently, three types of lines may be present in the map file:

1. Contour line only, ie a line through points that are at the same height above sea level. The altitude (z) is given in metres.
2. Roughness line only, ie a line separating areas of different roughness lengths. This type of line is described by two parameters: the roughness length on the left-hand side z_{0l} and the roughness length on the right-hand side z_{0r} of the line. The roughness lengths are given in metres.
3. Combined roughness and contour line, ie a line that is both a contour line and roughness line (eg a coastline). These lines have three parameters: the roughness length on the left-hand side z_{0l} , the roughness length on the right-hand side z_{0r} , and the altitude of the line z - all of which are given in metres.

The roughness classification should preferably extend to at least 5 km from any site likely to be investigated. If extensive water surfaces ($z_0 = 0$) occur in the area, it may even be extended to 10 km or more. Topographical maps on scales of 1:25 000 or 1:50 000 are well suited for the roughness classification and preparation of the roughness map.

The roughness map is conveniently digitized using the INPUT option of the MAPDATA menu. The map can further be edited, as well as stored and retrieved from disk file using the EDIT, DUMP and RELOAD commands of the MAPDATA menu, respectively (*not* in the ROUGHNESS menu). A description of the MAPDATA sub-menu is given in Chapter 7.

The actual site in the map can be chosen by invoking the **SITE** command in the **ROUGHNESS** or the **OROGRAPHY** menu. When the site has been fixed, a roughness rose will be generated by **WASP** for the site in question. This rose can be viewed and edited invoking the **EDIT** command of the **ROUGHNESS** menu. It may also be stored and retrieved using the **DUMP** and **RELOAD** commands of the **ROUGHNESS** menu, see Section 3.3. Each time a roughness rose is calculated by **WASP** it should be viewed and compared to the actual conditions – and edited if necessary.

3.2 The site-specific roughness description

In general, the roughness roses for the sites are conveniently calculated by **WASP** using the roughness map as input. However, sometimes, either due to the lack of a proper topographical map or because only one site calculation is needed, the roughness rose may be input directly. The specification of a roughness rose for a given site is – as for the roughness map – a matter of assigning proper roughness lengths to the various surface types around the site. Dividing the horizon in twelve 30-degree sectors, the classification is done sector by sector after the following principles:

1. The classification shall extend to at least 5 km from the site. If there are extensive water surfaces ($z_0 = 0$) further away it may even be extended to 10 km or more.
2. In case there are several roughness changes in one sector the following rule may be applied: Let X_1 be the distance from the site to the first roughness change, X_2 the distance from the site to the next, and X_n the distance to roughness change number n . Then,

$$X_n \geq 2X_{n-1} \quad n = 2, 3, \dots \quad \text{and} \quad n \leq 10 \quad (5)$$

This guideline should be adhered to in order to avoid an abundance of roughness changes, but it may be deviated from in cases where clear roughness boundaries are found, eg at a coastline. A maximum of ten roughness changes can be specified in each sector.

3. In case the terrain between two lines of roughness change is not uniform a resulting roughness, z_0^R , must be estimated. Dividing the sector segment into quarters of approximately equal roughness, Tab. 3 gives the overall roughness length of the segment as a function of the number of quarters of each roughness class in the segment.

This division has to be done keeping in mind that areas close to the site will exert the strongest influence on the wind speed at the site. By using the principle of Fig. 21 high weights are assigned to close-by areas when each of the areas I, II, III and IV are given the same weight. Hence, if area I, II, III and IV are of class 0, 1, 2 and 3, respectively, the resulting roughness derived from Tab. 3 is ≈ 0.04 m.

The roughness classification may be compiled on a separate sheet like the “Roughness Classification Form” provided in Appendix D.

Roughness of water

In order to signal to **WASP** that an area consists of water and thereby making it able to treat the stability right, the area must be assigned a roughness length of 0 m (zero) and not 10^{-4} m as one would expect by looking at Fig. 12.

| Class: | 0 | 1 | 2 | 3 | z_0^R |
|------------|--------|------|------|------|---------|
| z_0 [m]: | 0.0002 | 0.03 | 0.10 | 0.40 | [m] |
| | 3 | 1 | | | 0.001 |
| | 3 | | 1 | | 0.002 |
| | 3 | | | 1 | 0.003 |
| | 2 | 2 | | | 0.004 |
| | 2 | 1 | 1 | | 0.006 |
| | 2 | 1 | | 1 | 0.010 |
| | 2 | | 2 | | 0.009 |
| | 2 | | 1 | 1 | 0.015 |
| | 2 | | | 2 | 0.025 |
| | 1 | 3 | | | 0.011 |
| | 1 | 2 | 1 | | 0.017 |
| | 1 | 2 | | 1 | 0.027 |
| | 1 | 1 | 2 | | 0.024 |
| | 1 | 1 | 1 | 1 | 0.038 |
| | 1 | 1 | | 2 | 0.059 |
| | 1 | | 3 | | 0.033 |
| | 1 | | 2 | 1 | 0.052 |
| | 1 | | 1 | 2 | 0.079 |
| | 1 | | | 3 | 0.117 |
| | | 3 | 1 | | 0.042 |
| | | 3 | | 1 | 0.064 |
| | | 2 | 2 | | 0.056 |
| | | 2 | 1 | 1 | 0.086 |
| | | 2 | | 2 | 0.127 |
| | | 1 | 3 | | 0.077 |
| | | 1 | 2 | 1 | 0.113 |
| | | 1 | 1 | 2 | 0.163 |
| | | 1 | | 3 | 0.232 |
| | | | 3 | 1 | 0.146 |
| | | | 2 | 2 | 0.209 |
| | | | 1 | 3 | 0.292 |

Table 3. Area-weighted roughness lengths, z_0^R . The segment is divided into quarters and each quarter is classified according to the European Wind Atlas roughness classification. z_0^R is given as a function of the number of quarters of each roughness class in the area.

As an example, Fig. 22 shows a likely set-up for a meteorological mast at an airport. The anemometer is situated between the runways about 600 m from the border of the airport. The first roughness change, from class 1 to class 3, appears at the airport fence. The forest outside the airport has an irregular shape, but choosing the next change 1200 m from the site, in accordance with the rules set forth above, seems reasonable. The next change should then not be closer to the site than 2400 m. A choice of 2600 m makes good sense as the terrain here

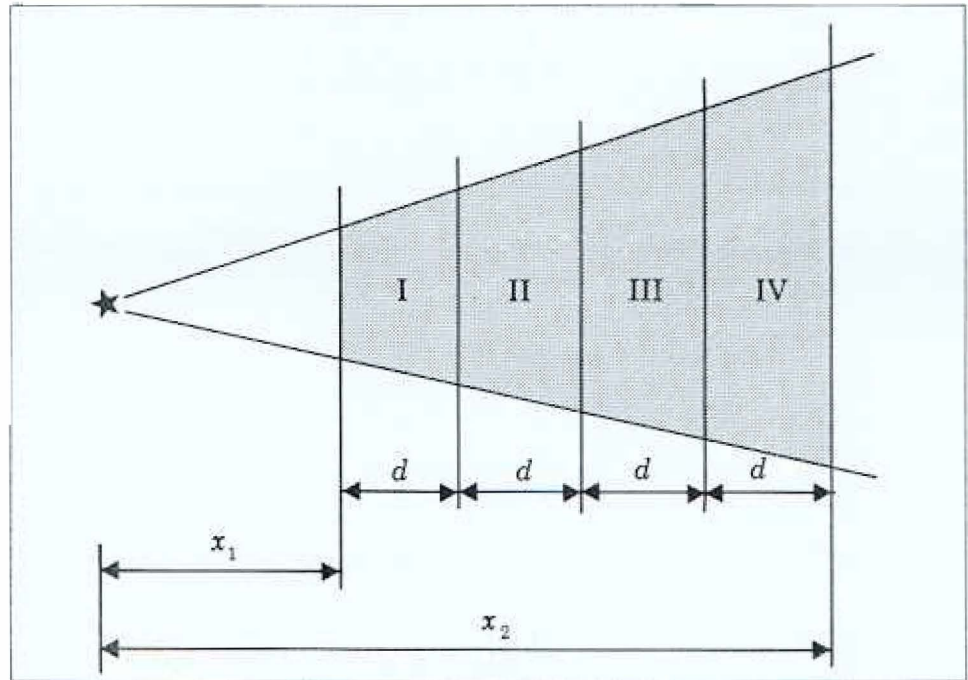


Figure 21. Principle of weighting areas in site-specific roughness calculations.

changes to class 2, this class extending far away from the site. For the segment between roughness change two and three Tab. 3 gives an overall roughness length of ≈ 0.01 m, corresponding to two quarters of class 0, one quarter of class 1 and one quarter of class 3.

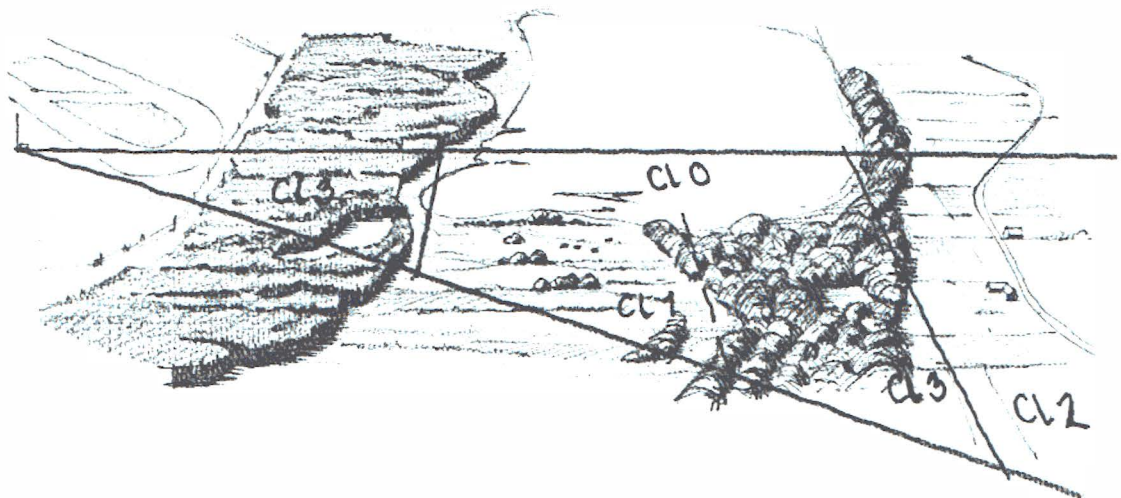


Figure 22. Site-specific roughness classification - an example.

3.3 The ROUGHNESS menu

When the roughness map has been prepared, or the roughness conditions in a number of sectors around the site have been classified and noted down in the "Roughness Classification Form", the ROUGHNESS menu in the main display may be invoked:

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

Notice, that the MAPDATA and SITE options refer to the roughness map and the remaining options to the roughness rose.

MAPDATA If the input data is a disk file containing digitized roughness change lines, the MAPDATA menu should be chosen. How to prepare a digitized map is explained in detail in Chapter 7.

SITE Reloading the map from the MAPDATA menu only enters the digital map to W&SP. The SITE option selects the actual site, for which W&SP is now able to calculate a roughness rose. If the map file contains height contours as well, the complex terrain model is also initialized by the SITE command.

Having invoked the SITE command the current map is displayed, see Fig. 23. It is now possible to select a site directly on the map by pressing <S> (for Site). For accuracy, it is often necessary to zoom in on a smaller area of the map by way of the Window command. The window is activated by pressing <W> and the size of the window is then adjusted with the arrow keys. The commands of the graphics menu shown in Fig. 23 are described below.

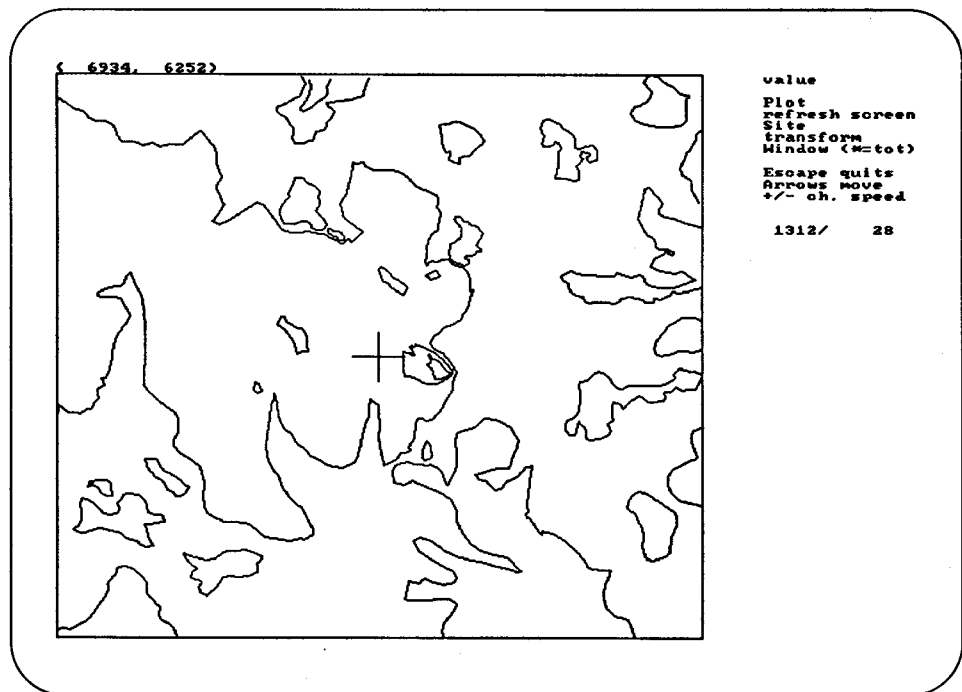


Figure 23. The digital map and graphics menu shown having invoked the SITE command in the ROUGHNESS menu, cf Fig. 20. The coordinates of the cross-hair are shown in the upper left-hand corner of the display.

- value The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line. Notice, that the values appear only until a new command is invoked or the cross-hair is moved.
- Plot Generates a plot file of the screen display – either a .PLT or a .HPG file. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen, that is redraws the map. This command can be used to eg remove the numbers generated by the value command, or spurious dots.
- Site The point marked by the graphics cursor is selected as the site and a roughness rose will be calculated for this site. This rose can be inspected by invoking EDIT in the ROUGHNESS menu, see below. Returning to one of the main displays, the roughness-change model can now be executed by simply updating the screen, ie pressing the *<Return>*-key.
- transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press *<t>* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *<Return>*. A window is now shown around the target – use arrow keys to enlarge this window and press *<Return>* to select. A 3-D rendering of the terrain is displayed after a short while, an example is given in Fig 46.
A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. The Plot option generates a plot file of the photo, as described above.
- Window Zooms in on part of the map, the size of which is can be changed using the arrow keys. When the window has been selected, press *<Return>* to zoom.
- * Zooms out to the original window.
- <Esc>* Leaving graphics mode is done by pressing the *<Esc>*-key. If the site was not fixed in graphics mode, WASP will inquire for the coordinates of the site. The site coordinates must be entered in metres. This way of selecting the site is generally preferred, since it allows for an accurate position to be specified.
- +/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The map coordinates of the cross-hair or window corner points are displayed on the top line. The cross-hair steps can be changed by pressing the + (larger steps) or – (smaller step) keys one or several times.

* * *

- EDIT Choosing the EDIT command in the ROUGHNESS menu it is possible to inspect the roughness rose calculated by WASP. Alternatively, a site-specific roughness description can be entered directly from the keyboard using the following syntax:

$$d_i[-d_j] : [(\textit{roughness description})][*p_{\text{user}}][T\Delta d_{\text{user}}] \quad (6)$$

where d_i and d_j are center angles of two sectors, p_{user} is the local or user-specified percentage change of wind speed and Δd_{user} is a user-specified turning of the wind direction, see below. Square brackets indicate an optional parameter. The roughness description is typed as follows:

$$\langle \textit{roughness description} \rangle = z_{01}[, X_1, z_{02}[, X_2, z_{03} \dots [X_{n-1}, z_{0n}]]] \quad (7)$$

where $n \leq 10$, and the roughness lengths, z_{0i} , and the distances from the site, X_i , are given in metres. The following lines are examples of valid input:

```

180: 0.01,500,0.20
120: 0.01,1200,0.07 *-5
300-330: 0.06,500,0.10,1200,0.40,3000,0.10 *6 T4

```

Notice, that only the first 5 roughness changes are displayed on the screen (Fig. 24) even though up to 10 changes of roughness can be specified. The roughness description file (.RDS) can also be edited using an ASCII file editor, in which case the entire description (up to ten changes of roughness) can be inspected. The total number of roughness changes and the user-specified corrections for each sector are given in the result display.

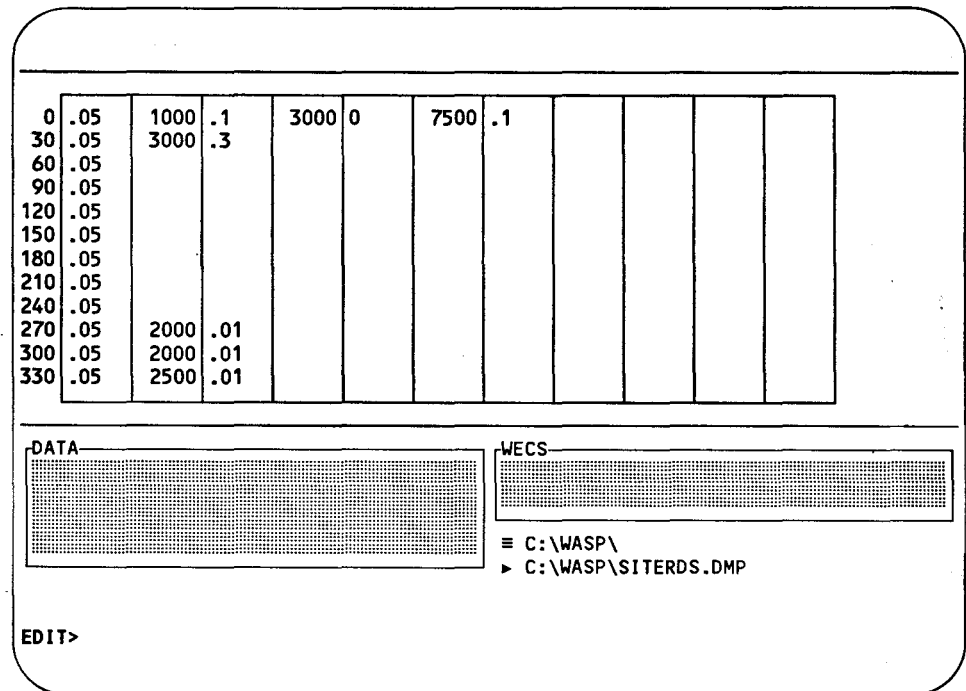


Figure 24. The roughness rose is shown when the EDIT option is invoked. The rose may be calculated by WASP or may be entered directly.

- TEXT** It is possible to designate a text to the roughness description, this is done using the TEXT option. The text is shown in the main display.
- DUMP** Once the complete site description has been entered it may be stored on disk file using the DUMP option of the ROUGHNESS menu. The roughness rose calculated by WASP from a roughness map may also be stored in this way. The contents of a roughness description file appear from Appendix C. The default extension for roughness rose disk files is .RDS.
- RELOAD** Site description files are retrieved from disk using the RELOAD option. Enter a file name to reload a specific file, or enter an asterisk '*' to obtain a list of all .RDS files in the current directory. The file name may also include drive and path specification.
- DOS** As in the main menu.
- HELP** As in the main menu.

RETURN Returning to the main display of WASP.

Default site description If a site has not been specified on the roughness map and no site-specific roughness description has been provided, a default roughness rose is used. In this default rose the terrain is uniform with a roughness length in all sectors of 0.03 metres.

Model status The roughness-change model is executed each time the main display is refreshed by pressing the *<Return>*-key. The status display shows the name of the map file (.MAP) with roughness-change lines, or the roughness rose file (.RDS) – as well as the descriptive text strings assigned to these files.

Model results The result display shows the number of roughness changes in each sector. The effects on the wind speed and direction are not listed explicitly, but are taken into account in the calculation of the Weibull parameters, sector frequencies, etc.

User-specified corrections

As described above, the EDIT option in the ROUGHNESS menu can be used to enter user-specified corrections for one or more sectors. The results from wind tunnel measurements of shelter effects, results from another shelter model or results from another complex terrain model are examples of this.

Notice, that the user-specified corrections (shown in the right-hand side of the EDIT display) are kept unaltered unless explicitly changed by the user via the EDIT option, eg:

```
EDIT> 0-360: T0 *0
```

or by reloading another .RDS file.

Local effects It is also possible while entering or editing the roughness rose to enter strictly 'local' influences on the wind measurements. The word local is used here to characterize effects that cannot easily be classed with roughness, shelter or orography; or effects that – by experience or experiment – are known to the user.

If, for example, the shadowing effect of a wind vane mounted close to the anemometer is known to reduce the measured wind speed in a certain sector by 5%, this amount of reduction is noted in the "Roughness Classification Form" and entered together with the roughness description when running WASP, eg

```
EDIT> 120:0.01,1200,0.07 *-5
```

Notice the sign of the correction: -5% because the measured speed is 5% too low. In principle, the wind direction can be corrected in a similar way; however, since direction corrections are often applied to all directions/observations, this correction is most often applied directly to the meteorological data, see Sections 6.1 and 6.2.

4 Winds in complex terrain

WASP utilizes the “BZ-model” of Troen (1990) to calculate the wind velocity perturbations induced by orographic features such as single hills or more complex terrain. The BZ-model belongs to a family of models related to the Jackson and Hunt theory for flow over hills (Jackson and Hunt, 1975; Taylor *et al.*, 1983). The model was developed with the specific purpose of detailed wind energy siting in mind and has the following general features:

- It employs a high-resolution, zooming, polar grid. This is coupled with a map analysis routine in order to calculate the potential flow perturbation profile at the central point of the model.
- It integrates the roughness conditions of the terrain surface into the spectral or scale decomposition. The “inner-layer” structure is calculated using a balance condition between surface stress, advection and the pressure gradient.
- It uses an atmospheric boundary layer thickness of ≈ 1 km to force the large scale (say, more than a few kilometers) flow around high-altitude areas.

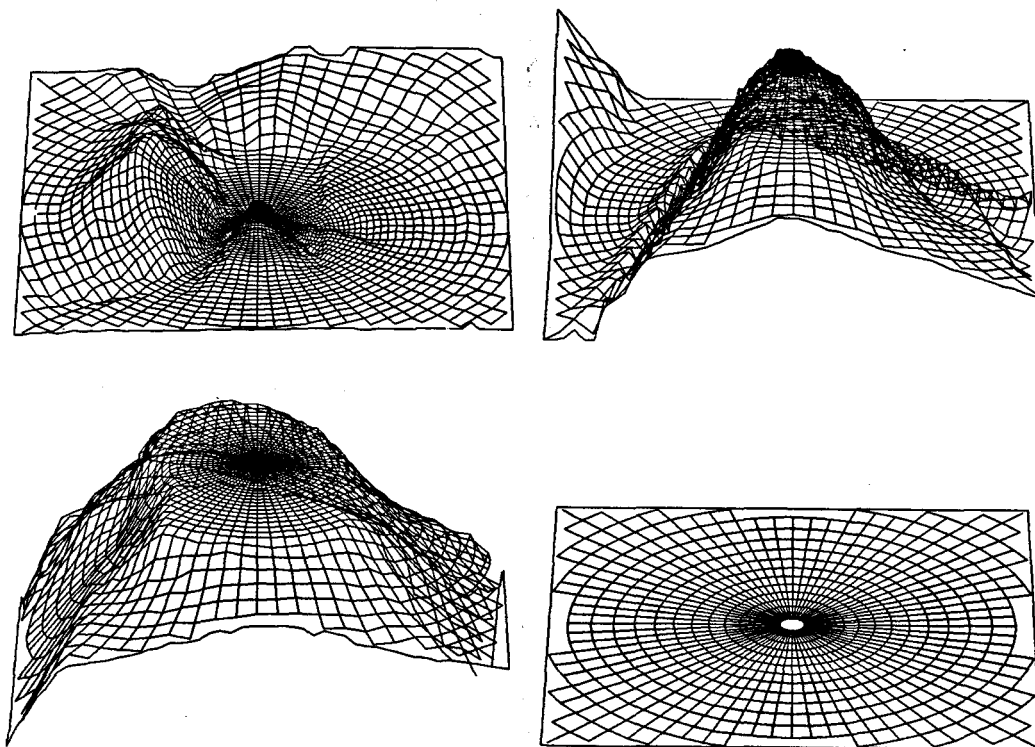


Figure 25. The zooming grid of the BZ-model seen with 4 different surface-eye distances.

The zooming grid of the BZ-model is illustrated in Fig. 25. A 25×25 km² section of Waspdale is shown in the upper left-hand corner of the figure. The grid is centered at the WECS site on Beevery Hill and has a radius of about 27 km. The BZ-model examines all the grid points when estimating the wind conditions at the hill site. In the upper right-hand corner a closer view of the same site and grid is shown, covering an area of 5×5 km². Still closer, the drawing in the lower

left-hand corner covers an area of about 1 km². Finally, the center of the grid is shown in the lower right-hand corner of the figure; this covers approximately 200 × 200 m². The grid resolution at the center of the model is 4 m.

4.1 The height contour map

In general, it is necessary to take the effect on the flow from the height variations around the site into account. In principle, the necessary input to the model is the height of the terrain at each grid point, but a much more convenient representation of the terrain heights is the contour lines (lines representing equal altitude) given on standard topographical maps. The model was designed, therefore, to directly accept arbitrarily chosen contour lines as input and it integrates the estimation of grid-point values and the numerical integrations into one process.

The zooming grid consists of 100 radial stations and the resulting resolution near the centre is approximately 2 m (!) for a model with $R = 10$ km, and approximately 10 m for $R = 50$ km, etc. Therefore, resolution is limited in practice only by the accuracy and density of the contour data from the topographical maps. An example of a standard topographical map is given in Fig. 26. Figure 27 shows the height contours obtained by digitizing the same map.

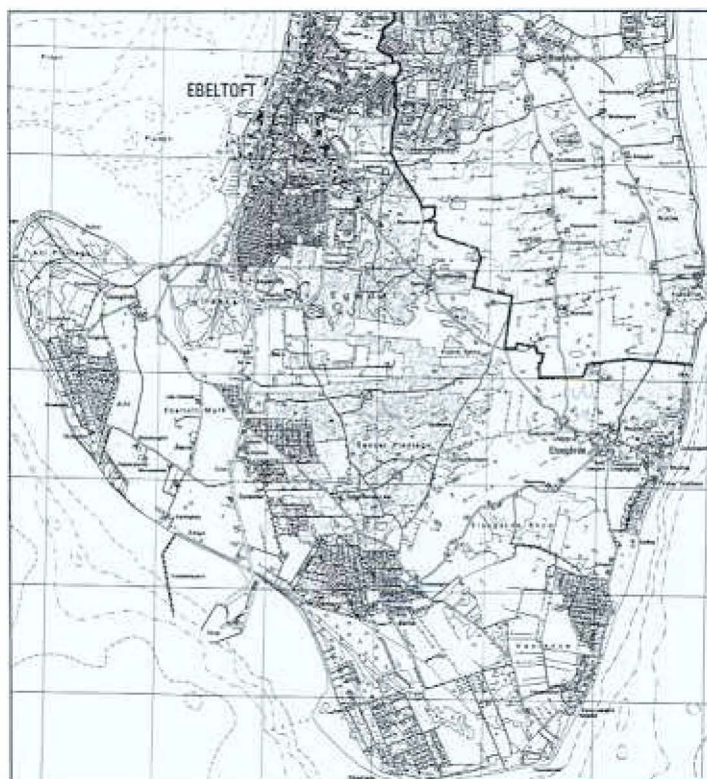


Figure 26. Example of a standard topographical map.

Chapter 7 explains how to obtain the height contours in practice, by digitizing topographical maps.

Accuracy and detail The zooming grid inherent in the BZ-model, indicates that the contour line descriptions close to the prospected site(s) should be as detailed and accurate as possible, and – conversely – that both detail and accuracy may be relaxed somewhat far away from the site(s).



Figure 27. Example of the height contours obtained by digitizing a standard topographical map, cf Fig. 26.

The site Special attention must be given to the site itself – especially if this is right on top of a hill or a ridge. Preferably, the ‘highest’ contour line should enclose the very site and in this way define the hill-top precisely. If this is not the case, one should supplement the map contours with a height contour just enclosing the site and with the same altitude as this.

4.2 Simple hills

In case a digital map of the terrain is not available or the terrain is particularly simple, WASP may generate a digital map of a simple Gaussian (bell-shaped) hill, see Fig. 28 and 29.

The following characteristics of the hill must be specified:

- height of the hill h
- location of hill center (x, y)
- orientation of major axis α
- half-widths of the hill

The different characteristics of the hill were illustrated in Fig. 15, see also Fig. 28 and 29. The height and half-widths must be given in metres – the half-widths are the distances from the hill center to points halfway to the base of hill in the direction of the major and minor axis. The location of the center of the hill are given in actual map coordinates (metres also). The orientation of the major axis is specified following the meteorological convention, ie degrees clock-wise from North. The hill may be displayed, edited, stored, and retrieved like any other digital map, see Section 4.3.

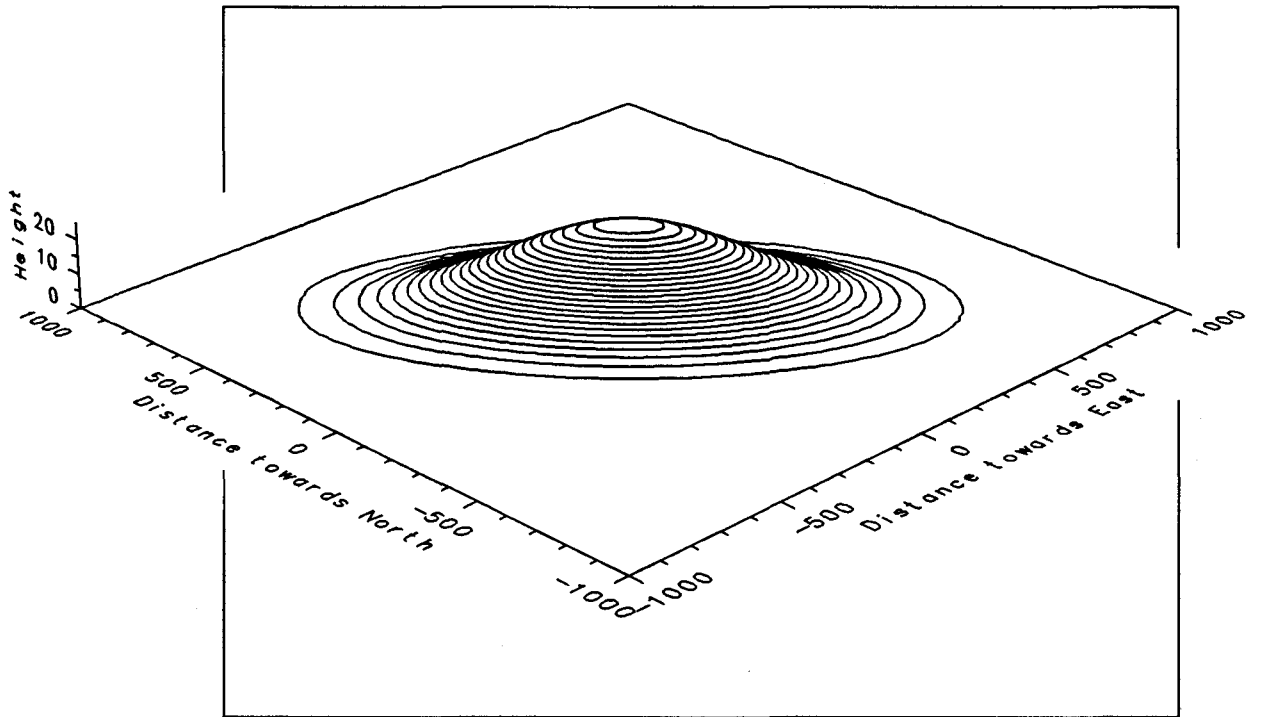


Figure 28. Perspective view of a simple Gaussian hill.

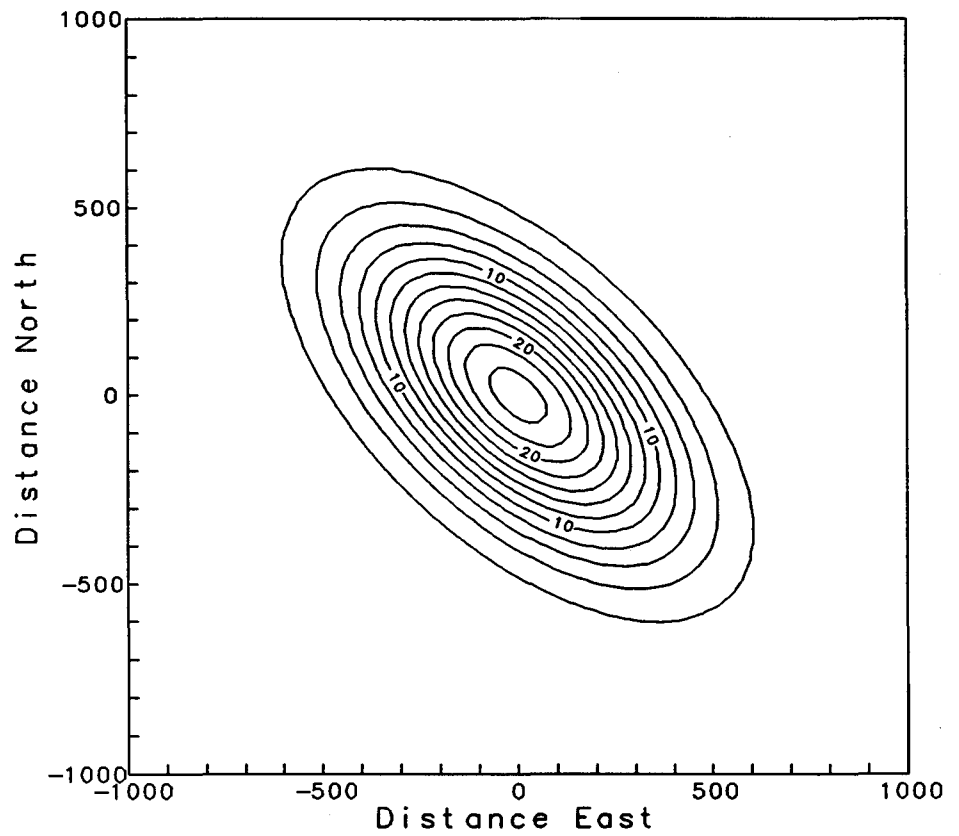


Figure 29. Map of a simple Gaussian hill, cf Fig. 28.

4.3 The OROGRAPHY menu

Entering a digital terrain description and initializing the BZ-model is performed via the OROGRAPHY-menu. The key-words in this menu are:

```
MAPDATA HILL SITE CLEAR TEXT
DOS HELP RETURN
```

MAPDATA If the input is a disk file containing a digitized map, the MAPDATA menu should be chosen. How to prepare a digitized map is explained in detail in Chapter 7.

HILL Alternatively, WASP may generate the digital height contours of a simple Gaussian hill. The height, location, orientation and horizontal dimensions of the hill are specified by the user. All parameters must be in metric units. This is obtained through the HILL option.

SITE Reloading the map from the MAPDATA menu or the HILL option only enters the digital map to WASP. The SITE option centers the model grid on a specific point, adjusts the model radius according to the domain size and initializes the model. If the map file contains roughness-change lines as well, a roughness rose will be generated by WASP for the site in question.

Having invoked the SITE command the current map is displayed, see Fig. 30. It is now possible to select a site on the map by pressing $\langle S \rangle$ (for Site). For accuracy it is often necessary to zoom in on a smaller area of the map by using the Window command. The window is activated by pressing $\langle W \rangle$ and the size of the window is then adjusted with the arrow keys.

The different options of the graphics menu shown in Fig. 30 are described below. Each option is invoked by pressing the first letter of the key-word (underlined>).

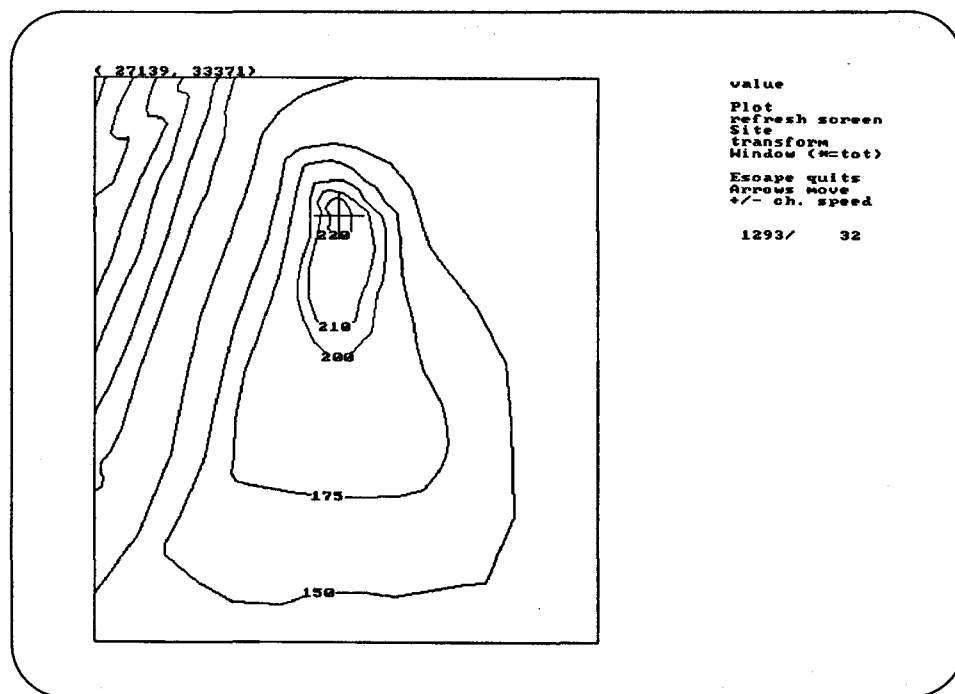


Figure 30. The digital map and graphics menu shown having invoked the SITE command in the OROGRAPHY menu. The coordinates of the cross-hair are shown in the upper left-hand corner of the screen.

- value Displays the altitude (in metres) of the line closest to the cross-hair. Height contour values are displayed as numbers on the line in question.
- Plot Generates a plot file of the screen display – either a .PLT or a .HPG file. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen, that is redraws the map. This command can be used to eg remove the numbers generated by the value command, or spurious dots.
- Site The point marked by the graphics cursor is selected as the site and the model grid will be centered on this point. Returning to one of the main displays, the BZ-model can now be executed by simply updating the screen, ie pressing the *<Return>*-key.
- transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press *<t>* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *<Return>*. A window is now shown around the target – use arrow keys to enlarge this window and press *<Return>* to select. A 3-D rendering of the terrain is displayed after a short while, an example is given in Fig 31.
- A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. Plot generates a plot file of the photo, as described above.
- Window Zooms in on part of the map, the size of which is can be changed using the arrow keys. When the window has been selected, press *<Return>* to zoom.
- * Zooms out to the original window.
- <Esc>* Leaving graphics mode is done by pressing the *<Esc>*-key. If the site was not fixed in graphics mode, WASP will inquire for the coordinates of the site. The site coordinates must be entered in metres. This way of selecting the site is generally preferred, since it allows for an accurate position to be specified.
- +/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The cross-hair steps can be changed by pressing the + (larger steps) or – (smaller step) keys one or several times.
- CLEAR The CLEAR option removes the map from the scenario, as indicated in the main displays. The same action can be obtained typing –OROGRAPHY in the main menu. However, the map is still present in the memory of the computer, and it may be reactivated by invoking the SITE option.
- TEXT The TEXT option makes it possible to specify a text string that will appear in the main display whenever the map in question is loaded.
- DOS As in the main menu.
- HELP As in the main menu.
- RETURN Returning to the main display of WASP.

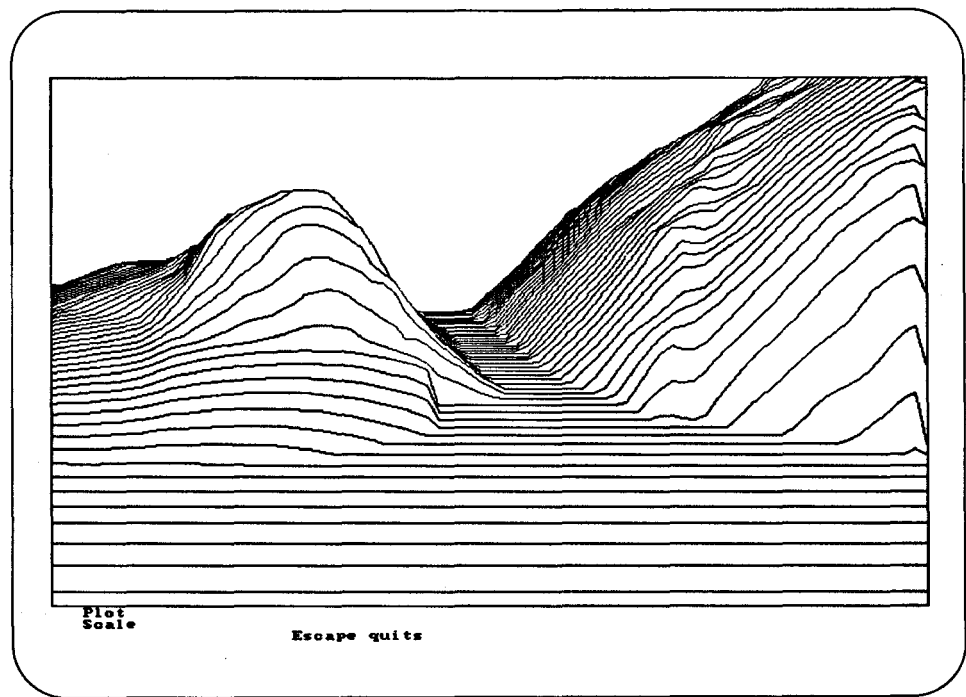
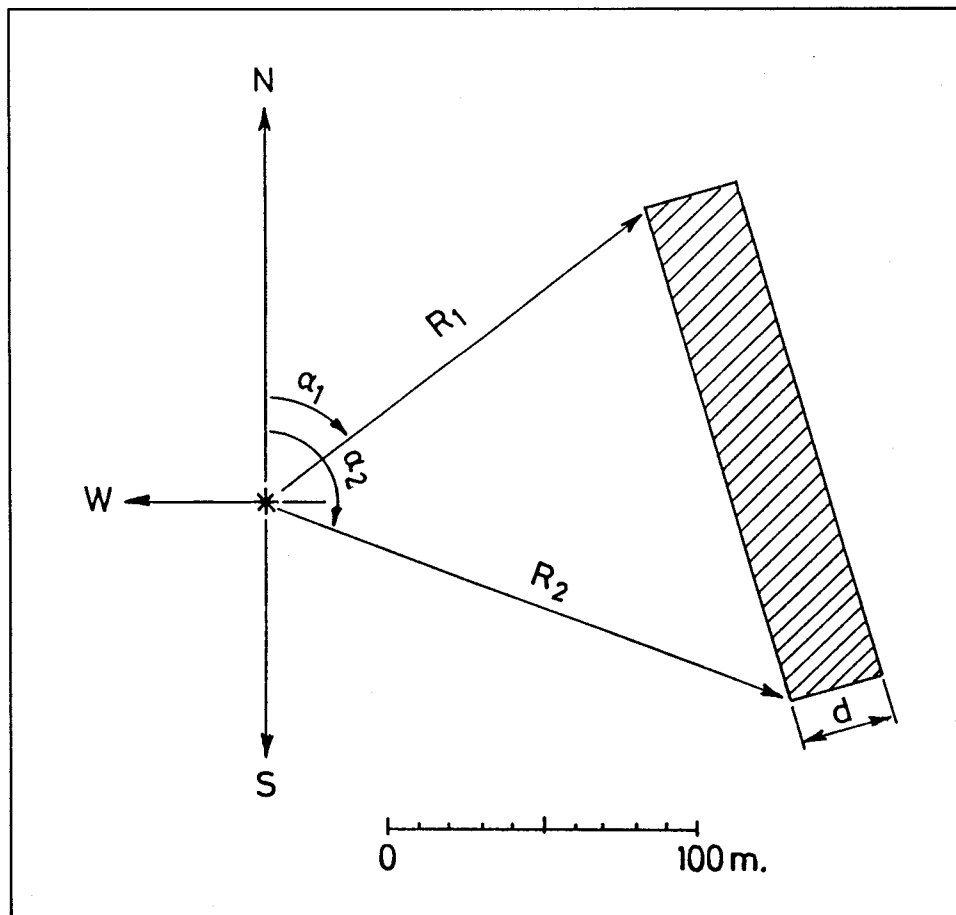


Figure 31. The graphics display and commands obtained by invoking the transform option in the SITE menu.

Model results The model-derived wind speed changes and turning of the wind for each sector are shown in the result display. Changing the height of calculation in the main menu (by typing HEIGHT) and updating the screen will lead to model results for the new height.

5 Shelter behind obstacles

Obstacles are considered by WASP as 'boxes' with a rectangular cross-section. Each obstacle must be specified by the position relative to the site, its dimensions and must be assigned a porosity. Figure 32 defines the quantities that specify a single obstacle and that must be input to WASP. The information may be compiled on a separate sheet like the "Obstacle Description Form" provided in Appendix D. WASP can handle up to 50 obstacles at the same time.



| | |
|------------|--------------------------------------|
| * | position of site |
| α_1 | angle from N to first corner [deg] |
| R_1 | radial distance to first corner [m] |
| α_2 | angle from N to second corner [deg] |
| R_2 | radial distance to second corner [m] |
| h | height of obstacle [m] |
| d | depth of obstacle [m] |
| P | estimated porosity |

Figure 32. Providing shelter information. Angles are measured from 0 (north) to 360 degrees clockwise. Obstacles are specified relative to a specific site and are not linked directly to the topographic map.

Obstacle or roughness element?

Figure 17 in Chapter 2 may serve as a guideline when deciding whether to include obstacles in the terrain as sheltering obstacles or as roughness elements:

- if the point of interest (anemometer or wind turbine hub) is closer than about 50 obstacle heights to the obstacle and closer than about three obstacle heights to the ground, the object should probably be included as an obstacle. In this case the obstacle should not at the same time be considered as a roughness element.
- if the point of interest is farther away than about 50 obstacle heights or higher than about three obstacle height, the object should most likely be included in the roughness description.

Since most anemometers are mounted at a standard height of 10 m a.g.l. and often quite close to buildings, the shelter effect is potentially serious in the analysis of wind data. On the other hand, a wind turbine with a hub height of 30 m a.g.l. and sited well away from buildings will rarely experience serious shelter effects.

Limitations of the shelter model

Very close to an obstacle, corresponding to the hatched area in Fig. 17, the obstacle model will not yield realistic results. Recent investigations by Taylor (1992, pers. comm.) indicate that the shelter model of WASP probably overestimates the shelter provided by 3-dimensional obstacles – in some cases by as much as a factor of 2 – whereas the shelter calculated for 2-dimensional fences seem to be very similar to the model results and experimental data reported by Taylor.

The shelter or wake effects from other wind turbines should be calculated using the *PARK* program – and *not* the shelter model.

Local or user-specified effects

Occasionally, some sheltering or ‘shadowing’ effects are known quantitatively from measurements at the site or perhaps from wind tunnel experiments. Such knowledge may be supplied to WASP directly through the site description, see Chapter 3.

Figure 33 depicts the anemometer conditions at Waspdale Airport, and Fig. 34 shows the corresponding obstacle characteristics.

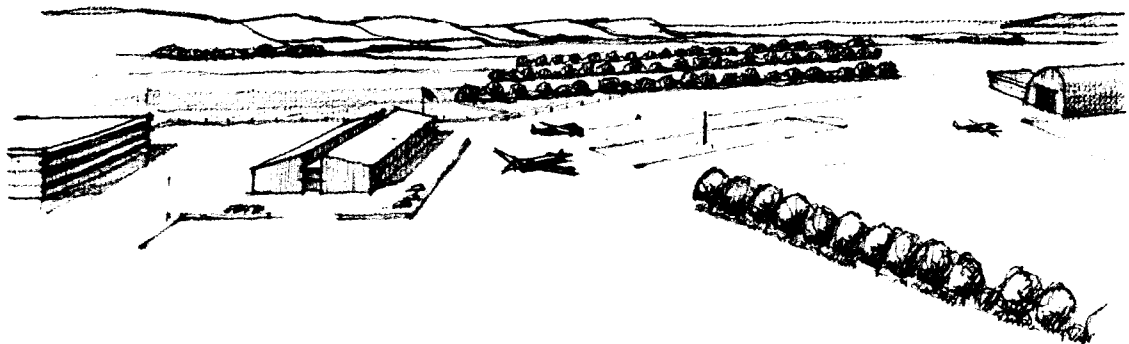


Figure 33. Example showing a configuration of various sheltering obstacles at Waspdale Airport. The airport area is viewed from SE.

| # | α_1 | R_1 | α_2 | R_2 | h | d | P | type |
|---|------------|-------|------------|-------|-----|-----|-----|----------------------|
| 1 | 11 | 134 | 26 | 120 | 6 | 30 | 0.0 | building |
| 2 | 26 | 120 | 43 | 110 | 6 | 60 | 0.0 | building |
| 3 | 112 | 500 | 146 | 74 | 5 | 16 | 0.4 | rows of trees, dense |
| 4 | 200 | 90 | 248 | 76 | 4 | 26 | 0.0 | building |
| 5 | 215 | 154 | 237 | 144 | 6 | 46 | 0.0 | building |
| 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 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

Figure 34. Obstacle characteristics at Waspdale Airport corresponding to the situation depicted in Fig. 33.

5.1 The OBSTACLE menu

Entering and editing a list of obstacles for a specific site is taken care of by the OBSTACLE menu. The OBSTACLE menu is reached by typing OBSTACLE or OBS in the main menu:

```
INPUT EDIT DISPLAY MOVE CLEAR TEXT DUMP RELOAD
DOS HELP RETURN
```

- INPUT** Invoking the INPUT option obstacles may be entered one by one. The obstacle characteristics are typed in the same order as given in the obstacle description form (Fig. 34). Distances, heights, and depths are in metres; angles are in degrees from N, positive clockwise, and the porosity must be greater than or equal to 0 (solid) and less than or equal to 1 (no effect).
- EDIT** The EDIT option lists the obstacles specified in the current set-up and allows for changing the characteristics of one or more obstacles. Deleting an obstacle from the list is done by entering the number of the obstacle only. Extending the list may be done in either INPUT or EDIT mode.
- DISPLAY** Having entered a list of obstacles a sketch map of these may be shown by invoking the DISPLAY option, see Fig. 35. The site and sector division corresponding to the analysis are shown on the sketch map.
- MOVE** In case there are more than one site of interest close to a given set-up of obstacles, these need only be specified and typed in once. The MOVE option recalculates the obstacle descriptions relative to a new site. First, you are prompted to enter the coordinates of the present site, and next you are prompted to enter the coordinates of the new site. The coordinates should be given in metres in a Cartesian coordinate system, the x - and y -axis of which points towards east and north, respectively. The new set-up should be checked by invoking the DISPLAY option.
- Notice, that obstacles are specified *relative to the site* – in a local coordinate system which is not (necessarily) linked to the map coordinate system.

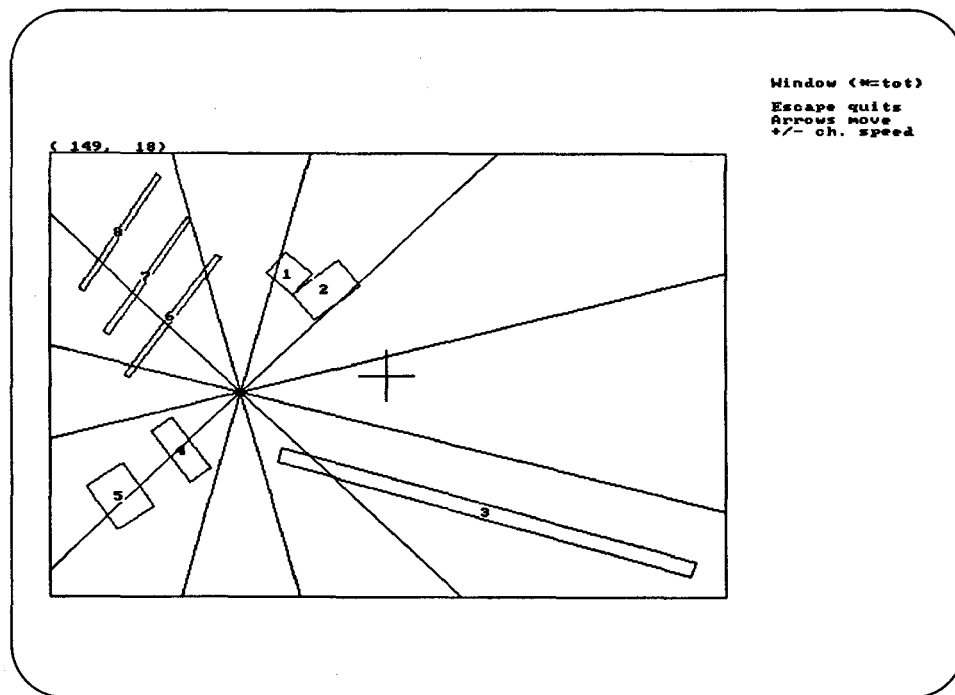


Figure 35. Obstacles at Waspdale Airport as viewed with the DISPLAY option in the OBSTACLE menu, cf Fig. 33.

- CLEAR** An obstacle list may be cleared completely by the CLEAR command. Typing -OBS in the main menu also clears the list, but in this case the same list may be reactivated by invoking the EDIT option.
- TEXT** Input of a character string identifying the obstacle list given in the display.
- DUMP** Once the obstacle list is established it may be stored on disk file using the DUMP option. A default file name extension of .OBS is assumed by WASP. The OBS-file can also be edited directly with an ASCII editor.
- RELOAD** Obstacle list files are retrieved from disk using the RELOAD option. Enter a file name to reload a specific file, or enter an asterisk '*' to obtain a list of all .OBS files in the current directory.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of WASP.
- Model status* The shelter model is executed each time the main display is refreshed by pressing the *(Return)*-key. The status display shows the name of any reloaded obstacle list file as well as the text string assigned to the list.
- Model results* The result display gives the reduction in per cent of wind speeds in the various sectors due to the shelter effects.

6 The meteorological data input

The meteorological input to W^{ASP} may be *raw* or *processed* data. Raw data are usually measurements of wind speed and direction, either in the form of a time-series or compiled into a climatological table. These data will reflect the specific conditions under which they were obtained. Strictly speaking, they represent only the exact point of measurement. In order to extrapolate such data, one must take into account the effect of nearby obstacles, the surface roughness conditions, and the effect of the terrain height variations around the meteorological station. Only after “cleaning” the data in this way can they be used for estimating the wind climate at other places around the meteorological station.

By processed data we mean data for which this kind of analysis has already been performed, leading to a wind atlas for the region considered. The wind atlas gives the probability density functions (Weibull distributions) of wind speed for certain standard conditions, ie standard azimuth sectors, heights above ground and surface roughness conditions. Processed data are described further in Chapter 8.

Raw data This chapter outlines the ways to enter, process and store raw meteorological data. The routines to handle data input and output are collected in the DATA menu:

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

Meteorological data are usually stored in sequential ASCII disk files. However, input of time-series data is also possible from binary files.

6.1 Time-series data

Observations of wind speed and direction in the form of a time-series may be entered to W^{ASP} by invoking the RAWDATA option in the DATA menu. The purpose of this option is to transform any time-series of wind speed and direction into a table that gives the frequency of occurrence of wind speed versus wind direction. This histogram table is then used by W^{ASP} in the analysis of the wind climate.

The time-series may consist of one or more files – ASCII or binary – with one or more observations (scans) per file record (line). Files with observations in every *n*th record can also be processed.

Data file format

Having entered the file name (default file name extension .DAT), W^{ASP} will enquire for the format of the data records. Blank input (*Return*) is required for binary files, and any valid FORTRAN 77 format character expression for ASCII files (eg 8X, 2I3). An asterisk (*) is given for free-format ASCII input. In general, the data file format can be specified as follows:

$$\langle \text{format expression} \rangle \#[[N_1 N_2] N_3 N_4] N_5 \quad (8)$$

where the five integers $N_1 \dots N_5$ are optional (indicated by the square brackets) formatting parameters; these are preceded by a #-sign, if employed. The meaning of the format parameters are described below.

Free-format Ascii files If the input data file is a sequential ASCII file and the observations in each record are separated by commas or one or more spaces, the file can be read by a free-format statement. In this case the *format expression* reduces to an asterisk, viz

$$* \#[[N_1 N_2] N_3 N_4] N_5 \quad (9)$$

and the #-sign may be omitted when employing the formatting parameters.

Binary data files In case the wind data are stored in a sequential binary file, blank input (*Return*) or one or more spaces followed by (*Return*) must be entered:

$$[\#[[N_1 N_2] N_3 N_4] N_5]] \quad (10)$$

Also in this case is the #-sign optional if the formatting parameters are employed.

Fixed-format Ascii files Finally, if the input data are stored in a sequential ASCII file and you wish to read the file with a format statement, the following string must be entered at the RAWDATA prompt:

$$\langle \text{format expression} \rangle [\#[[N_1 N_2] N_3 N_4] N_5]] \quad (11)$$

where *format expression* is any valid FORTRAN 77 format character expression. In this case the formatting parameters *must* be preceded by the #-sign, if employed.

Optional formatting parameters

A time-series consists of a number of observations of wind speed and direction and, possibly, other meteorological parameters like temperature, humidity etc. One simultaneous observation of a number of variables is often referred to as a *scan*. It is common practice to store each measured scan in one file record, but occasionally this is not feasible. Hence, two or more scans may be listed in each file record or several file records may be used to store each scan.

In addition, one may sometimes want to process only part of a given time-series. The *formatting parameters* introduced above – plus the possibility of entering more than one data file during the RAWDATA analysis – makes it possible to handle most of the data file structures mentioned above. The meaning of the five parameters, which must be positive integers, is:

- N_1 Column number in scan (record) for wind speed
- N_2 Column number in scan (record) for direction
- N_3 First scan (record) to read
- N_4 Scan (record) increment when reading
- N_5 Last scan (record) to read

Notice that the parameters generally refer to the scan rather than the file record. The terms *scan* and *record* are equivalent only in case there is exactly one scan in each record. The parameters N_1 and N_2 are used to specify the 'position' in each scan of the wind speed and direction values, respectively, whereas $N_3 \dots N_5$ may be thought of as the initial, incremental and terminal values of a *do-loop*, determining what scans will be read and processed. Notice that your options are: 1) no format parameters, 2) N_1 and N_2 , 3) N_1, N_2, N_3 and N_4 , or 4) N_1, N_2, N_3, N_4 and N_5 . Examples on the use of the formatting notation are given below.

Free-format input

Example 6.1: *format expression* = *

One scan per record. The wind speed and direction values in the record are separated by commas or one or more spaces. Wind speed is the first number of each record (scan) and precedes direction (default), which is the second number of each record.

Example 6.2: *format expression* = * 1 2 1 3

As example 6.1, but only every third record (scan) is read. The entire file will be read since no terminal record is given. The format * 1 2 144 3 1584 would tell WASP to read every third record from record 144 through 1584 of the file.

Example 6.3: $\langle \text{format expression} \rangle = * 2 1$

One scan per record. Wind direction precedes speed. Since WASP assumes by default that speed precedes direction, you must use the formatting parameters N_1 (2) and N_2 (1) to specify the inverse order.

Example 6.4: $\langle \text{format expression} \rangle = * 9 3$

As example 6.3, with wind direction being the third and speed the ninth number in the record.

It is not possible, as with the fixed-format slash editing (“/”) described below, to advance to the next record or skip a number of records during the reading of one scan. Simultaneous values of wind speed and direction *must* therefore be listed in the same record in free-format files; however, you may skip records by employing the formatting parameters.

When two or more scans are listed in each record you must process the file two or more times, each time entering the format corresponding to the set of observations you want to read. The first time the file is read you enter the format string of the first set of observations (eg, * 2 3), the next time the format of the next set (eg, * 5 6) and so on.

Binary input The input of binary files is identical to free-format input except for the omission of the asterisk (*). The formats of examples 6.1–4 therefore take the following form if the data file is binary:

Example 6.5: $\langle \text{format expression} \rangle =$

Example 6.6: $\langle \text{format expression} \rangle = 1 2 1 3$

Example 6.7: $\langle \text{format expression} \rangle = 2 1$

Example 6.8: $\langle \text{format expression} \rangle = 9 3$

Binary files require less disk space and are processed much faster than ASCII files. Unfortunately, binary formats are specific for each programming language – the binary files associated with WASP employ the format used by Lahey FORTRAN 77.

Fixed-format input **Example 6.9:** $\langle \text{format expression} \rangle = 4X, I3, 6X, I4$
One scan per record. Wind speed (I3) precedes direction (I4). The first four characters in each record are skipped, as well as 6 characters between the speed and direction values. Using standard FORTRAN notation, the file records could also have been read with the format T5, I3, T14, I4, where T is the ‘tabulator’ of FORTRAN.

Example 6.10: $\langle \text{format expression} \rangle = 4X, I3, 6X, I4 \# 1 2 1 3$

As example 6.9, but only every third record (scan) is read. The entire file will be read since no terminal record is given. The format 4X, I3, 6X, I4 # 1 2 144 3 1584 would instruct WASP to read every third record from record 144 through 1584 of the file.

Example 6.11: $\langle \text{format expression} \rangle = 4X, I3, 6X, F4.1 \# 2 1$

One scan per record. Wind direction (I3) precedes speed (F4.1). Since WASP assumes by default that speed precedes direction, you must use the formatting parameters N_1 (2) and N_2 (1) to specify the inverse order.

Example 6.12: *(format expression)* = T15,I3,/,6X,F4.1 # 2 1

Each scan stored in two consecutive records. Wind direction (I3) is listed in columns 15–17 of the first record and speed (F4.1) in columns 7–10 of the next. Direction precedes speed in the scan, hence, the formatting parameters N_1 and N_2 must be set to 2 and 1, respectively. The slash skips to the next record.

Example 6.13: *(format expression)* = I10,1X,F3.1,I3,/,F6.2,F4.1 # 5 3

As above, but in this case the format string specifies 5 numbers. Direction (I3) precedes speed (F4.1) in the scan, and the formatting parameters N_1 and N_2 must in this case be set to 5 and 3, respectively.

Example 6.14: *(format expression)* = T15,I3,F4.1,/ # 2 1

Each scan stored in two consecutive records. Wind direction (I3) is listed in columns 15–17 of the first record and speed (F4.1) in columns 18–21 of the same record. Direction precedes speed, hence, the formatting parameters N_1 and N_2 must be set to 2 and 1, respectively. The “/” is used to skip the second part of the scan, written in the next record. Exactly the same action could be obtained by using the format expression: T15,I3,F4.1 # 2 1 1 2.

When two or more scans are listed in each record you must process the file two or more times, each time entering the format corresponding to the set of observations you want to read. The first time the file is read you enter the format string of the first set of observations (eg, 4X,F4.1,I3), the next time the format of the next set (eg, 15X,F4.1,I3) and so forth.

Fortran input descriptors

Some common FORTRAN input format descriptors are:

| | Meaning | | Examples | In general |
|---|--------------------|-------|---------------------|------------|
| X | skip character | 8X | skip 8 characters | nX |
| I | integer | I4 | 3027 ┐┐17 | Iw |
| F | real | F5.1 | -12.1 ┐┐0.7 | Fw.d |
| E | real with exponent | E10.3 | ┐0.123E+03 | Ew.d |
| T | tabulator | T15 | go to column 15 | Tn |
| / | slash editing | | skip to next record | |

Recommendation

Whilst WASP is capable of reading time-series data of almost any format the following format is recommended for straightforward reading of data files: one wind speed and direction value in each file record, separated by commas or spaces.

Data clipping

Lower and upper limits for wind speed (u) and direction (d) can be specified during the RAWDATA analysis. The limits u_{\min} , u_{\max} , d_{\min} and d_{\max} specify the *window* in which measurements are analysed further, whereas measurements outside this window are discarded as missing observations. The data are thus divided into two groups on the basis of these limits: *dummy values* and *wind observations*. A third group of ‘observations’ is *reading errors*. These three types of observations are then defined as follows:

| | |
|--------------------|--|
| dummy values | $d < d_{\min}$ or $d > d_{\max}$ or $u < u_{\min}$ or $u > u_{\max}$ |
| valid observations | $u_{\min} \leq u \leq u_{\max}$ and $d_{\min} \leq d \leq d_{\max}$ |
| reading errors | non-numeric input in record |

Notice, that the data clipping limits must be given in *unscaled* units, ie referring to the data as given in the file. Blank or empty lines in the file should be avoided.

Optionally, a threshold wind speed for calms may be specified. This limit divides the valid observations into calms and wind observations *within* the specified data window:

$$\begin{array}{ll} \text{calms} & u_{\min}^{\text{scaled}} \leq u \leq u_{\text{calm}} \\ \text{wind observations} & u_{\text{calm}} < u \leq u_{\max}^{\text{scaled}} \end{array}$$

This division takes place *after* scaling the data, hence, the calm limit must be specified in *scaled* units (metres per second). *If no calm speed is given, zero m/s is assumed.* The total number of observations N is thus given by:

$$N = \text{wind observations} + \text{calms} + \text{reading errors} + \text{dummy values}$$

Data scaling

WASP offers the possibility of scaling the data linearly if the wind measurements are not given in $[\text{ms}^{-1}]$ and $[\text{deg}]$, or if the data need recalibration. A scaling factor and an offset can be specified for both wind speed and direction and are applied in the following way

$$X_{\text{new}} = \langle \text{scaling factor} \rangle \times X_{\text{old}} + \langle \text{offset} \rangle \quad (12)$$

where X represents either wind speed or direction.

Data discretization

Using raw data as the initial data source is generally preferable, since this allows detection of errors in the data which may be undetectable in data summaries. An important consideration is the question of whether the data has already been truncated. If, for example, a “raw” dataset is given in integral ms^{-1} due to prior processing (which is common practice for some meteorological stations) use of the RAWDATA option with the default setting for the wind speed bins of 1 ms^{-1} will cause errors, since the speed value $u = n$ (n integer) will add to the n th bin, which is subsequently represented by its *midpoint* value $u_m = n + \frac{1}{2}$.

To avoid this shifting of the wind speed distribution, it is possible to specify the *discretization bins* apparent in the raw data. WASP will then automatically correct for this effect when calculating the distribution. Any discretization error will be apparent in the ‘summary display’ of the RAWDATA option, see Fig. 38 and the accompanying explanation.

If a table/histogram has already been compiled on the basis of a discretized time-series and the series is not readily available for re-processing, the bin limits of the TAB-file should be adjusted using a text editor (after having terminated WASP). The corrected file is subsequently used as input by invoking the TABLE option, see Section 6.2.

Reading and displaying the time-series

WASP reads the data from disk file according to the specifications provided by the user and displays the time traces of wind speed and direction on the graphics screen. The layout of this display is given by parameters P_{69} and $P_{71}-P_{74}$ in the file WASP.PAR, see Appendix B.

Time-series plot

The time traces are displayed by default; with direction above speed on the screen, see Fig. 36. The scaling and division of the two y -axes are given in the upper and

lower right-hand corners of the screen, respectively, and the number of observations shown in the display is given in the lower left-hand corner of the screen. The observation number and values of speed and direction at which the cursor points are shown in the upper left-hand corner of the screen. With one full screen of data displayed the key options described below are available.

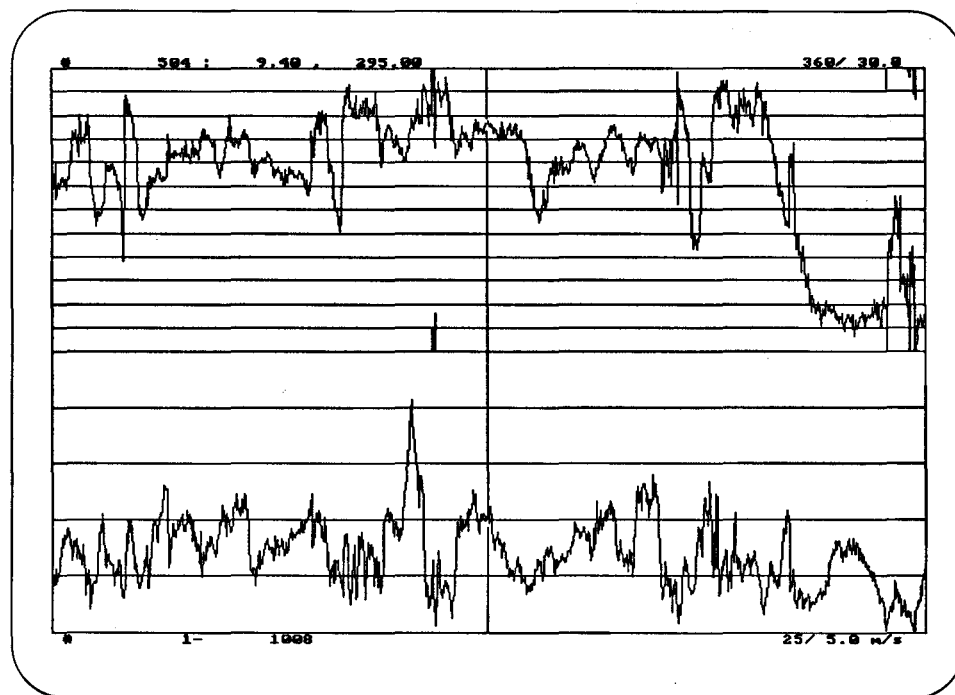


Figure 36. Time-series display (default). The cursor has the shape of a vertical line.

- <Return>** Pressing the **<Return>**-key toggles to the next screen of data. If the entire time-series has been read WASP returns to the RAWDATA menu.
- <Esc>** Leaving graphics mode is done by pressing the **<Esc>**-key. WASP will then read the remaining part of the time-series without displaying it on the screen. The first screen of data will always be displayed unless graphics has been turned off (parameter #69 in WASP.PAR). Having read the entire time-series WASP returns to the RAWDATA menu.
- W** It is possible to zoom in on any part of the time-series shown on the screen by pressing **W**. The window shown can be moved with the left and right arrows, and is expanded with the up (expand to the right) and down (expand to the left) arrows, respectively. Pressing **<Return>** zooms in when the right position and size of the window has been obtained. Pressing the *****-key zooms out to the original window.
- +/-** The cursor/window step is made larger and smaller by pressing the **+** and **-** keys, respectively.
- Scatter plot** Pressing any other key than the ones described above toggles between the time-series plot and the scatter plot, see Fig. 37. The scatter plot shows the wind observations as points in a polar coordinate system. Each point marks the origin of the corresponding wind vector.

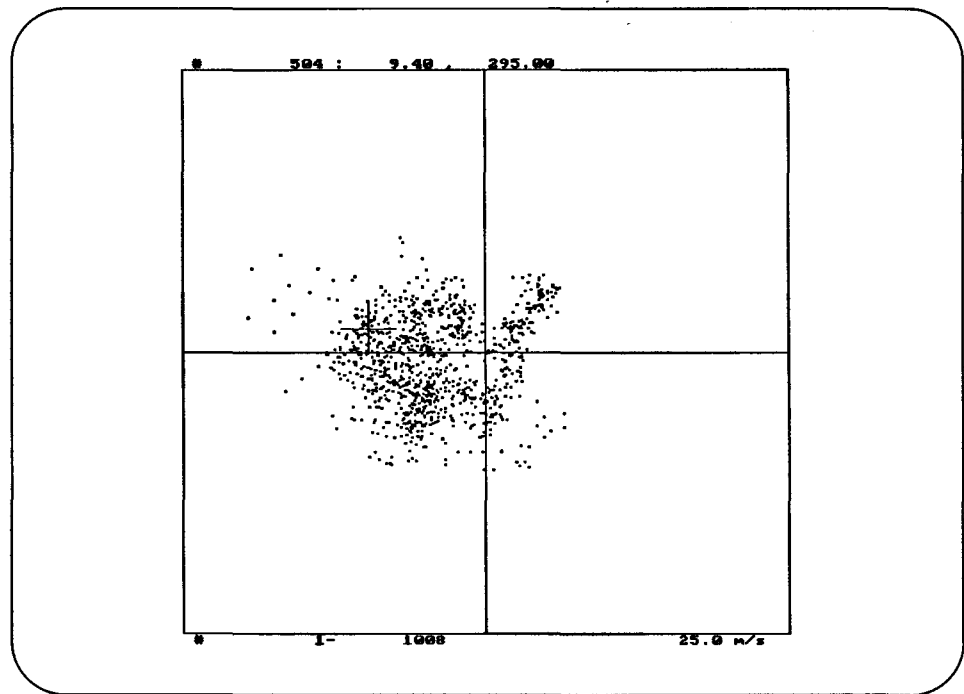


Figure 37. Scatter plot display.

Appending files

WASP is capable of processing more than one file in sequence. If a time-series is stored in several files (eg one for each month or year) they can (and should) be merged into one histogram by giving the name and data characteristics for each file. Notice, that data with different formats, limits and scaling factors may be merged into one data set (histogram) at this stage.

The time-series summary

Having processed the data file(s), WASP displays a summary of the observations, Fig. 38. Notice, that only the name of the last file processed is given in the display. The number of observations used in the summary is equal to the number of observations less reading errors and dummy values. Calms are included in the table, distributed evenly over the sectors in the lowest wind speed class.

Data check As an aid in evaluating the data quality, a Weibull distribution function is fitted to the observations in each sector and the calculated Weibull A and k parameters for each sector are shown. Furthermore, the mean wind speed and energy content – calculated from the raw time-series data – are shown in the lower right-hand corner of the display. For both these quantities the combined discretization and analysis errors are expressed as the deviations in per cent from the mean values based on the Weibull fit to the data. Since the mean speed is not a fitting parameter, significant errors in this will indicate bad Weibull fits; whereas the deviation in energy – which is a fitting parameter – will indicate any discretization errors.

DUMP The histogram may be saved on disk file (default extension .TAB) by invoking the DUMP option of this screen. When a time-series has been processed, invoking the DISPLAY option of the DATA menu will display this data summary table again.

| 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/m ² (2%) | | | | | | | | | | | |
| DISPLAY DUMP DOS RETURN | | | | | | | | | | | | | | | | | |
| RAWDATA>_ | | | | | | | | | | | | | | | | | |

Figure 38. Summary display of the RAWDATA option. The frequencies of occurrence are normalized sector-wise in per mille. The wind speed bin numbers correspond to $[ms^{-1}]$ only when the bin width is $1 ms^{-1}$. Notice the data checks in the lower right-hand corner of the display.

DISPLAY The distribution of the wind can also be shown graphically by invoking the DISPLAY option in the summary display. The sector-wise frequency distribution of the wind is then shown as a wind rose (Fig. 39) and the distribution of wind speeds is represented by a histogram curve (Fig. 40). Toggling between the two is done by pressing any key on the keyboard. The distribution of wind speeds within each sector can be shown by entering the center direction of the sector, eg 270 or -90 to display the distribution of wind speeds in the west sector. Also shown is the Weibull distribution fitted to the data. The graphics mode is left by pressing the $\langle Esc \rangle$ -key.

Return Typing RETURN or pressing the $\langle Return \rangle$ -key returns to the DATA menu.

Saving the histogram

The end result of the time-series processing is the histogram table. Whilst only a summary of this table is shown on the screen, WASP has internally divided the observations into 50 classes of wind speed and 12 classes of wind direction. The speed classes have a default bin width of $1 ms^{-1}$ and are defined as¹

$$1 : [0, 1[\quad 2 : [1, 2[\quad 3 : [2, 3[\quad \dots \quad 50 : [49, \infty[\quad (13)$$

Classes of wind direction or azimuth are 30 degrees wide (default) and defined as

$$1 : [345, 15[\quad 2 : [15, 45[\quad 3 : [45, 75[\quad \dots \quad 12 : [315, 345[\quad (14)$$

The default values of wind speed bin width and number of sectors may be altered by changing parameters P_{37} and P_{36} in the WASP parameter file, Appendix B.

¹Square brackets are used in the following sense: $[2, 3[$ is identical to $2 \leq x < 3$.

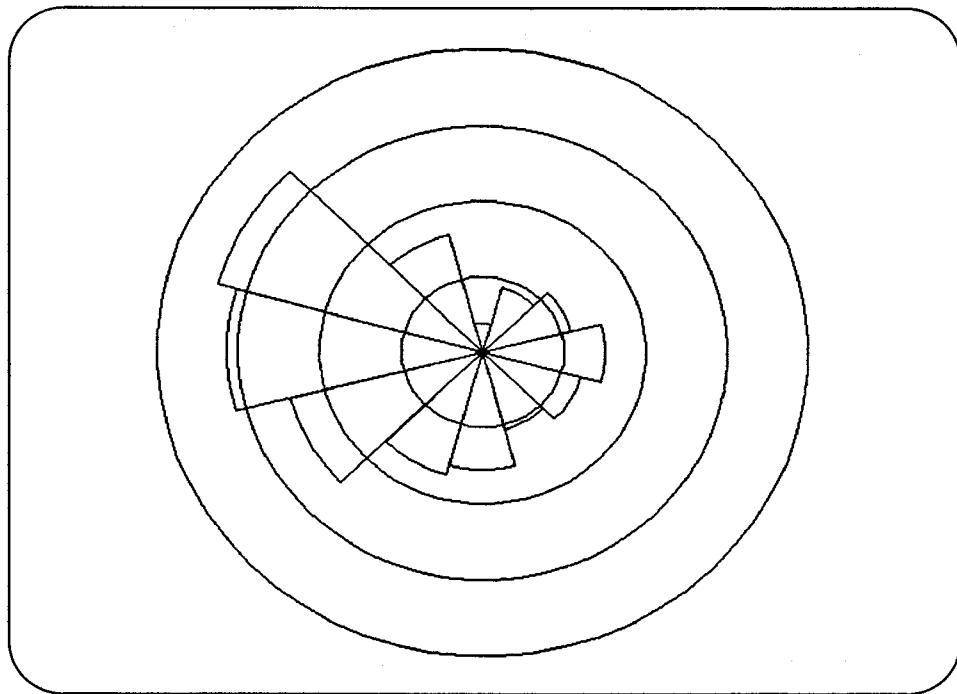


Figure 39. Sector-wise distribution of winds in the processed time-series.

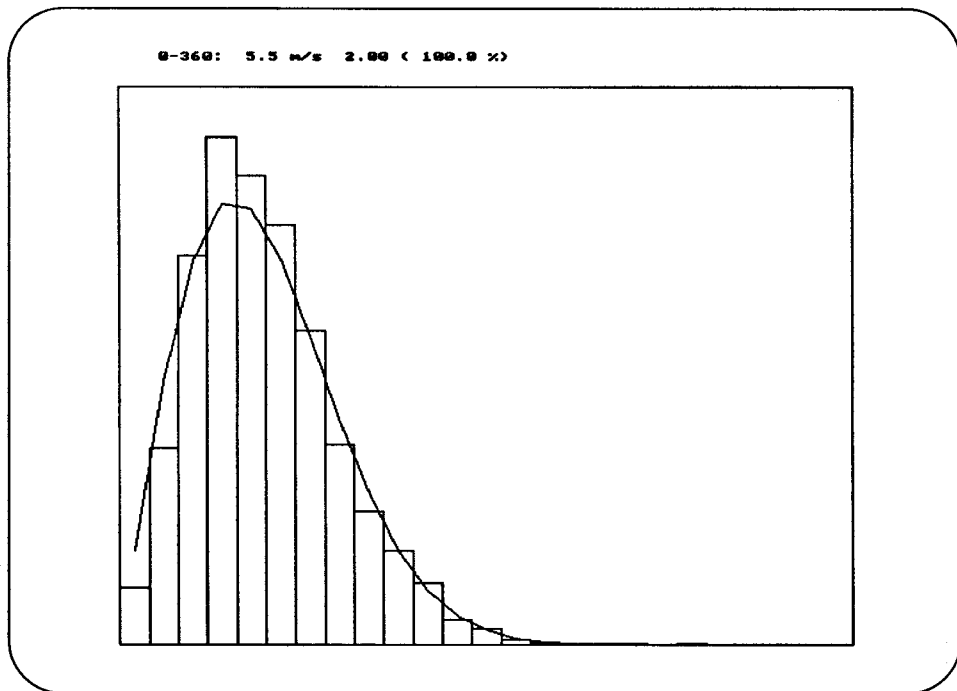


Figure 40. Distribution of wind speeds in the processed time-series.

WASP uses the histogram as the basis for further analysis of the wind climate. The histogram can be stored on disk file at this stage using the DUMP option (default extension .TAB). An example of a histogram file is given in the next section. Having compiled the histogram table WASP will not need the time-series data file(s) anymore – except for reprocessing of the time-series.

6.2 General climatological data

At most meteorological stations the observation series are compiled routinely into climatological tables, that provide a statistical summary of the measured time series. Such tables will often be the only readily available information on the wind climate at a certain station. Consequently, WASP has been equipped with routines to read this type of data – the **TABLE** option of the **DATA** menu. Tables giving the frequency of occurrence of wind speed versus wind direction are of primary interest in this context. It should be borne in mind, that even though the data have been processed statistically, they still constitute raw data and must be treated accordingly.

Histogram file Before invoking the **TABLE** option, a disk file containing the climatological table as well as some additional information should be prepared with an ASCII editor. Notice, that this histogram file is similar to the output of the time-series processing – with one important exception: the classes of wind speed need *not* be equidistant in the histogram. A sample histogram file is shown in Fig. 41.

```
Wasp Airport 1983-85. Runway NW anemometer.
-55.70      -167.90      12.00
      12      1.00      0.00
      2.0    4.4    5.6    7.5    6.2    5.3    7.8    8.4    12.2    15.7    16.8    8.1
1.00    48    32    23    34    28    42    24    21    11    13    10    12
2.00   174    90   159   113   113    80    47    59    25    32    52    82
3.00   311   201   251   226   202   171   130   122    57    61    84   198
4.00   144   241   263   235   218   247   214   166    99   133   136   201
5.00   168   169   138   213   211   216   226   129   152   132   137   157
6.00   132   122    73   125   149   153   181   140   156   141   172   127
7.00    24    48    44    38    38    44    84   133   153   152   165   98
8.00     0    66    27    13    24    18    29    98   132   102    87   51
9.00     0    21    13     3    13     9    24    64    89    78    59   35
10.00    0     8     2     0     4    13    18    28    61    65    45   25
11.00    0     3     8     0     0     4    17    20    43    45    29    7
12.00    0     0     0     0     0     2     5     8    16    20    12    6
13.00    0     0     0     0     0     0     3    11     4    18     6    1
14.00    0     0     0     0     0     0     0     1     2     6     1    0
15.00    0     0     0     0     0     0     0     0     1     0     1    0
16.00    0     0     0     0     0     0     0     0     0     1     1    0
17.00    0     0     0     0     0     0     0     0     0     2     0    0
18.00    0     0     0     0     0     0     0     0     0     1     1    0
19.00    0     0     0     0     0     0     0     0     0     0     1     0
```

Figure 41. Sample histogram file. The frequencies of occurrence are normalized sector-wise in per mille.

Surface data Referring to Fig. 41, *line 1* is a character string identifying the contents of the file. *Line 2* gives the latitude and longitude of the station and height above ground level of the anemometer. Conventionally, latitude N and longitude² E are considered positive. *Line 3* states the number of sectors, a scaling factor for wind speed and an offset for direction. The scaling factor is used to convert the given wind speed class limits to [ms⁻¹]. The offset angle serves to rotate the user frame of reference, so as to center the first sector given in the table on 0 degrees (north). *Line 4* gives the frequencies of occurrence in per cent, of winds in the various sectors. *Line 5* and onward contain the climatological table, each line corresponding to one wind speed class. First, the *upper* limit of the speed class is given, then follow the frequencies of occurrence of this class in the sectors. A maximum of 50 speed classes can be specified.

²The longitude is not used for calculations by WASP and may be set to any number.

The distributions may be normalized sector-wise as in Fig. 41, or may be given in absolute units, eg hours. In the latter case line 4 of the file should contain non-numeric input instead of frequencies. Note that the format of the file is free, ie numbers must be separated by a comma or one or more blank characters (spaces).

Upper-air data In case the table summarizes upper-air observations, the height of observation in line 2 should be set to some non-numeric input like “*” or “radiosonde data”. The table is then regarded as statistics for the geostrophic wind.

Having prepared the histogram file it can be loaded into WASP by invoking the TABLE option. WASP will then enquire for the file name – assuming .TAB as the default file name extension. If an asterisk (*) is given for the file name a list of all .TAB files in the current directory is displayed. Returning to one of the main displays observe that the table has *no* effect on the calculations or results yet. For this to happen you must explicitly have executed the wind atlas model by invoking the GENERATE option of the ATLAS menu, see Chapter 8.

Histogram format option

Occasionally, climatological tables may be compiled in other ways than described above. In order to minimize the amount of work required to prepare such tables for input to WASP, an optional *table format parameter* can be employed in line 3 of the table file. In general, line 3 of this file then takes the following form:

$$\langle \# \text{ of sectors} \rangle \langle \text{scaling factor} \rangle \langle \text{offset} \rangle [\langle \text{format \#} \rangle] \quad (15)$$

The format number may take either of the values -1 , 0 , 1 , or 2 . The values -1 and 1 indicate that the table frequencies are cumulated starting at the highest or lowest wind speed class, respectively. A value of 0 is default and corresponds to the table described above (Fig. 41).

With a value of 2 the wind speed distributions are specified using Weibull parameters rather than frequencies. In this case *line 4* gives the frequencies of occurrence in per cent of winds in the various sectors; *line 5* states the Weibull A parameters and *line 6* the k parameters for each of the (twelve) sectors.

Histogram files illustrating the various format options are supplied on the WASP diskette as WASP-1.TAB, WASP0.TAB, WASP1.TAB and WASP2.TAB, respectively.

Displaying the histogram

The distribution of the wind can also be shown graphically by invoking the DISPLAY option in the DATA menu. The sector-wise frequency distribution of the wind is then shown as a wind rose (Fig. 39) and the distribution of wind speeds is represented by a histogram curve (Fig. 40). Toggling between the two is done by pressing any key on the keyboard. The distribution of wind speeds within each sector can be shown by entering the center direction of the sector eg, 180 to display the distribution of wind speeds in the south sector. Also shown is the Weibull distribution fitted to the data. The graphics mode is left by pressing the $\langle \text{Esc} \rangle$ -key.

6.3 Data inspection and quality control

Time-series of wind data or climatological summaries are obtainable from synoptic stations, from stations established for the collection of climatic data and from other sources. In the selection of wind data a number of goals should be aimed at which can be summarized as follows:

- Sufficient time period. At least one year, but preferably several years.

- Well exposed anemometer, far from buildings and other obstacles. This requirement is often the most difficult to satisfy.
- Accurate description of anemometric conditions and data of 10-min or hourly averages collected for eg each 3-hour period throughout the 24-hour day.

Data should be carefully inspected even though they are assumed to be quality-controlled by the supplying organization. The most important checks after receipt of the data are: visual inspection of the time series and inspection of the frequency table (histogram). By inspection, it is possible to detect data deficiencies such as:

- abnormally high wind speeds
- an abnormal number of observations in certain wind speed classes and/or wind direction sectors
- certain patterns in the table caused by the transformation of data originally reported in Beaufort, knots, miles per hour etc. to metres per second. The transformation of data measured in for example 16 sectors to 12 sectors may also cause a pattern in the table.
- stations with a systematic lack of observations, eg no night-time observations

The cure for these data deficiencies is often quite simple (European Wind Atlas, 1989). The abnormally high wind speeds can be removed manually. Abnormal occurrences of wind speeds and directions should be checked against known climatology. The patterns caused by data discretization can be eliminated by W&S, given the discretization intervals.

In general, there is no simple procedure for filling in missing data.

6.4 Parameters in the data analysis

A number of parameters in the file `WASP.PAR` affect the way meteorological data are processed and displayed:

- P_{36} Number of direction sectors in the analysis of time-series data. Maximum is 36 sectors, default is 12.
- P_{37} Wind speed bin width in the analysis of time-series data. Default is 1.0 m s^{-1} .
- P_{71} Number of observations per frame in time-series plot. Default is 4000.
- P_{72} Plot range for speed (integer part) and fractional divisions (fractional part). Default is 25.2, corresponding to a range of $0\text{--}25 \text{ m s}^{-1}$ and divisions every 5 m s^{-1} (0.2×25.0).
- P_{73} Plot range for direction (integer part) and fractional divisions (fractional part). Default is 360.083333, corresponding to a range of $0\text{--}360^\circ$ and divisions every 30° (0.083333×360.0).
- P_{74} Default plot mode: 1 for time trace plot of speed and direction, 2 for polar scatter plot. Default is 1.

The default values correspond to the initial settings in `WASP.PAR`. – The graphics displays are shown per default, but graphics can be turned off by setting P_{69} equal to zero.

7 Digitizing and editing maps

The most convenient way of obtaining the map coordinates is by digitizing the height contours and/or roughness-change lines from a standard topographical map using the WASP INPUT option. However, the map can also be digitized using other programs. In this case, or if a digital map is already available, the coordinates may be in any units as WASP is capable of transforming these into metric units on the basis of two fixed points, see Appendix C. Most digitizers provide Cartesian coordinates, but polar coordinates can also be processed. It is recommended to use standard map coordinate systems, like the Universal Transverse Mercator (UTM) provided on many topographic maps.

The map file

The digital map is stored in a map file. This file may contain height contours only, roughness-change lines only, or both. The WASP map file consists of strings of coordinate pairs, each string specifying one height contour line or one roughness-change line. The coordinates may be given as (x, y) -values in a Cartesian coordinate system or as (r, θ) -values in a polar system, see Section C.4. However, the INPUT option of WASP always generates Cartesian coordinates.

With the standard version of WASP, the map file must not contain more than approximately 10 000 points:

$$\langle \text{number of lines} \rangle \times 3 + \langle \text{number of points} \rangle \leq 10\,000$$

If the map file contains more than approx. 10 000 points, only the first 10 000 points are read by WASP and a warning message is displayed. Large map files may to some extent be reduced by the techniques mentioned below (*The reload option*).

The specific format of a map file is described in Appendix C. Maps not digitized with WASP can be transformed into WASP-compatible .MAP files using this information. A sample map file – WASPDALE.MAP – is provided on the WASP diskette.

Height contours

When planning for the provision of the digital height contour map one should take the following points into consideration:

- WASP employs a polar grid with resolution concentrated in one point. Thus, resolution is very high close to the center of the model (the site) and gets progressively lower towards the edge of the model.
- The grid of the model is “zooming”, ie the scale of the grid is adjusted so it contains the entire domain described in the digital map.

The relation between domain size – defined here as the distance from the model center to the point farthest away from this in the map – and the grid size at the center of the model is illustrated in the table below. The radial grid size is enlarged by 6 per cent from one cell to the next.

| | | | | | |
|---------------------------|-----|-----|-----|------|------|
| Domain size (radius) [km] | 5 | 10 | 20 | 50 | 100 |
| Grid size (center) [m] | 1.3 | 2.7 | 5.3 | 13.3 | 26.6 |

The zooming grid inherent in the BZ-model, indicates that the contour line description close to the prospected site(s) should be as detailed and accurate as possible, and – conversely – that both detail and accuracy may be relaxed somewhat far away from the site(s).

7.1 The MAPDATA menu

All commands concerning input, editing, display, storage, and retrieval of maps are collected in the MAPDATA menu:

```
INPUT EDIT DISPLAY DUMP RELOAD
DOS HELP RETURN
```

Notice, that this menu can be reached from either the ROUGHNESS or the OROGRAPHY menu. The different commands or options are described below.

The INPUT option

The INPUT option makes it possible to digitize a map containing height contours, roughness change lines, or both. In the following it is assumed that a digitizer is installed, see Section B.4. The syntax of the INPUT option is:

```
[+]INP[UT]
```

where the optional +-sign must be used if the map to be digitized should be appended to the current map, ie the map already present in the memory of WASP. If only INP is specified, the map to be digitized will be the current map, and any 'old' map in the memory will be replaced by the digitized map.

Mounting the map on the tablet

The map in question is mounted on the digitizing tablet and the 'active' area (window) on the map is specified. This is done by entering two opposite corner points on the map/digitizer – at the prompt: 'set (two opposite) corner points on the digitizer'. The lower left-hand and upper right-hand corners of the active area are entered by positioning the digitizer's locator (mouse) on these points in sequence and then pressing the active button on the locator. A beep sound is heard when a point has been successfully entered. The active window should be a little larger than the area to be digitized.

Coordinate system set-up

Subsequently, the correspondence between the coordinates provided by the digitizer and the coordinates on the map has to be established. Two fixed points on the map are marked, their corresponding map coordinates are found, and the coordinates of the points are entered – at the prompts: 'set digitizer locator at fixed point 1', and 'set digitizer locator at fixed point 2'. The map coordinate system must be Cartesian and the coordinates should be given in metres. If at all possible, use the Universal Transverse Mercator (UTM) system provided on most topographic maps.

Digitizing the first line

Having established the correspondence between the digitizer and map coordinate systems it is now possible to enter the first contour line or roughness change line from the map. The digitization is started by simply entering the value of the line in question:

1. If one value (number) is entered (eg 100.0), the line will be considered as a height contour line and the value specified will be the altitude of the line in metres above sea level.
2. If two values are specified (eg 0.02 0.40), the line will be considered a roughness change line; the first value being the left-hand side roughness length and the second the right-hand side roughness length. Both values must be given in metres.
3. If three values are specified, the line will be considered both a roughness change line and a height contour line (eg a coastline: 0.0 0.05 0.0). The

first number is the left-hand side roughness, the second is the right-hand side roughness, and the third is the altitude of this combined roughness/contour-line. All values must be given in metres.

The left- and right-hand sides of a roughness change line are defined in the following way: the left-hand side is the side to the left of the line, when moving along the line with the locator.

When one line has been digitized entirely, press the stop button on the locator. If the line is a closed curve, leave a little space between the last and the first points, and choose CLOSE after having pressed the stop button, see Fig. 42. WASP will then connect the first and last points, ensuring that the curve is properly closed.

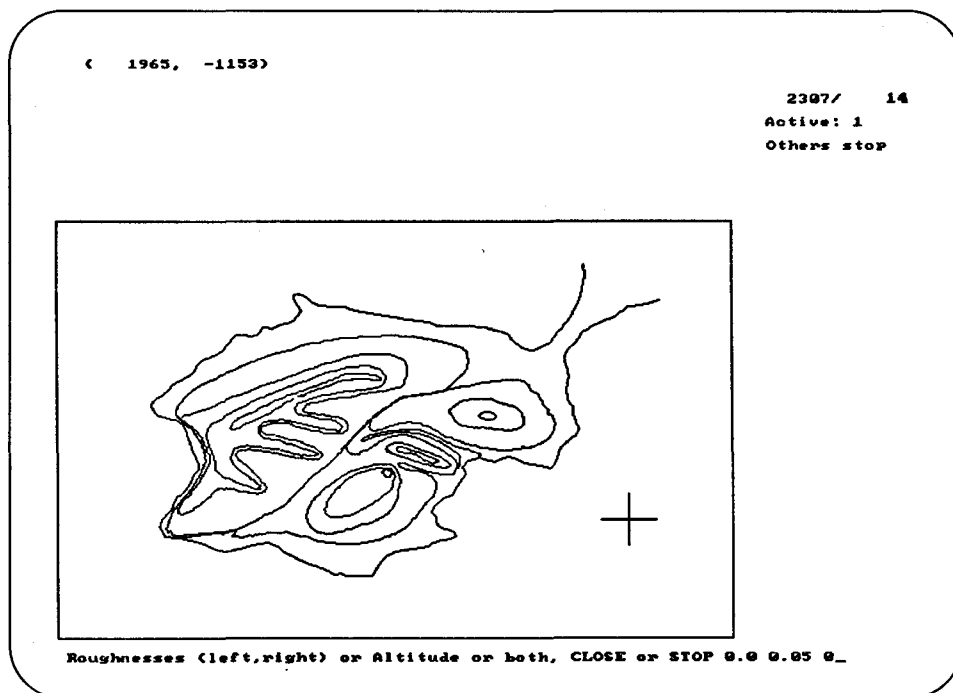


Figure 42. The graphics display and command line obtained by invoking the INPUT option in the MAPDATA menu.

The last line and closing

If more lines are going to be entered, specify the value(s) and proceed as described above. When the last line on the map has been digitized, invoke the STOP option. The digitized map can subsequently be displayed and edited using the DISPLAY and the EDIT commands, respectively, in the MAPDATA-menu. Notice, that the digitized map is present in the memory of WASP only; in order to save it on a disk file the DUMP option of the MAPDATA menu must be invoked, see below.

In case an electronic digitizer is not available you may have to obtain the coordinates manually. This can be attained using for example a protractor of the nautical plotter type. If this is not feasible or the terrain is relatively simple, a Gaussian hill may be specified as explained in Section 4.2 and 4.3.

The EDIT option

A digitized map or a map retrieved from disk file, can be edited invoking the EDIT option of the MAPDATA menu, see Fig. 43.

The graphics commands in the EDIT display are described below. Notice, that many of the commands only affect *marked* lines. A line can be marked by moving

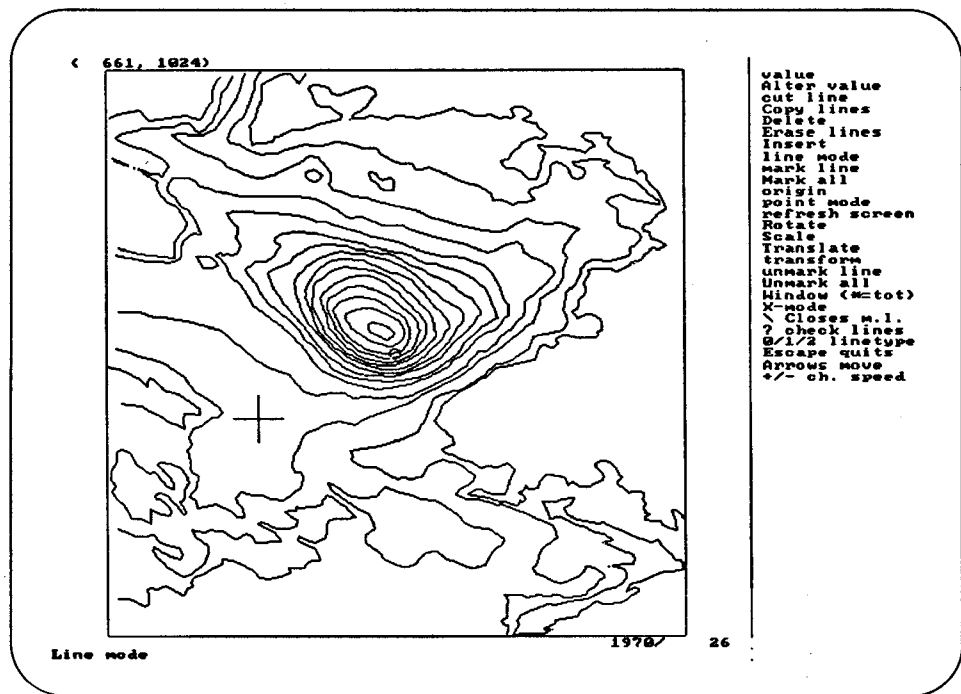


Figure 43. The graphics display and commands obtained by invoking the EDIT option in the MAPDATA menu. The coordinates of the cross-hair are shown in the upper left-hand corner of the screen. The mode (line/point) and the number of points/lines are shown in the lower left- and right-hand corners, respectively.

the cross-hair close to the line, and then press the $\langle m \rangle$ -key. Marked lines are shown in a different colour (or thickness if you have a monochrome display). All lines can be marked at once, by pressing $\langle M \rangle$.

value *Contour line.* The value of the height of the line closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.

Roughness line. The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line (ie the hatching) point towards the area on the left-hand side.

Combined roughness and contour line. The height is written on the line, and the roughness length on the left- and right-hand side of the line will appear on the bottom line. (Note: the values on the bottom line will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line (ie the hatching), points towards the area on the left-hand side.

Alter value Immediately after the value command has been used, it is possible to alter the value(s) and type of the line in question. For a contour line the height can be changed, for a roughness line the left- and right-hand side roughness lengths can be changed, and for a combined roughness and contour line the two roughness lengths and the height can be changed. Furthermore, the type of the line may be changed simply by entering the appropriate number of values.

cut line Cuts a marked line into two separate lines at the point nearest to the cross hair.

- Copy lines Makes a copy of all marked lines. Marks the copies and unmarks the originals, ie the copies can be translated, rotated etc. immediately after the Copy command.
- Delete Deletes all marked lines from the screen *and* from the internal map file (line mode), or deletes current point if in point mode, see below.
- Erase lines Erases all marked lines from the screen, and *only* from the screen. The lines can be regenerated by the command refresh, ie pressing the *(r)*-key.
- Insert Makes it possible to insert a line or point on the map (depending on the mode). Insert line by moving cross-hair to the start of the line, then press *(Return)*, then move cursor and press *(Return)* whenever you want a point on the line. Finish by pressing *(Esc)*. Insert point by moving cross-hair to desired location and press *(Return)*.
- linemode If in point mode the mode is changed to line mode.
- mark line Marks the line closest to the cross-hair. This enables the line to be cut, deleted, erased, rotated, scaled, and translated.
- Mark all Marks ALL lines, thereby enabling the lines to be cut, deleted, erased, rotated, scaled, and translated.
- origin The origin is marked by a circle and is the point with respect to which all rotations and scalings are done. A new origin is set by moving the cross-hair to the desired point and pressing *o*. This command is also necessary to reset scalings, rotations and translations to inactive.
- point mode If a line is marked, this command shows all the points that define the line. This allows translation, deletion and insertion of single points in the line.
- refresh screen Refreshes the screen. The map is redrawn, marked lines are still marked. This command can be used to eg remove the display of height/roughness values (generated by the value command) and spurious dots.
- Rotate Rotates all marked lines around the origin using the up and down arrow keys. Pressing *+* increments the rotation step, and pressing *-* decrements the rotation step. The rotation angle is shown in the upper right-hand corner of the display. A given rotation angle can be preset before marking the line(s), whereafter the lines can be marked and transformed, see below.
- Scale Scales all marked lines with respect to the origin. The up-arrow brings the lines further away from the origin, and the down-arrow brings the lines closer to the origin. Pressing *+* increments the scale factor, and pressing *-* decrements the scale factor.
- Translate All marked lines and the origin (line mode) or a selected point (point mode) are translated using the arrow keys.
- transform Transforms all marked lines. The transformation is the combination of all rotations, translations and scalings specified since you started, or since the last time you selected the origin (by pressing *o*).
- unmark line Unmarks the marked line closest to the cross-hair.

Unmark all Unmarks all marked lines.

Window Zooms in on an area of the map selected by using the arrows. When the area has been selected press *<Return>* to zoom.

Furthermore, up to 10 different window settings can be stored in a cyclic buffer and retrieved sequentially as new window settings – this enables switching between several (even disjoint) windows without having to go via total window (by pressing the **-key*) every time.

Initially the window stack is empty. A new window can be added to the stack by pressing the *<Ins>*-key. If this is done during setting of a sub-window (pressing *<W>* and using the arrow keys) the window frame disappears as the *<Ins>*-key is pressed – to signal that the window has been stored in the stack; no other action is taken. To immediately switch to this particular window, use the *<PgUp>*-key. The current window setting can be stored by simply pressing the *<Ins>*-key, without first selecting a window.

Windows in the stack can be viewed in sequence by pressing *<PgUp>* (next window in stack) or *<PgDn>* (previous window in stack). With several windows in the stack it may be difficult to remember the sequence and location of these. Therefore, the stack can be viewed using *<Ctrl><PgUp>* (to show the next window in the stack) or *<Ctrl><PgDn>* (to show the previous window in the stack). Once the desired window has been selected, press *<PgUp>* to activate it.

The simplest application of this feature is to select smaller parts of the map to look/work on; storing them using the *<Ins>*-key. It is then possible to work in the different sub-windows at will; switching between these – and even to the total map if this has been selected as a window – by simply pressing the *<PgUp>*- or *<PgDn>*-keys.

* Zooms out to the smallest window containing the entire map.

X-mode When the X-mode is on, lines are not erased on the screen when they are translated, rotated, and scaled.

\ Closes all marked lines. This can also be used when you have made a line, by using the Insert *<I>* command, and you want to be sure it is properly closed.

? Check lines. The question mark invokes a check routine when either contours or roughness lines have been selected (see below). With roughness lines, WASP will search the roughness map for inconsistent or conflicting roughness values and point these out.

With height contours, WASP will show the terrain profile between the map origin (marked by a circle) and the position of the cross-hair. The cross-hair can be moved using the arrow keys and a new cross-section is shown when pressing the *<Return>*-key, see Fig. 44. The vertical range in the cross-section plot is the total map height range ($z_{\max} - z_{\min}$), the horizontal range corresponds to the length of the profile.

0/1/2 Pressing 0, 1, or 2 you may choose to view height contours only, roughness lines only, or both types of lines. The proper type of the lines displayed must be chosen before the check routine described above can be invoked. – Only visible lines are ‘active’, ie can be marked, edited etc.

<Esc> Leave graphics mode if in line mode, otherwise leave current mode and go to previous mode.

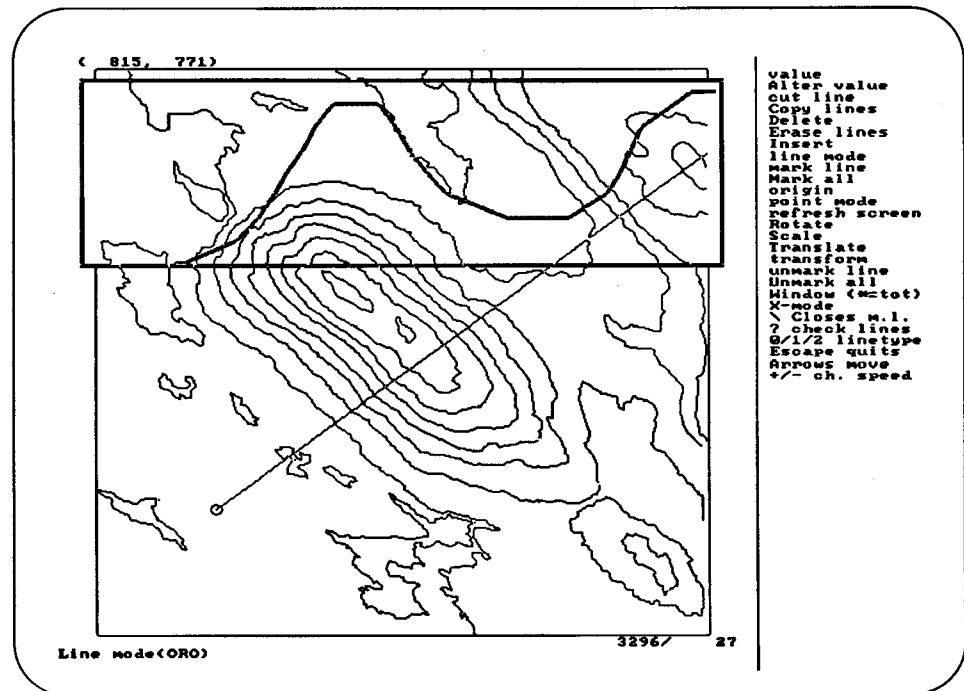


Figure 44. The graphics display obtained by invoking the ? option in the EDIT menu. When height contours have been selected, the terrain profile along the line from the origin to the cross-hair is shown in a window overlaid on the map.

+/- The cross-hair is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) key one or several times. Also used for changing the rotation angle step.

The number of points and curves, as well as the type of lines displayed, are shown below the current window. The numbers are refreshed if the values are changed during the editing process.

Example 7.1 Three uses of the more sophisticated options in the EDIT menu are: Moving a line, or moving a point on the line, because of errors in the digitization and transform an entire map. A line is moved by the following sequence of commands:

1. press *<U>* to Unmark all lines
2. point at the line you want to move with the cross-hair
3. press *<m>* to mark this line
4. press *<T>* to Translate this line
5. use the arrows to move the line to the desired place
6. press *<Esc>* to leave Translate mode
7. press *<U>* to Unmark all lines

A point on a line is moved in the following way:

1. press *<U>* to Unmark all lines
2. point at the line containing the point you want to move with the cross-hair
3. press *<m>* to mark line
4. press *<p>* to enter point mode
5. use the arrows to select the point you want to move
6. press *<T>* to Translate point

7. use the arrows to move the point to the desired place
8. press *(Esc)* to leave the Translate mode
8. press *(Esc)* to leave point mode
9. press *(U)* to Unmark all lines

A set lines can be transformed in the following way:

1. press *(U)* to Unmark all lines
2. move cross-hair to desired origin (center for rotations, scalings)
3. press *(o)* to fix new origin
4. press *(R)* to enter Rotate mode
5. use up/down arrows and *+/-* to set desired rotation angle
6. press *(T)* to enter Translate mode
7. use arrow keys to select translation vector
8. press *(S)* to enter scaling mode
9. use up/down arrows and *+/-* to select scaling factor
10. press *(Esc)* to return to line mode
11. move cursor to each line you wish to include in the transformation and press *(m)* to mark the line(s). To transform entire map: press *(M)* to mark all lines.
12. press *(t)* for transform
13. press *(Return)* to perform transformation
14. press *(U)* to unmark all lines

The DISPLAY option

The DISPLAY option makes it possible to display the current map on the screen, see Fig. 45, to display a 3-D rendering ('photo') of the terrain, and to plot either on a plot file.

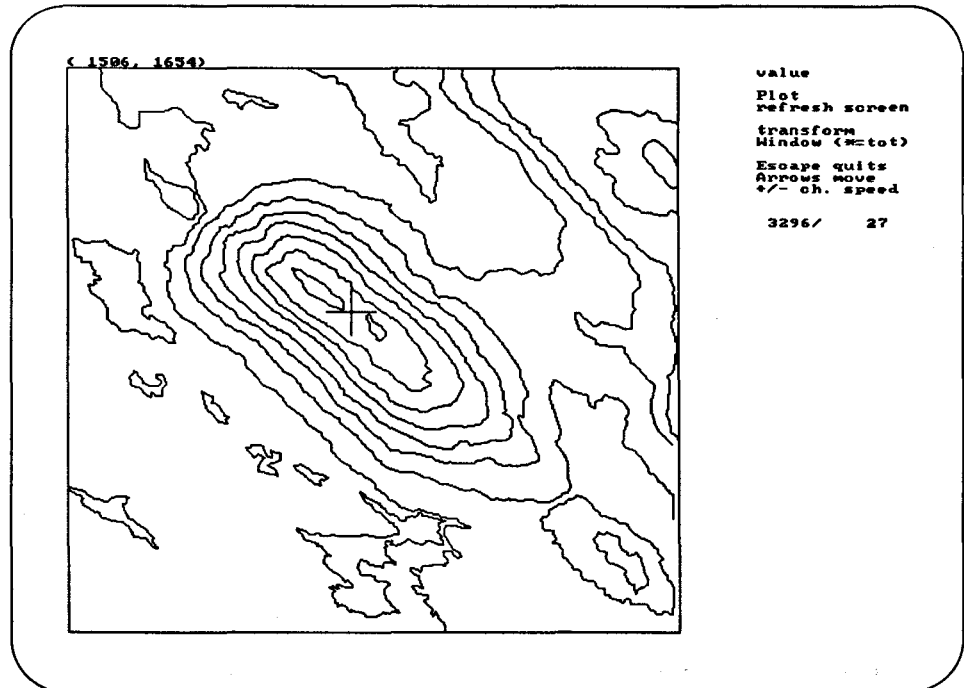


Figure 45. The graphics display and commands obtained by invoking the DISPLAY option in the MAPDATA menu. The coordinates of the cross-hair are shown in the upper left-hand corner of the screen.

value *Contour line.* The value of the height of the line closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.

Roughness line. The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair).

Combined roughness and contour line. The height is written on the line, and the roughness length on the left- and right-hand side of the line will appear on the bottom line.

Plot Makes a plot file of the map or photo (either a .PLT or a .HPG file), see below. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.

refresh screen Refreshes the screen, ie the map is redrawn. This command can be used to eg remove the display of height/roughness values (generated by the value command) and spurious dots.

transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press <t> for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press <Return>. A window is now shown around the target – use arrow keys to enlarge this window and press <Return> to select. A 3-D rendering of the terrain is displayed after a short while, see Fig 46.

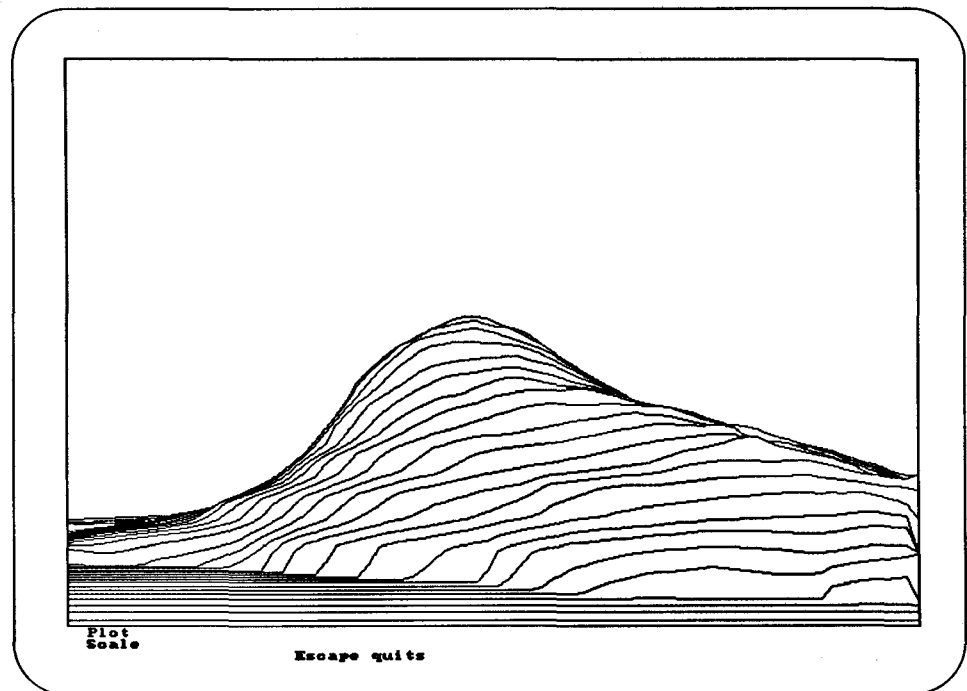


Figure 46. The graphics display and commands obtained by invoking the transform option in the DISPLAY menu.

A new camera height Z (above local ground), terrain height scaling $\times z$ (vertical exaggeration), and photo vertical scaling $\times y$ can be selected by invoking Scale, see Fig 47. The Plot option generates a plot file of the photo, as described above.

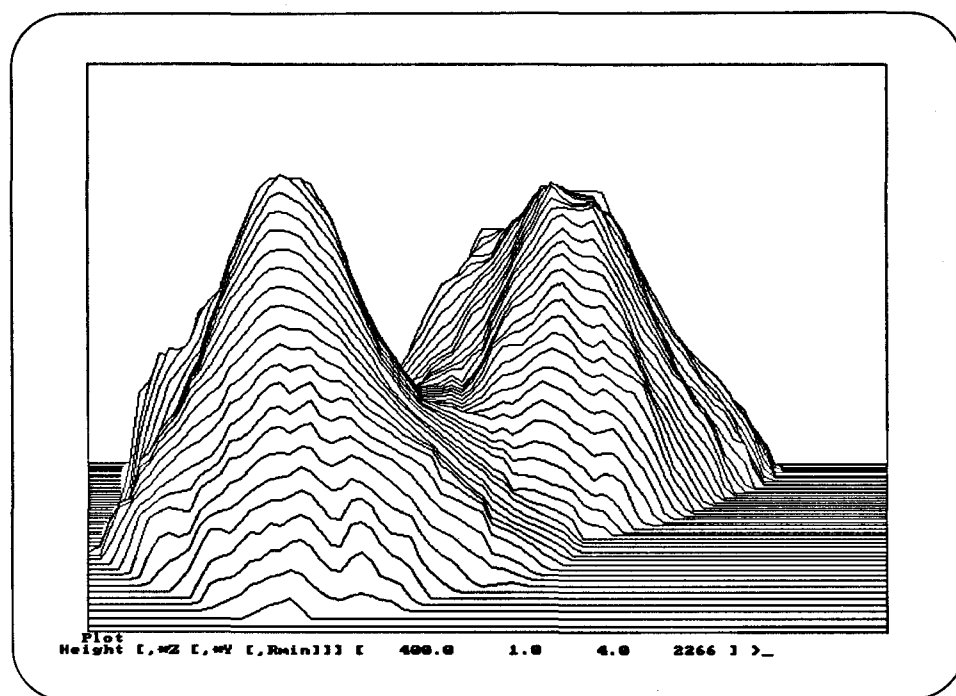


Figure 47. The characteristics of the terrain photo can be changed by invoking Scale in the transform display.

- Window Zooms in on the area, that you select using the arrows. When you have selected the area press *(Return)*.
- * Zooms out to the original window.
- (Esc)* Leave graphics mode.
- +/- The cross-hair is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair on the map are displayed on the top line. The step length of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) key one or several times.

The number of points and curves in the map is shown below the graphics menu.

The DUMP option

The DUMP option stores the current map on a disk file. The entire map, or the roughness/height contour lines only, can be stored in an ASCII or binary file. The syntax is:

```
DUM[P][*] [(type)]
```

A binary file is saved as default, if the optional asterisk is given the disk file will be in ASCII-format. Notice, that the input/output of binary files is much faster than the i/o of ASCII files. Binary files also require less disk space. However, to make a visual inspection of the map file using a text editor, or if the map is to be read by the utility program WGRID, the ASCII format of the map must be used.

The entire map is stored as default. Only height contours will be stored if the optional *(type)* is equal to ORO and only roughness lines will be stored if *(type)* is equal to ROU.

Finally, if the file name extension `.DXF` is specified, the map will be stored in an AUTOCAD readable format. If you do not specify any extension, W^AS^P assumes the default extension `.MAP`.

The RELOAD option

The RELOAD option retrieves an existing map, or parts thereof, from disk file. The syntax is:

```
[+]REL[OAD] [<type>] [<thin>]
```

The optional `+`-sign means that the map file from the disk will be appended to the current map file. The optional `<type>` can be either `ORO` or `ROU`, with the result that only height contours or only roughness lines are reloaded, respectively. If no `<type>` is specified, all the lines in the map file will be reloaded.

Whilst the `<type>` can only be specified with the RELOAD option, the `[+]` and `<thin>`-options can also be used when subsequently entering the filename:

```
[+]filename.ext [<thin>]
```

The `<thin>` option may take one of the following four forms (where `|` is the vertical bar on the keyboard, decimal value 124):

1. `| dx` – where `dx` is the maximum allowed error introduced by deleting points in contour lines. Every point on a truncated line will be closer than `dx` to the original line. End points are not deleted.
2. `| i1 i2` – where `i1` is the first contour line to input and `i2` the frequency of following lines. Default is all lines, ie `i1 = i2 = 1`. Setting `i1 = 1` and `i2 = 2` selects every second line starting with the first.
3. `| x1 y1 x2 y2` – where `(x1, y1)` and `(x2, y2)` are the lower left and upper right corner of the desired window. During the reload, map contour lines will be truncated to these limits. Extra points are inserted where contours cross window limits.
4. `| x1 y1 x2 y2 dx` – if `dx > 0` contours inside the window are kept un-altered, extra points are inserted at window limits where contours cross, outside the window contours are truncated as under 1. If `dx` is less than zero, then contour parts inside the window are deleted, while rest of map is unaltered.

The default extension when reloading maps is `.MAP`. A list of files with the extension `MAP` in the current directory can be obtained by entering an asterisk when W^AS^P enquires for the file name – or any valid DOS path including an asterisk, eg `\wasp\examples*.map`.

Other options

The `DOS` and `HELP` options work as described in the main menu. The `RETURN` option returns to either the `ROUGHNESS` or the `OROGRAPHY` menu.

8 The wind atlas analysis

The main purpose of WASP is twofold. First, it incorporates routines to correct wind data measured at a specific point and transform these into a data set describing the wind climate of a region – a so-called wind atlas. Secondly, it utilizes such data sets to estimate the wind conditions at any particular site and height in the region, in principle by applying the same routines or models.

WASP integrates the various models mentioned in the preceding sections, and is thus capable of producing wind atlas data based on surface wind observations as well as on geostrophic wind data; the latter derived from radiosonde observations or surface pressure analysis. The reason for estimating the wind climate at a specific point of interest by applying wind atlas data for that region is discussed in Jensen *et al.* (1984) and the European Wind Atlas (1989).

Generating a wind atlas data set using WASP proceeds in the following steps:

1. The measured meteorological data, whether in the form of a time-series or a climatological table, are transferred to disk file and processed as described in Chapter 6.
2. The description of the meteorological station can be entered directly from the keyboard or digitizing tablet and may subsequently be stored on disk file for future reference. The description comprises the anemometer height, the surface roughness conditions around the station, and possibly the presence of sheltering obstacles close to the station.
In case the measurements are thought to be influenced by orographic forcing, the information required by the complex terrain model should be provided as well (Chapters 4 and 7).
3. Based on the information given in points 1–2, WASP calculates for each sector and wind speed class in the histogram, the corresponding wind direction and wind speed far upstream of the anemometer. In this process the data are “cleaned” for the effects of nearby obstacles, roughness inhomogeneities, and perturbations due to terrain geometry.
4. Using the empirical relations between the wind over homogeneous terrain and the overlying large- or synoptic scale wind, the data are extrapolated to yield the geostrophic wind climate for the region. This is considered to be independent of the specific conditions at the surface. This process is referred to as “upward transformation” in the program.
5. The inverse calculation is then performed (“downward transformation”), to obtain the wind climate at several standard heights and over various standard surface roughnesses.
6. Finally, these data are analysed in terms of the Weibull distribution function. The Weibull parameters obtained constitute the “wind atlas” for the region in question and is the starting point for wind energy siting calculations.

A schematic representation of the wind atlas analysis model is shown in Fig. 48.

Wind atlas data are thus truly processed data in the sense that the wind statistics at a given station have been “reduced” to certain standard conditions. As such, they are the natural meteorological basis for a wind turbine siting project. Still, only few countries of the world are covered by wind atlas data. The Danish Wind Atlas (Petersen *et al.*, 1981) is supplied with WASP (as DENMARK.LIB on the

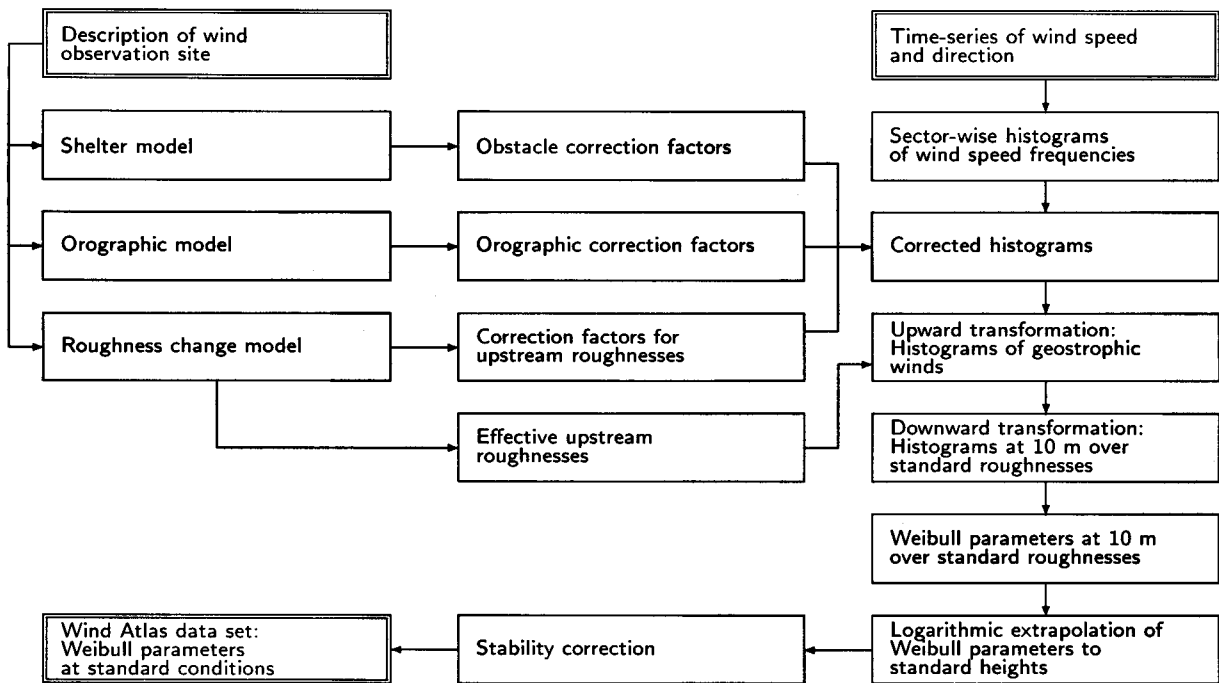


Figure 48. A schematic representation of the WASP analysis model.

diskette), and wind atlas data covering the countries of the European Communities, as well as Sweden, Finland and Algeria are also available. In addition, the results of a WASP session can be stored as wind atlas files, providing the user with means of establishing her own library of wind atlas data for the regions of interest.

8.1 The ATLAS menu

The wind atlas calculation procedure outlined above in points 3–6 is performed by WASP upon invoking the GENERATE option of the ATLAS menu:

```
GENERATE DUMP RELOAD
DOS HELP RETURN
```

- GENERATE** The raw data set supplied is transformed into Weibull A and k parameters for 4 roughness classes, 5 standard heights and 12 azimuth sectors. The calculated wind atlas thereafter replaces the “current” wind atlas of WASP, as indicated in the main display. Hence, you may immediately proceed with siting calculations. Changing the site description, setting a new height, specifying a new obstacle list and moving the site in the terrain, WASP is now able to calculate and display the wind climate for that particular site and height.
- DUMP** The DUMP option lets you store the generated wind atlas data set for future use, ie the analysis need not be repeated. The contents of a wind atlas data set are shown in Table 4. A default file name extension of .LIB is assumed by WASP.
- RELOAD** A wind atlas data set is retrieved with the RELOAD option. Enter a file name to reload a specific file, or enter an asterisk ‘*’ to obtain a list of all .LIB files in the current directory.

Roughness Class 0

| <i>z</i> | 0 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | Total |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| 10 | 7.9 | 6.9 | 6.3 | 6.6 | 6.6 | 6.0 | 5.6 | 6.6 | 7.9 | 8.5 | 8.2 | 7.7 | 7.3 |
| | 2.52 | 2.62 | 2.38 | 2.41 | 2.56 | 2.32 | 2.04 | 2.18 | 2.37 | 2.40 | 2.22 | 2.19 | 2.21 |
| 25 | 8.6 | 7.6 | 6.8 | 7.2 | 7.2 | 6.6 | 6.1 | 7.3 | 8.6 | 9.3 | 9.0 | 8.5 | 7.9 |
| | 2.60 | 2.70 | 2.46 | 2.49 | 2.64 | 2.40 | 2.11 | 2.25 | 2.44 | 2.47 | 2.29 | 2.26 | 2.27 |
| 50 | 9.3 | 8.1 | 7.3 | 7.8 | 7.8 | 7.1 | 6.5 | 7.8 | 9.3 | 10.0 | 9.6 | 9.1 | 8.5 |
| | 2.67 | 2.77 | 2.53 | 2.55 | 2.71 | 2.46 | 2.16 | 2.31 | 2.51 | 2.53 | 2.35 | 2.31 | 2.32 |
| 100 | 10.0 | 8.8 | 8.0 | 8.4 | 8.4 | 7.7 | 7.1 | 8.5 | 10.1 | 10.8 | 10.4 | 9.9 | 9.2 |
| | 2.58 | 2.68 | 2.44 | 2.47 | 2.63 | 2.38 | 2.09 | 2.23 | 2.43 | 2.45 | 2.28 | 2.24 | 2.26 |
| 200 | 11.1 | 9.7 | 8.8 | 9.3 | 9.3 | 8.5 | 7.8 | 9.4 | 11.1 | 12.0 | 11.5 | 10.9 | 10.2 |
| | 2.45 | 2.54 | 2.31 | 2.34 | 2.49 | 2.26 | 1.98 | 2.12 | 2.30 | 2.33 | 2.17 | 2.12 | 2.15 |
| Freq | 5.3 | 4.7 | 5.9 | 7.7 | 9.2 | 8.1 | 6.2 | 7.7 | 12.8 | 13.6 | 10.9 | 7.9 | 100.0 |

Roughness Class 1

| <i>z</i> | 0 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | Total |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| 10 | 5.6 | 4.6 | 4.3 | 4.7 | 4.6 | 4.1 | 3.9 | 4.8 | 5.6 | 6.1 | 5.5 | 5.4 | 5.1 |
| | 2.24 | 2.19 | 1.92 | 2.06 | 2.15 | 1.85 | 1.69 | 1.88 | 2.02 | 2.04 | 1.81 | 1.89 | 1.88 |
| 25 | 6.7 | 5.5 | 5.2 | 5.6 | 5.5 | 4.8 | 4.6 | 5.7 | 6.7 | 7.3 | 6.6 | 6.5 | 6.1 |
| | 2.41 | 2.37 | 2.08 | 2.22 | 2.32 | 1.99 | 1.82 | 2.04 | 2.18 | 2.18 | 1.94 | 2.05 | 2.01 |
| 50 | 7.7 | 6.3 | 6.0 | 6.5 | 6.4 | 5.6 | 5.4 | 6.6 | 7.8 | 8.4 | 7.7 | 7.5 | 7.0 |
| | 2.71 | 2.67 | 2.33 | 2.49 | 2.61 | 2.24 | 2.05 | 2.29 | 2.45 | 2.42 | 2.17 | 2.30 | 2.24 |
| 100 | 9.1 | 7.5 | 7.2 | 7.7 | 7.5 | 6.7 | 6.4 | 7.9 | 9.2 | 9.8 | 9.1 | 8.9 | 8.3 |
| | 2.89 | 2.84 | 2.49 | 2.66 | 2.78 | 2.39 | 2.18 | 2.44 | 2.61 | 2.59 | 2.32 | 2.45 | 2.38 |
| 200 | 11.4 | 9.3 | 8.9 | 9.6 | 9.4 | 8.3 | 7.9 | 9.8 | 11.5 | 12.1 | 11.2 | 11.1 | 10.3 |
| | 2.76 | 2.71 | 2.37 | 2.54 | 2.65 | 2.28 | 2.08 | 2.33 | 2.49 | 2.48 | 2.22 | 2.34 | 2.29 |
| Freq | 4.7 | 4.9 | 6.4 | 8.2 | 9.5 | 7.5 | 5.7 | 8.6 | 14.3 | 13.0 | 10.2 | 7.1 | 100.0 |

Roughness Class 2

| <i>z</i> | 0 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | Total |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| 10 | 4.9 | 3.9 | 3.8 | 4.1 | 4.0 | 3.5 | 3.4 | 4.2 | 4.9 | 5.4 | 4.7 | 4.8 | 4.4 |
| | 2.28 | 2.22 | 1.90 | 2.07 | 2.15 | 1.81 | 1.66 | 1.91 | 2.02 | 2.04 | 1.77 | 1.93 | 1.87 |
| 25 | 6.0 | 4.8 | 4.7 | 5.1 | 4.9 | 4.3 | 4.2 | 5.2 | 6.1 | 6.6 | 5.9 | 5.9 | 5.5 |
| | 2.44 | 2.38 | 2.04 | 2.22 | 2.30 | 1.94 | 1.77 | 2.05 | 2.16 | 2.16 | 1.89 | 2.06 | 1.99 |
| 50 | 7.1 | 5.6 | 5.5 | 6.0 | 5.8 | 5.1 | 4.9 | 6.2 | 7.1 | 7.7 | 6.9 | 6.9 | 6.4 |
| | 2.70 | 2.64 | 2.26 | 2.45 | 2.55 | 2.14 | 1.96 | 2.27 | 2.39 | 2.37 | 2.08 | 2.28 | 2.19 |
| 100 | 8.4 | 6.7 | 6.5 | 7.1 | 6.9 | 6.0 | 5.8 | 7.3 | 8.5 | 9.1 | 8.2 | 8.2 | 7.6 |
| | 2.96 | 2.90 | 2.48 | 2.70 | 2.80 | 2.35 | 2.15 | 2.49 | 2.63 | 2.60 | 2.29 | 2.51 | 2.38 |
| 200 | 10.4 | 8.3 | 8.1 | 8.8 | 8.5 | 7.4 | 7.2 | 9.0 | 10.5 | 11.0 | 10.0 | 10.1 | 9.4 |
| | 2.84 | 2.77 | 2.37 | 2.58 | 2.68 | 2.25 | 2.06 | 2.38 | 2.51 | 2.49 | 2.19 | 2.40 | 2.30 |
| Freq | 4.4 | 4.9 | 6.6 | 8.3 | 9.6 | 7.3 | 5.6 | 8.9 | 14.8 | 12.8 | 10.0 | 6.7 | 100.0 |

Roughness Class 3

| <i>z</i> | 0 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 | 270 | 300 | 330 | Total |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|-------|
| 10 | 3.8 | 3.0 | 3.0 | 3.3 | 3.1 | 2.7 | 2.8 | 3.4 | 3.9 | 4.2 | 3.7 | 3.8 | 3.5 |
| | 2.28 | 2.18 | 1.93 | 2.08 | 2.13 | 1.83 | 1.71 | 1.91 | 2.03 | 2.03 | 1.78 | 1.96 | 1.88 |
| 25 | 5.0 | 4.0 | 4.0 | 4.3 | 4.1 | 3.6 | 3.7 | 4.5 | 5.2 | 5.5 | 4.9 | 5.0 | 4.6 |
| | 2.42 | 2.31 | 2.04 | 2.21 | 2.26 | 1.94 | 1.81 | 2.02 | 2.15 | 2.13 | 1.88 | 2.08 | 1.99 |
| 50 | 6.0 | 4.8 | 4.8 | 5.2 | 5.0 | 4.4 | 4.4 | 5.4 | 6.2 | 6.6 | 5.9 | 6.0 | 5.5 |
| | 2.63 | 2.51 | 2.22 | 2.40 | 2.45 | 2.11 | 1.97 | 2.20 | 2.34 | 2.29 | 2.04 | 2.26 | 2.14 |
| 100 | 7.2 | 5.8 | 5.8 | 6.2 | 6.0 | 5.3 | 5.3 | 6.5 | 7.5 | 7.9 | 7.2 | 7.2 | 6.7 |
| | 2.99 | 2.87 | 2.53 | 2.74 | 2.79 | 2.40 | 2.24 | 2.50 | 2.66 | 2.60 | 2.32 | 2.57 | 2.41 |
| 200 | 8.8 | 7.1 | 7.1 | 7.6 | 7.3 | 6.4 | 6.5 | 8.0 | 9.2 | 9.6 | 8.7 | 8.8 | 8.1 |
| | 2.88 | 2.76 | 2.44 | 2.63 | 2.69 | 2.31 | 2.16 | 2.41 | 2.57 | 2.51 | 2.24 | 2.48 | 2.34 |
| Freq | 4.5 | 5.1 | 6.8 | 8.5 | 9.5 | 7.1 | 5.8 | 9.6 | 14.7 | 12.4 | 9.5 | 6.4 | 100.0 |

Table 4. Contents of a wind atlas data set: Weibull *A* and *k* parameters and frequencies of occurrence for 4 roughness classes, 5 heights and 12 sectors. The standard conditions are specified in the WASP parameter file. The contents of the corresponding wind atlas file, eg WASPDALE.LIB, are given schematically in Appendix C, Section C.6.

The data may come from the Danish Wind Atlas, the European Wind Atlas or may be supplied by the user. The Danish Wind Atlas is supplied with WASP as DENMARK.LIB (8 sectors only!), the wind atlas data of the European Wind Atlas are available on diskette from Risø National Laboratory.

DOS As in the main menu.

HELP As in the main menu.

RETURN Returning to the main display of WASP.

Displaying the wind atlas

If the site description is changed to the standard conditions inherent in the wind atlas data set, the distribution of the wind given by the wind atlas can be shown graphically by invoking the DISPLAY option in the main menu.

The sector-wise frequency distribution of the wind is shown as a wind rose and the distribution of wind speeds is represented by a histogram curve. Toggling between the two is done by pressing any key on the keyboard. The distribution of wind speeds within each sector can be shown by entering the center direction of the sector, eg 180 to display the distribution of wind speeds in the south sector. Notice, that the Weibull distribution curve and the histogram curve represent the same data points. The graphics mode is left by pressing the *(Esc)*-key.

8.2 Changing the standard conditions

The wind climate at a site is always estimated by WASP on basis of the current wind atlas data set, the identification of which is given in the status display. This data set was originally generated with a specific set of standard conditions, ie a number of standard heights, azimuth sectors and roughness classes (lengths).

The default set of standard conditions is specified in the file WASP.PAR and have the characteristics shown in Table 5.

Table 5. Default standard conditions for wind atlas generation.

| | |
|---------------------------------|--|
| Five heights above ground level | 10, 25, 50, 100, 200 m a.g.l |
| Twelve wind direction sectors | 1 : [345, 15[2 : [15, 45[... 12 : [315, 345[|
| Four roughness classes | 0, 0.03, 0.10, 0.40 m |

WASP extrapolates or interpolates on the basis of these standard conditions when calculating the wind climate at some specific site. The standard conditions can be changed, prior to the analysis, by changing the corresponding values in the parameter file WASP.PAR:

- P_1 Number of wind direction sectors for calculations and display. Default and maximum is 12 sectors.
- P_{12} Number of standard heights for wind atlas files. Default and maximum is 5. The standard heights are given as parameters 13 through 17.
- $P_{13}-P_{17}$ Standard heights #1-5. Default values are 10 m, 25 m, 50 m, 100 m, and 200 m a.g.l.
- P_{18} Number of standard roughness lengths for wind atlas files. Default is 4 and maximum is 5. The standard roughnesses are given as parameters 19 through 23.
- $P_{19}-P_{23}$ Standard roughness lengths #1-5. Default values are 0.00 m, 0.03 m, 0.10 m, 0.40 m, and 1.00 m.

8.3 Application of wind atlas data

For the generation of wind atlas data, the analysis model described in the preceding section is complete. Equally important, however, is the application model which was built to enable an inverse calculation of site-specific wind speed distributions from the regional climatology. The model is shown schematically in Fig. 49.

The application model is designed to be as close as possible to the inverse of the analysis model. The correction factors for local shelter, orography, and roughness changes are calculated exactly as in the analysis model, now of course using the obstacle list, roughness description, and orographic data pertaining to the site where the wind atlas data are to be applied.

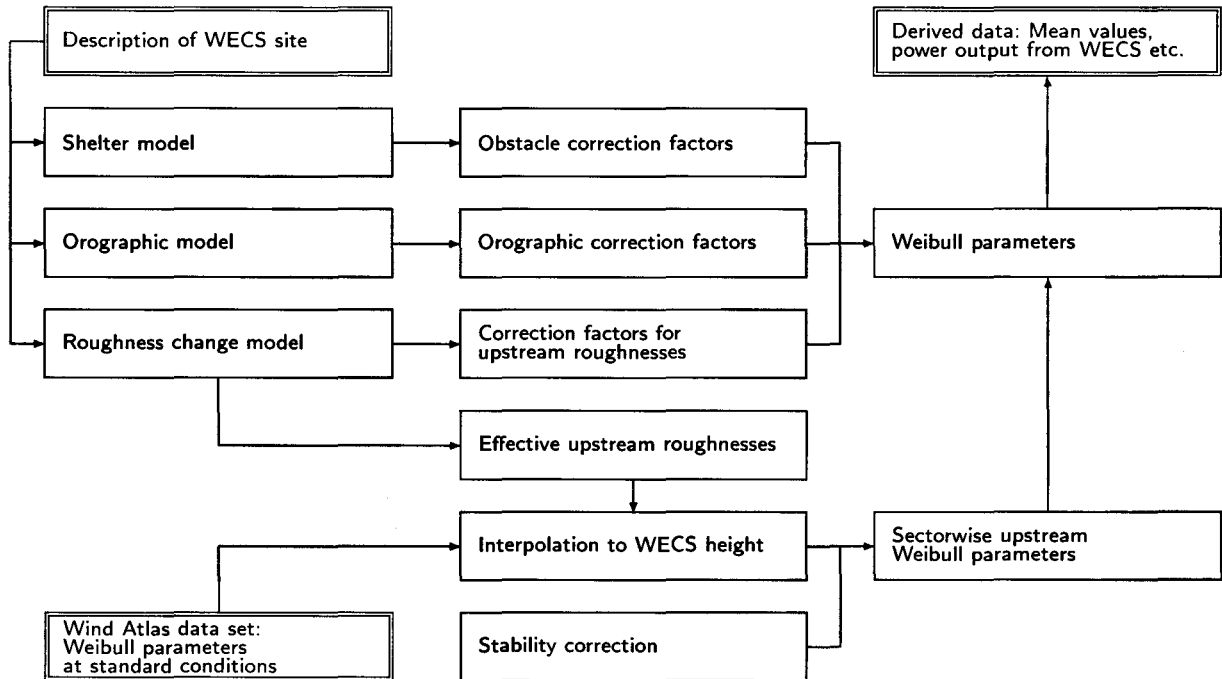


Figure 49. A schematic representation of the WASP application model.

For a given height above the terrain and from a specification of terrain roughnesses, sheltering obstacles, and orographic details, the model calculates values of the sector-wise Weibull parameters and sector frequencies for a chosen regional climatology. The practical aspects of running the application model are described in the next section.

Default wind atlas data

Notice, that if no wind atlas data set is generated or retrieved from disk file, WASP will use a *default* wind atlas data set for the calculations. In this default data set the wind rose is uniform, i.e. 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 m/s and 1.90, respectively. Notice, that this is calculated for a height of 10 meters above ground level.

9 Estimation of wind power

The question of primary interest in wind power applications is: "What power production can be expected from a given wind turbine at a given site?". To answer this, it is necessary to know the power curve of the wind turbine as well as the probability density function of the wind speed at hub height. The product of these two functions gives the power density curve, the integral of which is the mean power production (European Wind Atlas, 1989). This integral is evaluated by WAsP in terms of the Weibull distribution parameters and approximating the power curve with a piecewise linear function.

The power production by a wind turbine varies with the wind that strikes the rotor. It is common practice to use the wind speed at hub height as a reference for the power response of the wind turbine. The power produced as function of the wind speed at hub height is conventionally called the *power curve*. Figure 50 shows a sample power curve: when the wind speed is less than the *cut-in* wind speed, the turbine will not be able to produce power. When the wind speed exceeds the cut-in speed, the power output increases with increasing wind speed to a maximum value, the *rated power*; thereafter the output is almost constant. At wind speeds higher than the *cut-out* speed the wind turbine is stopped to prevent structural failures.

| 250 kW turbine | |
|----------------|---------|
| 30.5 | |
| 1.0 | 1000.0 |
| 3.487 | 0.070 |
| 4.621 | 0.537 |
| 5.519 | 10.287 |
| 6.512 | 30.694 |
| 7.511 | 56.743 |
| 8.526 | 88.617 |
| 9.498 | 121.378 |
| 10.463 | 155.919 |
| 11.493 | 189.832 |
| 12.565 | 223.393 |
| 13.528 | 247.183 |
| 14.485 | 262.366 |
| 15.470 | 268.559 |
| 16.461 | 264.636 |
| 17.388 | 248.879 |
| 18.545 | 244.898 |
| 19.476 | 239.943 |
| 20.624 | 211.317 |

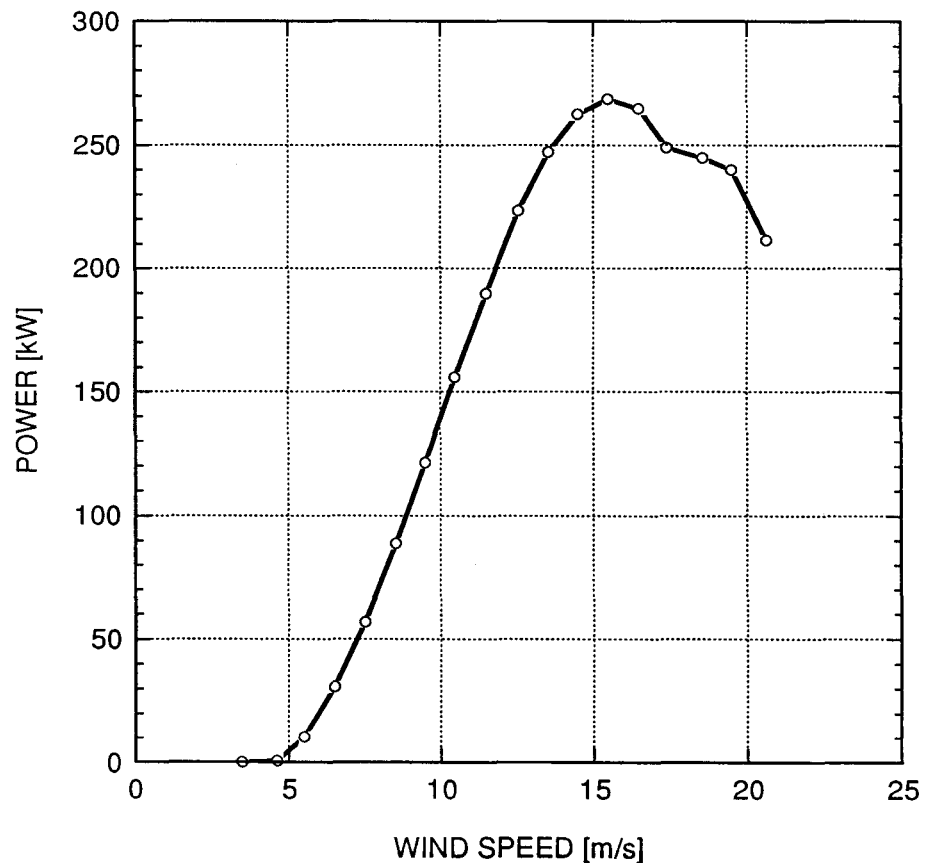


Figure 50. Measured power curve of a 250 kW wind turbine. The power curve is plotted as a piecewise linear curve with nodes for every 1 ms^{-1} .

The probability density function or distribution function gives the frequency of occurrence of a given wind speed. Estimating the relevant probability density function or Weibull distribution is the subject of the preceding sections.

9.1 Determining mean power production

Preparing the power curve

Before invoking the WECS option of the main displays, a disk file containing the power curve data of the wind turbine in question should be prepared. The file corresponding to the sample power curve mentioned above is shown in Fig. 50 and contains the following information: *Line 1* is a character string identifying the contents of the file. *Line 2* states the actual or projected hub height of the wind turbine. *Line 3* gives two scaling factors for wind speed and power output, respectively. These scaling factors are simply the conversion factors from the units of speed and power used in the file, to $[\text{ms}^{-1}]$ and $[\text{W}]$, respectively. From *Line 4* and onward, corresponding values of wind speed and power output are listed. The power curve may be described by a maximum of 100 points. Notice, that the power production will be calculated for the interval of wind speed between the cut-in and the cut-out speeds – as specified in the file.

Estimating power production

Having prepared the power curve file and established the wind statistics, the WECS option may be invoked. WASP will then enquire for the name of the power curve file – assuming .POW as the default file name extension. Enter a file name to reload a specific file, or enter an asterisk '*' to obtain a list of all .POW files in the current directory.

The yearly, mean power production of the wind turbine is calculated and shown in the main display. Observe that *the current height of WASP is set to the hub-height* read from the file. However, by using the HEIGHT option you may even estimate the power production for various hub-heights. Note also that the units given may vary according to the actual size of the power production. Once the WECS option has been invoked, the power production of the wind turbine is recalculated each time the main display is refreshed.

Furthermore, the main display gives the total energy available in the wind, ie the average kinetic energy flux per unit area. This quantity may be useful in a preliminary evaluation of the wind power potential at several different sites. Notice, that this quantity is calculated using an air density corresponding to standard conditions, see below.

The distribution of the total energy content of the wind in the various sectors is also given in the result display. If a wind turbine power curve has been entered, the sector-wise distribution of the actual power production is displayed instead. You may change this default setting by altering parameter #43 of the parameter file (Appendix B). A more detailed treatment of wind power estimation in general is given in Petersen *et al.* (1981), Jensen *et al.* (1984) and the European Wind Atlas.

Air density

The power curve for any given wind turbine depends on air density, which changes with temperature and air pressure (altitude). The power curve is usually referred to a standard density of 1.225 kg m^{-3} corresponding to conditions of standard sea level pressure and a temperature of 15°C . A power curve applied to a site where the average air density is different from the standard value is commonly assumed to be proportional to the ratio of the site air density to the standard value. This is generally acceptable due to the rather limited range of air densities encountered. For wind turbines where the power output is used for control, as is the case for most pitch-regulated turbines, the correct calculation of mean power output may be more involved.

Sample power curves

The sample power curve shown in Fig. 50 is provided on the WASP diskette as WECS251.POW. Furthermore, a number of actual power curves, measured and published by the Test Station at Risø, are included on the diskette.

9.2 The RESOURCEFILE option

The procedure outlined above provides results for one site only. Invoking the RESOURCEFILE option of the main menu, it is possible to make a file containing information on the wind climate and resources in several points. The information is written in a file with the extension .RSF, the format of which is described in Appendix C, Section C.8. With the RESOURCEFILE option you may choose to specify the sites in either of the following two ways:

- a regular grid
- randomly spaced points

Limitations In both cases, the grid or arbitrarily chosen sites can be specified anywhere within the area described by the digital terrain map. Consequently, not only the orography, but also the roughness conditions should be described in the form of a map, preferably covering the same area. By the same token, obstacles are *not* taken into account when using this option – since the obstacle description is not linked to the map.

To calculate the wind resources in several points *employing the entire set of models provided by WASP*, is most easily done through the batch mode operation of WASP, see Section 1.2. In this case, dump files are used to store the results, see Chapter 10. – Both dump files and resource files can be used as input to the PARK program.

The Grid option

Choosing the Grid option, the wind resource will be calculated in all the grid points of a regular grid defined by the user. First you are prompted to enter the name of the file in which the results are to be saved (default extension .RSF). If the file already exists, it will be overwritten. The map of the area is then displayed on the screen, see Fig. 51. The commands shown in the Grid graphic display are:

- value *Contour line.* The altitude of the height contour closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.
- Roughness line.* The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair).
- Combined roughness and contour line.* The altitude is written on the line, and the roughness lengths on the left- and right-hand side of the line are displayed on the bottom line. (Note: the values on the bottom line will disappear when you type a new command or move the cross-hair).
- Grid area The selected part of the map shown on the screen (window or total) is chosen as the grid area. Upon leaving the graphics mode you will be prompted to enter the resolution of the grid (in metres).
- Plot Makes a plot file of the displayed window or photo (either a .PLT or a .HPG file). The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen, ie the map is redrawn. This command can be used to eg remove values (generated by the value command) and spurious dots.

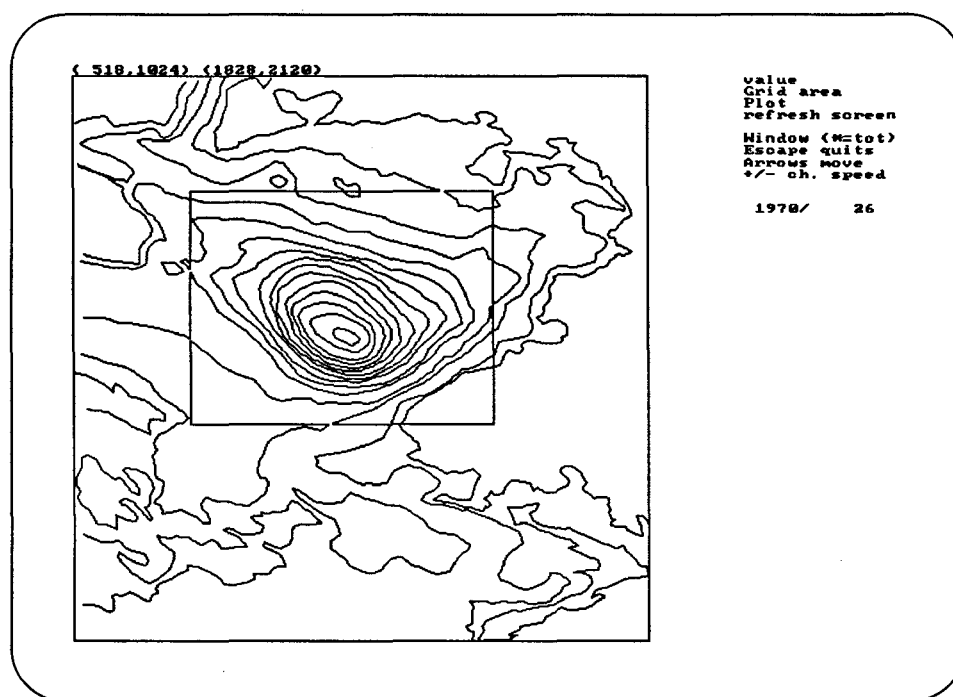


Figure 51. The graphic display and commands obtained by invoking the Grid option. The coordinates of the grid area are shown in the upper left-hand corner of the screen.

transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press *(t)* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *(Return)*. A window is now shown around the target – use arrow keys to enlarge this window and press *(Return)* to select. A 3-D rendering of the terrain is displayed after a short while, an example is shown in Fig 46.

A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. The Plot option generates a plot file of the photo, as described above.

Window Zooms in on the area, that selected by using the arrows. When you have selected the area press *(Return)*.

* Zooms out to the original window. No effect if you haven't used the window command.

(Esc) Leave the graphics mode. If you have not chosen a grid area, you will be prompted to enter the coordinates of two opposite grid area corner points and, subsequently, the grid resolution (all in metres).

+/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The step length of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) keys one or several times.

The Random points option

Choosing the Random points option it is possible to select specific points, where the wind resources are to be calculated. First you are prompted to enter the name of the resource file (default extension .RSF). If the file already exists you will be asked whether to append (A) or overwrite (O) the results to the file. If you chose the *append* option, the points already present in the file will be used in the calculations, as well as any additional points specified in graphics mode. This has the advantage, that if several points are already specified (eg the positions of the wind turbines in a wind farm) you can use an editor (before entering W^AS^P) to type in the coordinates, eg:

```
Site-1    640.0    385.0
Site-2    720.0    446.0
Site-3    799.0    506.0
Site-4    879.0    566.0
Site-5    959.0    626.0
```

The resulting .RSF file – as well as any other existing .RSF file – can also be used directly as input.

Choosing the *overwrite* option, the points already present in the file will be deleted. An easy way to enter a few points on the map is to enter them in graphics mode, directly on the displayed map, see Fig. 52.

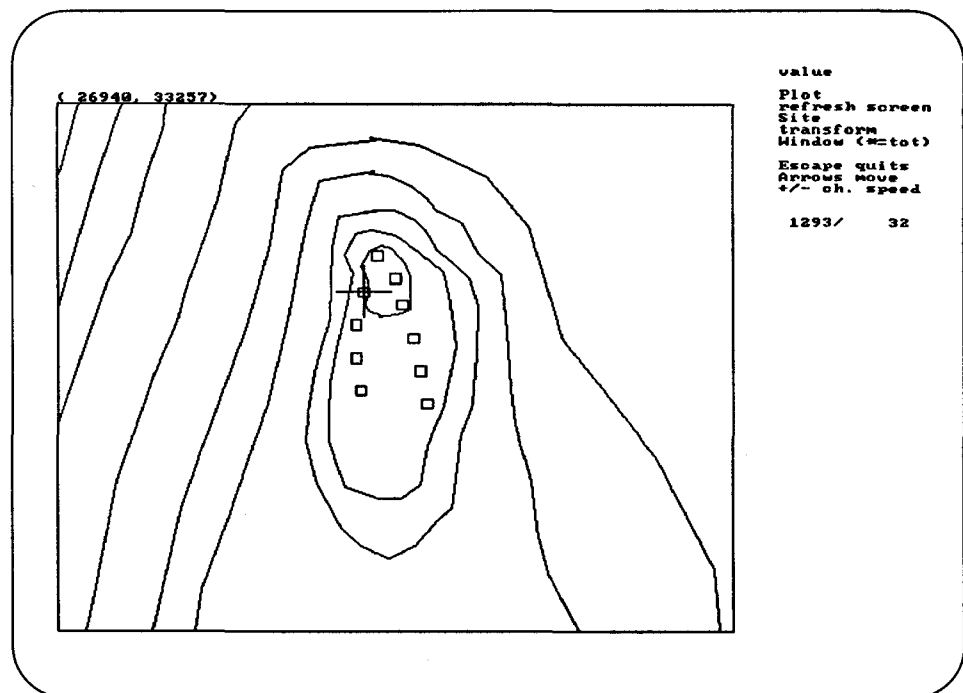


Figure 52. The graphics display and commands obtained by invoking the Random option. The coordinates of the cross-hair are shown in the upper left-hand corner of the screen.

The commands shown in the Random points graphic display are described below.

value Contour line. The altitude of the height contour closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.

Roughness line. The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will

disappear when you type a new command or move the cross-hair).

Combined roughness and contour line. The altitude is written on the line, and the roughness lengths on the left- and right-hand side of the line are displayed on the bottom line. (Note: the values on the bottom line will disappear when you type a new command or move the cross-hair).

- Plot Makes a plot file of the map or photo (either a .PLT or a .HPG file). The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen, ie the map is redrawn. This command can be used to eg remove displayed height/roughness values (generated by the value command) and spurious dots.
- Site Every time you use this command, the point at the cross hair is added to the list of points for which the resource calculations will be done. Each time a point has been selected, you are prompted to enter a label characterizing that specific point, this label will appear in the resource file. Notice, that the label must not contain any blanks (spaces).
- transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press *t* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *Return*. A window is now shown around the target – use arrow keys to enlarge this window and press *Return* to select. A 3-D rendering of the terrain is displayed after a short while, an example is shown in Fig. 46.
- The selected sites are shown as flags, correctly placed in the terrain. The length of the flags is initially chosen so that even the most distant flags will be visible on the screen. However, any flag length (in metres) can be chosen using the Scale option: specify desired length as a *negative height value*, eg –32.5 means 32.5 metre flags. An example is shown in Figure 53.
- Window Zooms in on the area, that you select by using the arrows. When you have selected the area press *Return*.
- * Zooms out to the original window. No effect if you haven't used the window command.
- <Esc>* Leave the graphics mode. If you have not chosen the coordinates of the site(s) while in graphics mode, you will be returned to the main menu.
- +/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or – (decreasing) keys one or several times.

The results can now be plotted using a plotting program as eg SURFER, an example is shown in Fig. 54.

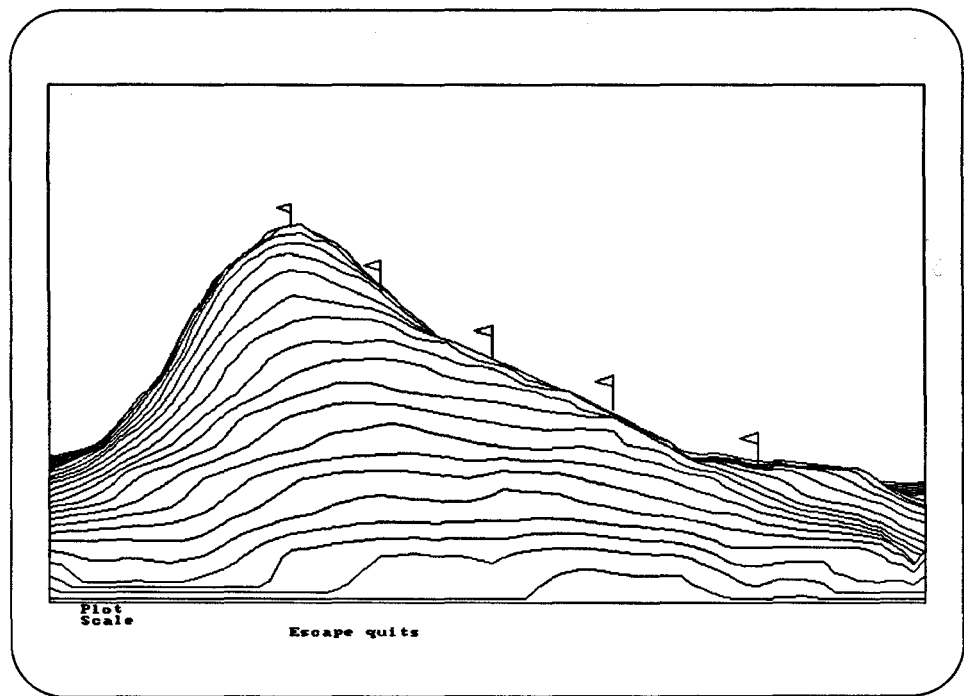


Figure 53. An example of a 3-D rendering of a terrain. The sites are marked by flags with a height corresponding to the projected wind turbines.

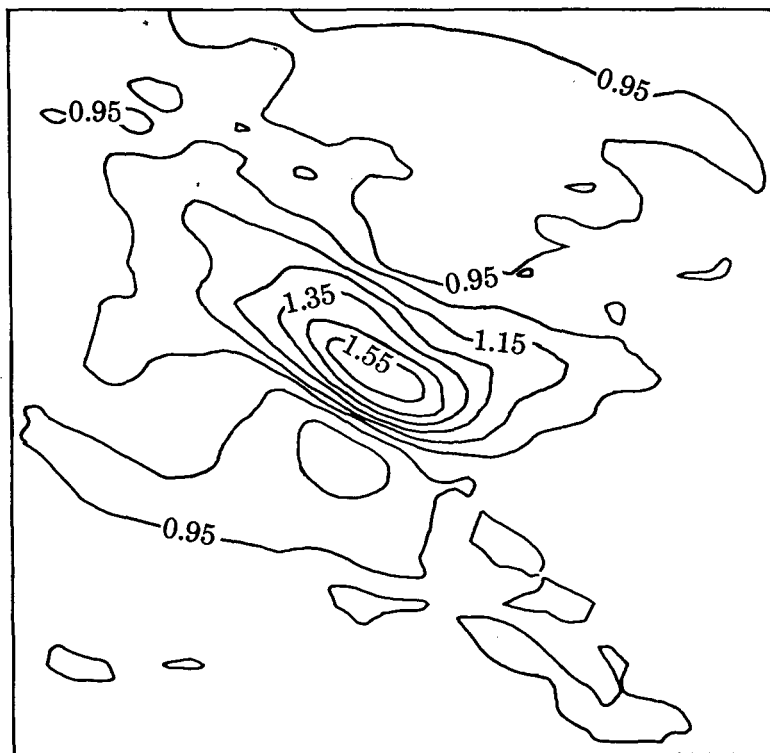


Figure 54. An example of a plot showing the results derived from a resource calculation. The relative increase of wind speed at a fixed height above ground level is shown by contours of equal speed increase/decrease.

10 Reporting and hard-copy

At some point you may probably want to store the results of a WASP session on disk file or make a hardcopy of one or more of the screens displayed by the program. Several simple ways of saving the results of a WASP session are described below.

10.1 Storing and printing alphanumeric results

Screen dump on printer

The simplest way of storing WASP results is to print it directly on a side printer. If you have a printer connected to your PC, you can make a hardcopy of any of the alphanumeric displays displayed by WASP simply by pressing the `<PrtSc>`-key on your keyboard. Since most displays are 80 characters wide, it may be necessary to choose a narrow (12 or 16.66 pitch) printer font.

Memory-resident programs

You can also store an exact copy of the alphanumeric display employing a memory-resident program like eg SideKick. Such programs are capable of “importing” alphanumeric displays into their text editor where they can be edited and stored on disk file for further processing. In this way you may even use the displays directly as figures in a report or print them on paper for future reference. To utilize this, your computer should have at least 640 kbytes of memory (RAM).

WASP dump option

WASP itself also offers optional dump of results on a disk file – the so-called *dump file* – with the default extension `.DMP`. To activate the dump option and open the dump file simply type:

```
:filename[.ext]
```

in the main menu of WASP. Notice that the dump file is only given a name and connected to WASP by issuing this command. To actually write the results in the file you must press either of the keys `>` (greater than sign) or `:` (colon). The effect of pressing these keys is:

- Dump file options*
- `>` The alphanumeric display is dumped in the file just as it appears on the screen. For example, the status display and the result display may typically be dumped this way. The file can subsequently be printed or imported into some text editor or word processing system.
 - `:` The results of the WASP calculations are written in the dump file using a format determined by the parameter `P63` in the file `WASP.PAR`. This option can be used if the results are to be read by another program – the *PARK* program, for example, can use one of these formats as input.

The current dump file is closed and saved whenever WASP is terminated or a new dump file is invoked.

- Dump file formats*
- The four different dump file formats that can be obtained by changing parameter `#63` in `WASP.PAR` are shown and described briefly below. Notice, that the actual set-up and numbers are used for illustration purposes only and may not seem entirely realistic.

$P_{63} = -1$ The simplest format of the dump file is illustrated in Fig. 55. This format is a one line summary of the results: height above ground level [m], Weibull A - and k -parameters for the total distribution, mean wind speed [m/s], total energy content [W/m^{-2}], yearly power production (if a wind turbine power curve has been loaded), and a text string identifying the site. This format is convenient for comparing the overall wind climate and power production at a (large) number of sites.

```
31.50  6.01  2.25  5.32  158 P= 336.6 MWh/y Runway NW anemometer
```

Figure 55. Contents of a dump file with $P_{63} = -1$, cf. DUMP-1.DMP on the WASP diskette.

$P_{63} = 0$ Changing parameter #63 in WASP.PAR to zero invokes the dump file format illustrated in Fig. 56. The first line of this format is a one line summary of the results, identical to the format described above. Then follows a table with results for each sector in the analysis: center angle of the sector, frequency of occurrence, Weibull A - and k -parameters for the distribution. The last six columns list the corrections employed by WASP in the analysis: the user-specified corrections in [%] and [deg] (columns 5 and 6), the obstacle model correction (columns 7), and, finally, in columns 9 and 10, the corrections calculated by the orographic model. Notice, that column 8 is inactive and always equal to zero.

```
31.50  6.01  2.25  5.32  158 P= 336.6 MWh/y Runway NW anemometer

  0  2.47  4.07  2.26  0.00  0.00  0.00  0.00  -2.10  -0.19
 30  4.24  4.93  2.23  0.00  0.00  0.00  0.00  -2.46  -0.24
 60  5.49  4.30  2.01  0.00  0.00  0.00  0.00  -2.73  -0.04
 90  7.33  4.35  2.81  0.00  0.00  0.00  0.00  -2.56  0.20
120  6.21  5.24  2.60  5.00  0.00  -0.42  0.00  -2.08  0.23
150  5.30  4.75  2.56  0.00  0.00  -0.34  0.00  -1.96  0.04
180  7.48  5.16  2.33  0.00  0.00  -0.19  0.00  -2.21  -0.16
210  9.02  6.27  2.37  0.00  0.00  0.00  0.00  -1.71  -0.20
240 11.97  7.18  2.99  0.00  0.00  0.00  0.00  -2.51  -0.03
270 15.73  7.33  2.60  0.00  0.00  0.00  0.00  -2.02  0.22
300 16.49  6.92  2.60  0.00  0.00  0.00  0.00  -1.89  0.20
330  8.27  5.33  2.19  0.00  0.00  0.00  0.00  -1.79  0.00
```

Figure 56. Contents of a dump file with $P_{63} = 0$, cf. DUMPO.DMP on the WASP diskette. This is the default setting of P_{63} .

$P_{63} = 1$ Changing parameter #63 in WASP.PAR to 1 invokes the dump file format illustrated in Fig. 57. This format also contains a table with results for each sector in the analysis, identical to the table described above. The table is preceded by an overview of the current set-up: the wind atlas data used, the map employed (and the site coordinates x , y , and z), the site-specific roughness description (if any) and the obstacle list file. Then follows a one line summary of the results: height above ground level, Weibull A - and k -parameters for the total distribution, mean wind speed, total energy content, and yearly power production (if a wind turbine power curve has been loaded). This dump file format can be read directly by the *PARK* program.

$P_{63} = 2$ Changing parameter #63 in WASP.PAR to 2 invokes the dump file format illustrated in Fig. 58. This format contains nearly the same information as described above,

```

-----
WASP Airport 1983-85. Runway NW anemometer.
C:\WASP3\WASPDAL.MAP ( 29622, 39127), 124)
C:\WASP3\AIRPORT.RDS
C:\WASP3\AIRPORT.OBS
-----

```

```

-----
z      A      k      m      E      P
-----
31.50  6.01  2.25  5.32  158  P= 336.6 MWh/y
-----

```

| | z | A | k | m | E | P | | | |
|-----|-------|------|------|------|------|-------|------|-------|-------|
| 0 | 2.47 | 4.07 | 2.26 | 0.00 | 0.00 | 0.00 | 0.00 | -2.10 | -0.19 |
| 30 | 4.24 | 4.93 | 2.23 | 0.00 | 0.00 | 0.00 | 0.00 | -2.46 | -0.24 |
| 60 | 5.49 | 4.30 | 2.01 | 0.00 | 0.00 | 0.00 | 0.00 | -2.73 | -0.04 |
| 90 | 7.33 | 4.35 | 2.81 | 0.00 | 0.00 | 0.00 | 0.00 | -2.56 | 0.20 |
| 120 | 6.21 | 5.24 | 2.60 | 5.00 | 0.00 | -0.42 | 0.00 | -2.08 | 0.23 |
| 150 | 5.30 | 4.75 | 2.56 | 0.00 | 0.00 | -0.34 | 0.00 | -1.96 | 0.04 |
| 180 | 7.48 | 5.16 | 2.33 | 0.00 | 0.00 | -0.19 | 0.00 | -2.21 | -0.16 |
| 210 | 9.02 | 6.27 | 2.37 | 0.00 | 0.00 | 0.00 | 0.00 | -1.71 | -0.20 |
| 240 | 11.97 | 7.18 | 2.99 | 0.00 | 0.00 | 0.00 | 0.00 | -2.51 | -0.03 |
| 270 | 15.73 | 7.33 | 2.60 | 0.00 | 0.00 | 0.00 | 0.00 | -2.02 | 0.22 |
| 300 | 16.49 | 6.92 | 2.60 | 0.00 | 0.00 | 0.00 | 0.00 | -1.89 | 0.20 |
| 330 | 8.27 | 5.33 | 2.19 | 0.00 | 0.00 | 0.00 | 0.00 | -1.79 | 0.00 |

Figure 57. Contents of a dump file with $P_{63} = 1$, cf. DUMP1.DMP on the WASP diskette. This value of P_{63} is used when the dump file is to be read by the PARK program.

but written in the \LaTeX mark-up language. This format can be imported directly into \LaTeX documents.

```

\begin{table}\caption[]{\em
WASP Airport 1983-85. Runway NW anemometer.

C:\WASP3\WASPDAL.MAP
( 29622, 39127), 124)
C:\WASP3\AIRPORT.RDS
Runway NW anemometer
C:\WASP3\AIRPORT.OBS
Runway NW anemometer}
\begin{center}
\begin{tabular}{|r|r|r|r|r|}\hline
z & $\theta$& %& A& k & \ \ \hline
31.5& 6.01 & 2.25 & 5.32 & 158 & 2.25 \ \
& 0& 2.5& 4.1& 2.26 \ \
& 30& 4.2& 4.9& 2.23 \ \
& 60& 5.5& 4.3& 2.01 \ \
& 90& 7.3& 4.3& 2.81 \ \
& 120& 6.2& 5.2& 2.60 \ \
& 150& 5.3& 4.8& 2.56 \ \
& 180& 7.5& 5.2& 2.33 \ \
& 210& 9.0& 6.3& 2.37 \ \
& 240& 12.0& 7.2& 2.99 \ \
& 270& 15.7& 7.3& 2.60 \ \
& 300& 16.5& 6.9& 2.60 \ \
& 330& 8.3& 5.3& 2.19 \ \
\hline
\end{tabular}\end{center}\end{table}

```

Figure 58. Contents of a dump file with $P_{63} = 2$, cf. DUMP2.DMP on the WASP diskette. The results are written in the \LaTeX table environment for direct import into \LaTeX documents.

You may dump results to the same dump file several times during a session. As long as you do not change the file name, the new results will be appended to that file; if you choose another file name the old dump file will be closed and a new opened.

The RESOURCEFILE option

The resource file (.RSF) – described in detail in Chapter 9 – is another way of storing the results for a number of sites. This option has the advantage over the dump file options that the coordinates of the sites can be reused when repeating the calculations at a later stage. The resource file can also be read directly by the *PARK* program.

10.2 Storing and plotting WASP graphics

Most of the input data can be viewed on the screen during a WASP session. However, it is evidently desirable to be able to print or store the graphics displays on disk file so that it can be included in reports and other documentation. As with the alphanumeric results there are several ways of printing or storing graphics – these are described below.

Screen dump on printer

The simplest way of obtaining a hardcopy of WASP graphics is to print it directly on a side printer. If you have a printer connected to your PC, you can make a hardcopy of any of the graphics screens displayed simply by pressing the >-key (greater than sign) on the keyboard. This requires that printing is enabled – by setting P_{18} equal to 1 in the file GRAPHICS.PAR. Furthermore, the printer and its set-up must be specified in the file PRINT.PAR. The default configuration in this file is valid for an HP LaserJet+ or Series II printer, but most common matrix, inkjet, and laser printers can be specified. Refer to Section B.3 for details of the printer set-up.

Notice, that the resolution of pictures printed in this way is determined solely by the printer's capability and characteristics. And, for true black-and-white screen dumps the colours of the graphics screen should be changed to B&W by changing the appropriate parameters in the file GRAPHICS.PAR, see Section B.2.

Using the WASP plot option

The maps shown by WASP can also be converted into plot files, using the Plot option available when invoking the DISPLAY, SITE or RESOURCEFILE commands. The format of this plot file is determined by parameter #12 in the file GRAPHICS.PAR. If P_{12} is set equal to HPG the plot file will contain HP-GL commands, in which case it can be plotted directly on a printer or plotter with HP-GL emulation – or included directly in a word-processing system with this capability. If P_{12} is set equal to PLT the plot file can be plotted using the SURFER/GRAPHER software described below.

The resolution of pictures printed from plot files is determined by the characteristics of the printer or plotter.

Memory-resident programs

You can also store an exact copy of the graphics display employing a memory-resident program like eg Frieze. Such programs are capable of grabbing graphics

screen pictures and storing them on disk files. These files can be read by eg Paint-Brush, with which the pictures can be edited and printed. In this way you may use the graphics displays directly as figures in a report or print them on paper for future reference. To utilize this, your computer should have at least 640 kbytes of memory (RAM). Notice, that the resolution of pictures made in this way is that of the graphics monitor – even if the printer has a higher resolution.

Most of the figures in this guide illustrating the graphics capabilities of WASP was made in this way, with a resolution corresponding to standard VGA (640×480 pixels).

Interfacing to SURFER

WASP 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 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, you can create a contour map or 3-D surface plot of the digitized terrain. The map and 3-D surface can be viewed and plotted on most standard PC equipment.

Running WGRID The terrain surface is described by digitized height contour lines in WASP, whereas the input to SURFER is grid point spot heights in a regular grid. The purpose of WGRID is to convert a WASP map data file to a grid file. The program is started by typing WGRID at the DOS prompt.

1. Enter the name of the WASP map data file (.MAP) that you want to convert. Notice, that the map file should be in ASCII format.
2. Enter the name of the output file(s) to be generated by WGRID. The output is a grid file (default extension .GRD) and an optional contour line file (default extension .BLN). Blank input (*Return*) will assign the same file name to the output files as that of the input file.
3. You may optionally choose to make a grid file for only part of the area described in the map file by entering the coordinates (x_{\min}, y_{\min}) and (x_{\max}, y_{\max}) of two opposite corner points.
4. Enter the grid cell size by specifying either the number of grid points in the x -direction *or* the size of the grid cells in metres. Enter an integer if you want to specify the number of grid points (eg 10) or enter a real (including a decimal point) if you want to specify the grid size (eg 50.0). The grid is considered regular ($\Delta x = \Delta y$) in any case.

Optional parameters Optionally, you may enter one or two additional parameters when specifying the grid: *LR* and *WP*. *LR* is the resolution level which determines the number of 'rays' or directions examined by WGRID at each grid point. The larger the value of *LR*, the smoother the gridded surface; however, at the expense of a small 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).

WP is the power used in 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 α 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.

WGRID output files WGRID produces a grid file (.GRD) on basis of the input described above and this file may be used directly with SURFER. When the grid file has been stored, you may further choose to dump all or some of the original contour lines of the input file to a plot file (.BLN) which may also be viewed and plotted with SURFER. Hence, the WGRID utility and SURFER enable you to check your digitized maps as well as producing high quality plots for documentation and illustration purposes. Sample plots are shown in Fig. 59 and 60.

Other uses of SURFER The SURFER program can be used to analyse, 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 resourcefile (.RSF) are 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.

X-Y plots Most other WASP data, eg the power curve of the wind turbine, can be conveniently plotted with GRAPHER, a general viewing and plotting program for X-Y data.

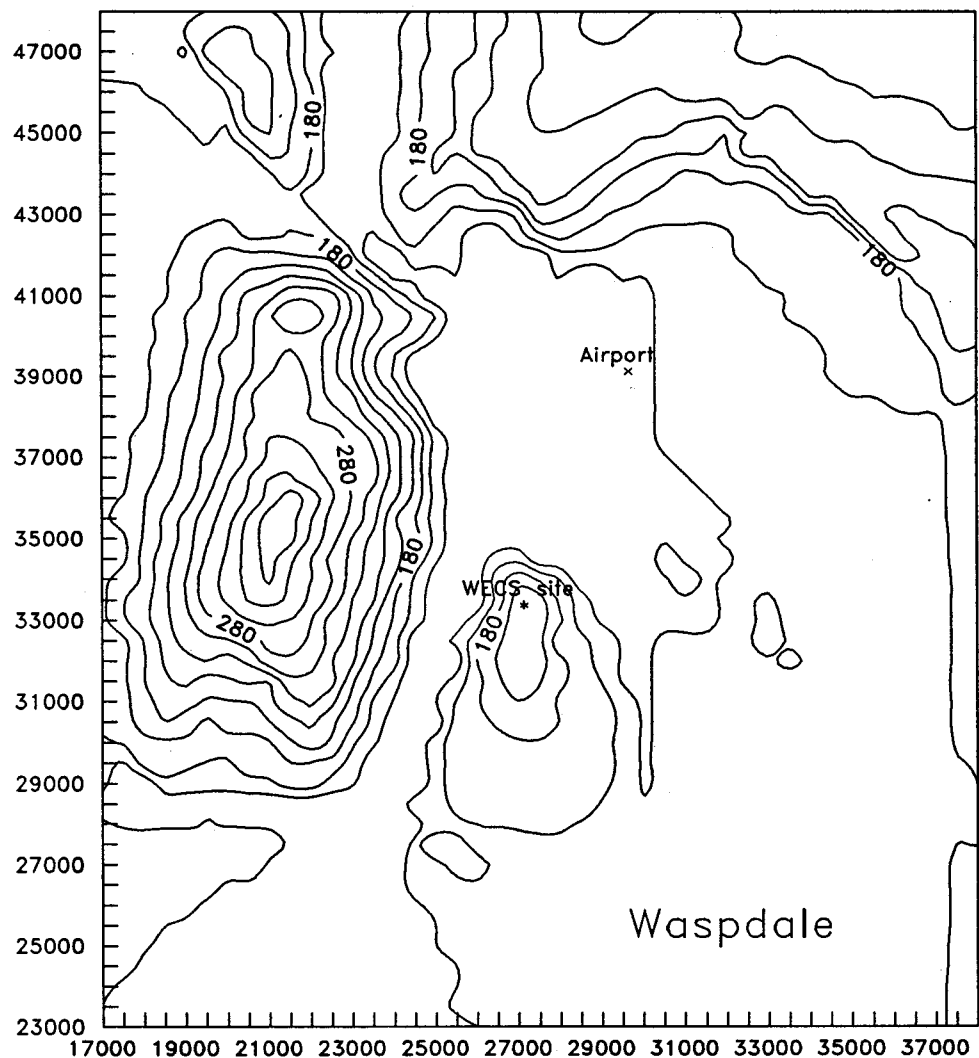


Figure 59. Contour map of Waspdale. The contours were generated by SURFER from a grid with 44×51 points, corresponding to a grid size of 500 m.

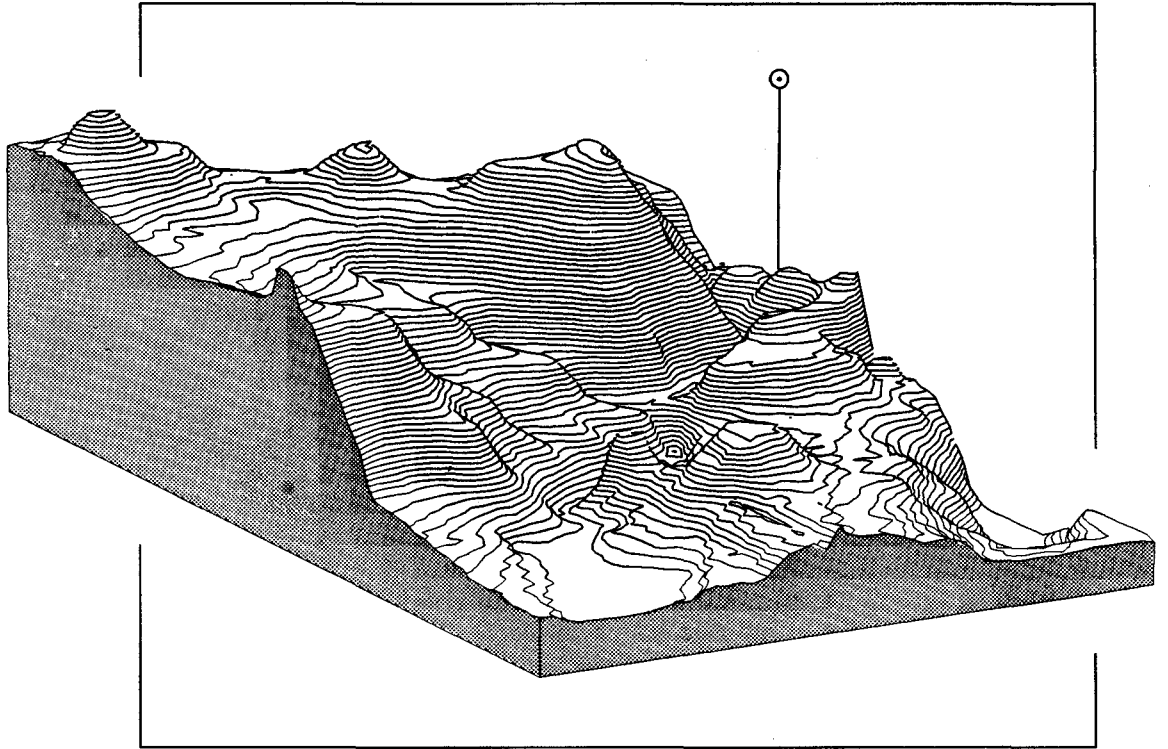


Figure 60. Perspective plot of the orographical setting of a meteorological station.

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A Summary of WASP key-words

WASP is primarily an interactive or menu-driven program. The various options of the program are chosen by invoking the commands or *key-words* shown in the menus. The key-words are invoked by typing the first three or more characters of the key-word in question, eg HEI for the HEIGHT option. The following pages list the available key-words and thus provide a summary of the capabilities of WASP. The key-words of the main menu are described in Section A.1, whereas the key-words of the DATA, RAWDATA, OBSTACLE, ROUGHNESS, OROGRAPHY, MAPDATA and ATLAS menus are described in Sections A.2–A.8.

Graphics options WASP includes many graphics features, the use of which is described under the appropriate menus. However, the following general points apply to all graphics options:

- All commands are accessed by pressing the relevant first letter of the command – please note that this is *case-sensitive*, ie if the command in the menu is transform, then you must press a lower-case t (t), and if the command is Translate you must press a capital t (T).
- The cross-hair can be moved around the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) keys one or several times.
- By pressing the > key (greater-than sign) you get a hard copy of the screen. Remember to install your printer (parameter #18 in GRAPHICS.PAR and the printer driver in line 1 of the file PRINT.PAR).
- To *exit* the graphics displays: press the <Esc>-key.

Map graphics When a map (contour/roughness) is shown on the screen, there may be three different kinds of lines, see also Chapters 3 and 4. They are:

1. Contour lines. That is lines going through points that are at the same height above sea level. Heights are given in metres.
2. Roughness lines. That is lines separating areas of different roughness lengths. These lines are described by two parameters: the roughness length on the left-hand side and the roughness length on the right-hand side. Roughness lengths are given in metres.
3. Combined roughness and contour lines. That is lines that are both contour lines and roughness lines (eg a coastline). These lines have three parameters: the roughness length on the left-hand side, the roughness length on the right-hand side, and the height of the line – all of which are given in metres.

Menu structure The overall layout of the alphanumeric and graphic menus in WASP is shown on the Quick Reference Sheet.

A.1 The WASP main menu

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

- DATA** The input and output routines to handle measured meteorological data (in the form of a time-series of wind speed and direction) and general climatological data (in the form of a climatological table) are collected in the DATA menu.
- OBSTACLE** Input and editing of the obstacle list for a specific site is taken care of by this menu. Typing **-OBSTACLE** – or just **-OBS** – in the main menu clears the obstacle list – the same list may be reactivated by invoking the **EDIT** option in the **OBSTACLE** menu.
- ROUGHNESS** Input and editing of the surface roughness conditions for a specific site – and, optionally, input of local wind speed corrections and wind direction correction angles for each sector – is done in the **ROUGHNESS** menu. The menu also contains a path to the **MAPDATA** menu and commands for specifying the site on a map containing roughness and/or height contour lines.
- OROGRAPHY** Input of a digitized map of the area or an idealized orography and initialization of the complex terrain model. Entering **-OROGRAPHY** removes the map from the set-up – the map is reactivated by invoking the **SITE** option in the **OROGRAPHY** menu.
- ATLAS** Calculation, storage or retrieval of wind atlas data are the options in the **ATLAS** menu. The wind atlas calculation combines the meteorological data and the site description to obtain a regionally representative data set. The wind atlas *must* be generated for table or raw data to have any effect on the results (the estimated wind climate).
- WECS** Retrieval of a wind turbine power curve. When a power curve has been loaded the yearly power production of the wind turbine in question is shown in the main display and recalculated as the display is updated. The sector-wise distribution of the energy production is also shown. Typing **-WECS** removes the turbine from the set-up – blank input reactivates the same power curve.
- HEIGHT** Sets a new height above ground level (m a.g.l.) for which results are calculated, eg the wind turbine hub height.
- DISPLAY** Shows graphically the wind statistics resulting from the current WASP calculations: the sector-wise frequencies of occurrence in a wind rose and the Weibull distribution of the wind speeds.
- RESOURCEFILE** The wind resources are calculated in several points which may be chosen at random or describe a regular grid. The results are written in a so-called resource file (**.RSF**). If you return to the main menu the list of points is kept, and you may append to the list and/or execute the calculations later by returning to the **RESOURCEFILE** option. Points can be chosen on the graphics screen or input through a free-format file. Entering **-RESOURCEFILE** (or **-RES**) closes relevant files and resets number of resourcefile points to zero.
- FREQUENCY** Calculates the probability that the wind occurs in a certain user-specified ‘window’ of wind speed and direction.

- DOS Entering and returning from the Disk Operating System without terminating WASP. This allows the user to execute DOS commands while having a WASP session, eg check a directory on disk or edit a file before it is entered to the program.
- HELP WASP is equipped with an on-line help function that offers a brief description of the menu key-words and their usage. The help function is invoked by the HELP option in the various menus. Furthermore, a question mark '?' may be input anywhere (except in graphics mode) in the dialogue with WASP to obtain context-sensitive help. WASP will then display a short message, stating what type of input or action is required.
- RETURN Invokes the different models of WASP and updates the screen with the new results. Switches between the two main displays if calculations are already updated: the *status display* and the *result display*. RETURN or RET is equivalent to pressing the <Return>-key.
- STOP Stops the execution of WASP. *Data and results not stored on disk files will be lost.*
- : and > Dumping the results of a WASP session on an ASCII file (default extension .DMP). :*filename.ext* opens the dump file. An exact copy of the alphanumeric screens can subsequently be dumped by pressing the 'greater-than' key (>), or a table of results suitable for further processing can be dumped by pressing the colon key (:). The format of this table is determined by parameter #63 in the file WASP.PAR.
- ? A question mark may be input anywhere in the dialogue with WASP – except in graphics mode – to obtain context-sensitive help. WASP will then display a short message, stating what type of input or action is required.

The RESOURCEFILE option

By choosing this option it is possible to make a file containing information concerning the wind resource in several points. The information is output to a file with the extension .RSF. Invoking this option you may choose between:

- Grid
- Random points

In the Grid option the following commands are available to select a regular grid, in which the resources are calculated:

value *Contour line.* The altitude of the height contour closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.

Roughness line. The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line point towards the area on the left-hand side.

Combined roughness and contour line. The altitude is written on the line, and the roughness lengths on the left- and right-hand side of the line are displayed on the bottom line.

Grid area The selected part of the map shown on the screen (window or total) is chosen as the grid area. Upon leaving the graphics mode you will be prompted to enter the resolution of the grid (in metres).

- Plot Makes a plot file of the displayed window or photo (either a .PLT or a .HPG file). The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen. That is redraws the map. This command can be used to eg remove values (generated by the value command) and spurious dots.
- transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press <t> for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press <Return>. A window is now shown around the target – use arrow keys to enlarge this window and press <Return> to select. A 3-D rendering of the terrain is displayed after a short while.
- A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. The Plot option generates a plot file of the photo, as described above.
- Window Zooms in on the area, that selected by using the arrows. When you have selected the area press <Return>.
- * Zooms out to the original window.
- <Esc> Leave the graphics mode. If you have not chosen a grid area, you will be prompted to enter the coordinates of two opposite grid area corner points and, subsequently, the grid resolution (all in metres).
- +/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) keys one or several times.
- Upon leaving the graphics mode you will be prompted to enter the resolution of the grid.
- In the random points option the following commands are available to choose the specific points, where you want the wind resource calculated:
- value *Contour line.* The altitude of the height contour closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.
- Roughness line.* The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line (ie the hatching) point towards the area on the left-hand side.
- Combined roughness and contour line.* The altitude is written on the line, and the roughness lengths on the left- and right-hand side of the line are displayed on the bottom line.
- Plot Makes a plot file of the map or photo (either a .PLT or a .HPG file). The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen Refreshes the screen. That is redraws the map. This command can be used to eg

remove displayed height/roughness values (generated by the value command) and spurious dots.

Site Every time you use this command, the point at the cross hair is added to the list of points for which the resource calculations will be done. You are prompted to enter a text label for each point, this label will appear in the resource file.

transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press *<t>* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *<Return>*. A window is now shown around the target – use arrow keys to enlarge this window and press *<Return>* to select. A 3-D rendering of the terrain is displayed after a short while.

The selected sites are shown as flags, correctly placed in the terrain. The length of the flags is initially chosen so that even the most distant flags will be visible on the screen. However, any flag length (in metres) can be chosen using the Scale option: specify the desired length as a *negative height value*, eg *-32.5* means 32.5 metre flags.

Window Zooms in on the area, that you select by using the arrows. When you have selected the area press *<Return>*.

* Zooms out to the original window.

<Esc> Leave the graphics mode. If you have not chosen the grid area while in graphics mode, you will be prompted to enter the coordinates of two grid area corner points and, subsequently, the grid resolution (all in metres).

+/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the *+* (increasing) or *-* (decreasing) keys one or several times.

Each time a point has been selected, you are prompted to enter a label characterizing that specific point, eg 'Turbine-1'. Notice, that the label must not contain any blanks (spaces).

The DISPLAY option

The current wind rose is shown. The following options are available:

number By entering any number you get the histogram of the distribution of wind speeds in the nearest sector, eg if you type 120 you get the histogram for the sector centered around 120 degrees.

Any other key By pressing any other key (except *<Esc>* and *<Return>*) you toggle between the wind rose and the histogram of the total distribution of wind speeds.

A.2 The DATA menu

RAWDATA TABLE DISPLAY
DOS HELP RETURN

- RAWDATA** Input of raw (measured) data in the form of a time-series of wind speed and direction. The input is an ASCII or binary file with one or more observations per record, and any format of the variables can be treated. Lower and upper limits for speed and direction can be specified, linear conversions can be applied, and discretization bins can be specified. The **RAWDATA** option displays a summary table when the time-series has been processed and further shows the wind rose and wind speed distribution graphically. The summary table can be written on a disk file invoking the **DUMP** option and read at a later stage with the **TABLE** option.
- TABLE** Input of general climatological data, ie a statistical table giving the frequency of occurrence of wind speed versus direction. This table may also be the output produced by **RAWDATA**.
- DISPLAY** Displays the summary table of a time-series processed with the **RAWDATA** option. The table may subsequently be stored on disk file and/or shown graphically on the screen. If a table has been loaded through **TABLE** only the graphics display is shown.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of **WASP**.

The RAWDATA option

Having entered the file name and other information about the data, the time-series is displayed as time traces of wind speed and direction on the graphics screen.

- <Return>** Pressing the **<Return>**-key toggles to the next screen of data. If the entire time-series has been read **WASP** returns to the **RAWDATA** menu.
- <Esc>** Leaving the graphics mode is done by pressing the **<Esc>**-key. **WASP** will then read the remaining part of the time-series without displaying it on the screen. The first screen of data will always be displayed unless graphics has been turned off (parameter #69 in **WASP.PAR**). Having read the entire time-series **WASP** returns to the **RAWDATA** menu.
- W** It is possible to zoom in on any part of the time-series shown on the screen by pressing **W**. The window shown can be moved with the left and right arrows, and is expanded with the up (expand to the right) and down (expand to the left) arrows, respectively. Pressing **<Return>** zooms in when the right position and size of the window has been obtained. Pressing the *****-key zooms out to the original window.
- +/-** The cursor/window step is made larger and smaller by pressing the **+** and **-** keys, respectively.
- Any other key** Pressing any other key than the ones described above toggles between the time-series plot and the scatter plot.

A.3 The RAWDATA menu

The RAWDATA menu appears when the time-series has been processed and is also accessible through the DISPLAY option in the DATA menu.

DISPLAY DUMP DOS RETURN

- DISPLAY** The distribution of the wind is shown graphically. The sector-wise frequency distribution of the wind is then shown as a wind rose and the distribution of wind speeds is represented by a histogram curve. Toggling between the two is done by pressing any key on the keyboard. The distribution of wind speeds within each sector can be shown by entering the center direction of the sector, eg 180 to display the distribution of wind speeds in the south sector. Also shown is the Weibull distribution fitted to the data. The graphics mode is left by pressing the *<Esc>*-key.
- DUMP** The histogram may be saved on disk file (default extension .TAB) by invoking the DUMP option of this screen. When a time-series has been processed, invoking the DISPLAY option of the DATA menu will display this data summary table again.
- DOS** As in the main menu.
- Return** Typing RETURN or pressing the *<Return>*-key returns to the DATA menu.

The DISPLAY option

The wind rose corresponding to the time-series or table is shown. The following commands are available:

- number* By entering any number you get the histogram of the distribution of wind speeds in the nearest sector, eg if you type 120 you get the histogram for the sector centered at 120 degrees.
- Any other key* By pressing any other key (except *<Esc>* and *<Return>*), you toggle between the sector-wise distribution and the histogram of the total distribution of wind speeds.

A.4 The OBSTACLE menu

INPUT EDIT DISPLAY MOVE CLEAR TEXT DUMP RELOAD
DOS HELP RETURN

- INPUT** Invoking the INPUT option obstacles may be entered one by one. The obstacle characteristics are typed in the same order as given in the obstacle description form. Distances, heights, and depths are in metres; angles are in degrees from N, positive clockwise, and the porosity must be greater than or equal to 0 (solid) and less than or equal to 1 (no effect).
- EDIT** The EDIT option lists the obstacles specified in the current set-up and allows for changing the characteristics of one or more obstacles. Deleting an obstacle from the list is done by entering the number of the obstacle only. Extending the list may be done in either INPUT or EDIT mode.
- DISPLAY** Having entered a list of obstacles a sketch map of these may be shown by invoking the DISPLAY option. The site and sector division corresponding to the analysis are shown on the sketch map.
- MOVE** In case there are more than one site of interest close to a given set-up of obstacles, these need only be specified and typed in once. The MOVE option recalculates the obstacle descriptions relative to a new site. First, you are prompted to enter the coordinates of the present site, and next you are prompted to enter the coordinates of the new site. The coordinates should be given in metres in a Cartesian coordinate system, the x - and y -axis of which points towards east and north, respectively. The new set-up should be checked by invoking the DISPLAY option.
- CLEAR** An obstacle list may be cleared completely by the CLEAR command. Typing -OBSTACLE in the main menu also clears the list, but in this case the same list may be reactivated by invoking the EDIT option.
- TEXT** Input of a character string identifying the obstacle list given in the display.
- DUMP** Once the obstacle list is established it may be stored on disk file using the DUMP option. A default file name extension of .OBS is assumed by WASP. The .OBS-file can also be edited directly with an ASCII editor.
- RELOAD** Obstacle list files are retrieved from disk using the RELOAD option. Enter a file name to reload a specific file, or enter an asterisk '*' to obtain a list of all .OBS files in the current directory.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of WASP.

A.5 The ROUGHNESS menu

MAPDATA SITE EDIT TEXT DUMP RELOAD
DOS HELP RETURN

- MAPDATA** Enters the MAPDATA menu for input, display and editing of a digitized map. A digitized map can be dumped to disk and existing maps may be reloaded.
- SITE** Setting the site coordinates on the map. WASP calculates the roughness rose for the site on the basis of the digitized roughness map. The site may be chosen with the cross-hair or the coordinates may be given. The **SITE** option also sets the site in the complex terrain model if height contour lines are contained in the current map file.
- EDIT** Changing the site-specific roughness description and entering user specified corrections for wind speed and direction.
- TEXT** Input of a character string identifying the roughness description given in the display.
- DUMP** The current site-specific roughness description and user-specified corrections can be stored on disk by executing the **DUMP** option.
- RELOAD** Reloading an existing site-specific roughness description from disk.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of WASP.

The **SITE** option

This option is used to choose the point in the map where you want the wind resource calculations done. The following commands are available:

- value** The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line. Notice, that the values appear only until a new command is invoked or the cross-hair is moved. The small ticks perpendicular to the line point in the direction of the left-hand side of the line (the first roughness length shown).
- Plot** Generates a plot file of the screen display – either a .PLT or a .HPG file. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen** Refreshes the screen, that is redraws the map. This command can be used to eg remove the numbers generated by the value command, or spurious dots.
- Site** The point marked by the graphics cursor is selected as the site and a roughness rose will be calculated for this site. Returning to one of the main displays, the roughness-change model can now be executed by simply updating the screen, ie pressing the *<Return>*-key.
- transform** Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired

target (center of photo) and press *(t)* for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press *(Return)*. A window is now shown around the target – use arrow keys to enlarge this window and press *(Return)* to select. A 3-D rendering of the terrain is displayed after a short while.

A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. The Plot option generates a plot file of the photo, as described above.

- Window Zooms in on part of the map, the size of which is can be changed using the arrow keys. When the window has been selected, press *(Return)* to zoom.

- * Zooms out to the original window.

- (Esc)* Leaving graphics mode is done by pressing the *(Esc)*-key. If the site was not fixed in graphics mode, WASP will inquire for the coordinates of the site. The site coordinates must be entered in metres. This way of selecting the site is generally preferred, since it allows for an accurate position to be specified.

- +/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The map coordinates of the cross-hair or window corner points are displayed on the top line. The cross-hair steps can be changed by pressing the + (larger steps) or - (smaller step) keys one or several times.

A.6 The OROGRAPHY menu

MAPDATA HILL SITE CLEAR TEXT
DOS HELP RETURN

- MAPDATA** If the input is a disk file containing a digitized map, the MAPDATA menu should be chosen.
- HILL** Alternatively, WASP may generate the digital height contours of a simple Gaussian hill. The height, location, orientation and horizontal dimensions of the hill are specified by the user. All parameters must be in metric units.
- SITE** Reloading the map from the MAPDATA menu or the HILL option only enters the digital map to WASP. The SITE option centers the model grid on a specific point, adjusts the model radius according to the domain size and initializes the model. If the map file contains roughness-change lines as well, a roughness rose will be generated by WASP for the site in question.
- CLEAR** The CLEAR option removes the map from the scenario, as indicated in the main displays. The same action can be obtained typing `-OROGRAPHY` in the main menu. However, the map is still present in the memory of the computer, and it may be reactivated by invoking the SITE option.
- TEXT** The TEXT option makes it possible to specify a text string that will appear in the main display whenever the map in question is loaded.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of WASP.

The SITE option

This option is used to choose the point on the map where you want the wind resource calculations done.

- value** Displays the altitude (in metres) of the line closest to the cross-hair. Height contour values are displayed as numbers on the line in question.
- Plot** Generates a plot file of the screen display – either a .PLT or a .HPG file. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR.
- refresh screen** Refreshes the screen, that is redraws the map. This command can be used to eg remove the numbers generated by the value command, or spurious dots.
- Site** The point marked by the graphics cursor is selected as the site and the model grid will be centered on this point. Returning to one of the main displays, the BZ-model can now be executed by simply updating the screen, ie pressing the `<Return>`-key.
- transform** Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press `<t>` for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position)

and press *Return*. A window is now shown around the target – use arrow keys to enlarge this window and press *Return* to select. A 3-D rendering of the terrain is displayed after a short while.

A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. Plot generates a plot file of the photo, as described above.

Window Zooms in on part of the map, the size of which is can be changed using the arrow keys. When the window has been selected, press *Return* to zoom.

* Zooms out to the original window.

Esc Leaving graphics mode is done by pressing the *Esc*-key. If the site was not fixed in graphics mode, WASP will inquire for the coordinates of the site. The site coordinates must be entered in metres. This way of selecting the site is generally preferred, since it allows for an accurate position to be specified.

+/- The cross-hair/window is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair/window on the map are displayed on the top line. The cross-hair steps can be changed by pressing the + (larger steps) or - (smaller step) keys one or several times.

A.7 The MAPDATA menu

INPUT EDIT DISPLAY DUMP RELOAD
DOS HELP RETURN

- INPUT** Input map contour or roughness data from digitizer/tablet. Use +INP to append digitizer input to current map.
- EDIT** Displays the digitized map of height contour lines and/or roughness change lines and provides a number of options to process/edit the map. These options are described in some detail below.
- DISPLAY** Displays the digitized map of height contour lines and/or roughness change lines. A 3-D rendering of the terrain can also be generated.
- DUMP** Dump digitized map of roughness lines, height contour lines or both to a binary disk file. An ASCII file can be obtained by entering DUMP*, and an AutoCad-compatible file by giving the file name the extension .DXF.
Entering DUM ROU or DUM ORO (or DUM* ROU or DUM* ORO) causes dumping of lines referring to either roughness lines or contour lines only.
- RELOAD** Reload an existing map – containing roughness lines, height contour lines or both – from a disk file. The map consists of strings of coordinate pairs (x, y) or (r, θ) , each string defining a line dividing areas of different roughness (or a height contour line or both).
Use +RELOAD to append map data to current map. Using REL ORO or REL ROU loads only contours or roughness lines, respectively. Parts of a map may be reloaded using optional parameters with the file name.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of WASP.

The EDIT option

Choosing the Edit option, the following commands are available:

value *Contour line.* The value of the height of the line closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.

Roughness line. The roughness lengths on the left- and right-hand side of the line closest to the cross-hair are displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line (ie the hatching) point towards the area on the left-hand side.

Combined roughness and contour line. The height is written on the line, and the roughness length on the left- and right-hand side of the line will appear on the bottom line. (Note: the values on the bottom line will disappear when you type a new command or move the cross-hair). The small lines perpendicular to the line (ie the hatching), points towards the area on the left-hand side.

- Alter value Immediately after the value command has been used, it is possible to alter the value(s) and type of the line in question. For a contour line the height can be changed, for a roughness line the left- and right-hand side roughness lengths can be changed, and for a combined roughness and contour line the two roughness lengths and the height can be changed. Furthermore, the type of the line may be changed simply by entering the appropriate number of values.
- cut line Cuts a marked line into two separate lines at the point nearest to the cross hair.
- Copy lines Makes a copy of all marked lines. Marks the copies and unmarks the originals, ie the copies can be translated, rotated etc. immediately after the Copy command.
- Delete Deletes all marked lines from the screen *and* from the internal map file (line mode), or deletes current point if in point mode, see below.
- Erase lines Erases all marked lines from the screen, and *only* from the screen. The lines can be regenerated by the command refresh, ie pressing the *<r>*-key.
- Insert Makes it possible to insert a line or point on the map (depending on the mode). Insert line by moving cross-hair to the start of the line, then press *<Return>*, then move cursor and press *<Return>* whenever you want a point on the line. Finish by pressing *<Esc>*. Insert point by moving cross-hair to desired location and press *<Return>*.
- linemode If in point mode the mode is changed to line mode.
- mark line Marks the line closest to the cross-hair. This enables the line to be cut, deleted, erased, rotated, scaled, and translated.
- Mark all Marks ALL lines, thereby enabling the lines to be cut, deleted, erased, rotated, scaled, and translated.
- origin The origin is marked by a circle and is the point with respect to which all rotation and scaling is done. A new origin is set by moving the cross-hair to the desired point and pressing *o*.
- point mode If a line is marked, this command shows all the points that define the line. This allows translation, deletion and insertion of single points in the line.
- refresh screen Refreshes the screen. That is redraws the map, marked lines are still marked. This command can be used to eg remove the display of height/roughness values (generated by the value command) and spurious dots.
- Rotate Rotates all marked lines around the origin using the up and down arrow keys. Pressing *+* increments the rotation step, and pressing *-* decrements the rotation step. The rotation angle is shown in the upper right-hand corner of the display. A given rotation angle can be preset before marking the line(s), whereafter the lines can be marked and transformed, see below.
- Scale Scales all marked lines with respect to the origin. The up-arrow brings the lines further away from the origin, and the down-arrow brings the lines closer to the origin. Pressing *+* increments the scale factor, and pressing *-* decrements the scale factor.

- Translate All marked lines and the origin (line mode) or a selected point (point mode) are translated using the arrow keys.
- transform Transforms all marked lines. The transformation is the combination of all rotations, translations and scalings specified since you started, or since the last time you selected the origin (by pressing *o*) to all marked lines.
- unmark line Unmarks the marked line closest to the cross-hair.
- Unmark all Unmarks all marked lines.
- Window Zooms in on an area selected by using the arrow keys. When you have selected the area press *<Return>* to zoom. Up to 10 different windows can be stored in a buffer and retrieved sequentially. A new window can be added to the stack by pressing the *<Ins>*-key. Windows can be viewed in sequence by pressing *<PgUp>* (next window in stack) or *<PgDn>* (previous window in stack). The stack can be viewed using *<Ctrl><PgUp>* (to show the next window in the stack) or *<Ctrl><PgDn>* (to show the previous window in the stack). Once the desired window has been selected, press *<PgUp>* to activate it.
- * Zooms out to the smallest window containing the entire map.
- X-mode When the X-mode is on, lines are not erased on the screen when they are translated, rotated, and scaled.
- \ Closes all marked lines. This can also be used when you have made a line, by using the Insert *<I>* command, and you want to be sure it is properly closed.
- ? Check lines. The question mark invokes a check routine when either contours or roughness lines have been selected (see below). With roughness lines, WASP will search the roughness map for inconsistent or conflicting roughness values and point these out.
 With height contours, WASP will show the terrain profile between the map origin (marked by a circle) and the position of the cross-hair. The cross-hair may be moved using the arrow keys and a new cross-section is shown when pressing the *<Return>*-key.
- 0/1/2 Pressing 0, 1, or 2 you may choose to view height contours only, roughness lines only, or both types of lines. The proper type of the lines displayed must be chosen before the check routine described above can be invoked. – Only visible lines are ‘active’, ie can be marked, edited etc.
- <Esc> Leave graphics mode if in line mode, otherwise leave current mode and go to previous mode.
- +/- The cross-hair is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or – (decreasing) key one or several times. Also used for changing the rotation angle step.

The DISPLAY option

Choosing the display option, the following commands are available:

- value *Contour line.* The value of the height of the line closest to the cross-hair is given by writing it on the line in the vicinity of the cross-hair.
- Roughness line.* The roughness length on the left- and right-hand side of the line closest to the cross-hair is displayed on the bottom line (Note: the values will disappear when you type a new command or move the cross-hair).
- Combined roughness and contour line.* The height is written on the line, and the roughness length on the left- and right-hand side of the line will appear on the bottom line.
- Plot Makes a plot file of the map or photo (either a .PLT or a .HPG file), see below. The file type is determined by the setting of parameter #12 in GRAPHICS.PAR. Writing the plot file may take a while, typically a minute or so.
- refresh screen Refreshes the screen. That is redraws the map. This command can be used to eg remove the display of height/roughness values (generated by the value command) and spurious dots.
- transform Makes 3-D rendering ('photo') of terrain orography. Move cross-hair to desired target (center of photo) and press <t> for transform. This point is now marked by a double cross-hair. Next, move cross-hair to desired viewpoint (camera position) and press <Return>. A window is now shown around the target – use arrow keys to enlarge this window and press <Return> to select. A 3-D rendering of the terrain is displayed after a short while.
- A new camera height (above local ground), terrain height scaling (vertical exaggeration), and photo vertical scaling can be selected using Scale. The Plot option generates a plot file of the photo, as described above.
- Window Zooms in on the area, that you select using the arrows. When you have selected the area press <Return>.
- * Zooms out to the original window.
- <Esc> Leave graphics mode.
- +/- The cross-hair is moved on the screen by using the arrow keys on the keyboard. The coordinates of the cross-hair on the map are displayed on the top line. The speed of the cross-hair can be changed by pressing the + (increasing) or - (decreasing) key one or several times.

A.8 The ATLAS menu

GENERATE DUMP RELOAD
DOS HELP RETURN

- GENERATE** Calculation of wind atlas data. The meteorological input is a table giving the frequency of occurrence of wind speed versus direction. The table is read from disk with the **TABLE** option or is present through execution of the **RAWDATA** option. The atlas is calculated on the basis of the current set-up (site description). This calculation, which links the meteorological data with the site description, *must* be done for table or raw data to have any effect on the results (the estimated wind climate and power production etc).
- DUMP** Saving the current wind atlas data set on disk file.
- RELOAD** Retrieving a wind atlas data set. This may stem from the Danish Wind Atlas, the European Wind Atlas or may be supplied by the user. The results of a previous **WASP** session can thus be stored as wind atlas data. The Danish Wind Atlas is supplied with **WASP** as **DENMARK.LIB** (in 8 sectors!), the wind atlas data of the European Wind Atlas are available on diskette from Risø National Laboratory.
- DOS** As in the main menu.
- HELP** As in the main menu.
- RETURN** Returning to the main display of **WASP**.

B WASP parameters

B.1 General parameters

WASP is initialized with the parameters and constants of the parameter file `WASP.PAR`. This offers the possibility of determining some of the specific conditions under which the program is running as well as how the results are displayed.

- P_1 Number of wind direction sectors for calculations and display. Default and maximum is 12 sectors.
- P_2 Width of coastal zone. During onshore winds this is the zone where the transition in thermal stability from over-sea to over-land conditions takes place. Default is 10 000 m.
- P_3 The height above ground where differences between stable and unstable profiles are smallest, usually identified as the height where the daily variation of wind speed changes from max during daytime to night-time maxima (for $z \geq P_3$). Default is 100 m. This parameter is not used if $P_{54} > 0$ (default).
- P_4 The rms-value of stability-induced relative amplitude of wind speed near the ground, usually close to the rms-value of the daily course of the wind speed near ground (at 10 m say). Default is 0.12. This parameter is not used if $P_{54} > 0$ (default).
- P_5 The relative increase of the wind speed at $z = P_3$ due to stability effects – relative to a logarithmic profile. Default is 0.11. This parameter is not used if $P_{54} > 0$ (default).
- P_6 Height of inversion in BZ model. Default is 1000 m. See note 1.
- P_7 Softness of inversion in BZ model. Can assume values between 0 and 1. Default is 1.0. See note 1.
- P_8 The von Kármán constant. Default is 0.40. See note 2.
- P_9 Constant in simplified drag law. Default is 0.485. See note 2.
- P_{10} A-parameter in geostrophic drag law for neutral conditions. Default is 1.80. See note 2.
- P_{11} B-parameter in geostrophic drag law for neutral conditions. Default is 4.50. See note 2.
- P_{12} Number of standard heights for wind atlas files. Default and maximum is 5. The standard heights are given as parameters 13 through 17.
- P_{13} Standard height #1. Default is 10 m a.g.l. A lower value is recommended if you wish to predict wind conditions at heights lower than 10 m.
- P_{14} Standard height #2. Default is 25 m a.g.l.
- P_{15} Standard height #3. Default is 50 m a.g.l.

- P_{16} Standard height #4. Default is 100 m a.g.l.
- P_{17} Standard height #5. Default is 200 m a.g.l.
- P_{18} Number of standard roughness lengths for wind atlas files. Default is 4 and maximum is 5. The standard roughnesses are given as parameters 19 through 23.
- P_{19} Standard roughness length #1. Default is 0.00 m.
- P_{20} Standard roughness length #2. Default is 0.03 m.
- P_{21} Standard roughness length #3. Default is 0.10 m.
- P_{22} Standard roughness length #4. Default is 0.40 m.
- P_{23} Standard roughness length #5. Default is 1.00 m and 'not used', see P_{18} .
- P_{24} LP-filter length in BZ model (0 for off). Default is 0.0. See note 3.
- P_{25} Wait time in seconds between each keyboard input. Default is 0 seconds (standard mode). Should only be set $\neq 0$ (say, 3 seconds) for demonstration purposes.
- P_{26} Factor in inner-layer equation in BZ model. Default is 0.27. See note 4.
- P_{27} Factor in outer-layer equation in BZ model. Default is 0.30. See note 4.
- P_{28} z_c . Upwind wind speed in BZ model is constant above z_c . Default is 1000 m.
- P_{29} Factor in outer roughness area/outer layer in BZ model. Default is 5.0. See note 4.
- P_{30} Power in inner-layer power law. Default is 0.67. See note 4.
- P_{31} Decay length for roughness area size. Default is 10 000 m.
- P_{32} If > 0 suspend execution if error or problem.
- P_{33} Drag-law stability offset factor. Default is 1.06. This parameter is not used if $P_{54} > 0$ (default).
- P_{34} True up-wind direction (BZ-model): 1. No: 0. Default is 1.
- P_{35} Display date as 1) DA-MO-YE or 2) MO-DA-YE. Default is 1.
- P_{36} Number of direction sectors in analysis of raw data. Maximum is 36, default is 12.
- P_{37} Wind speed bin width in analysis of raw data. Default is 1.0 m/s.
- P_{38} Enable (1) or disable (0) dump options to overwrite existing files. Default is 1 (enable overwrite).
- P_{39} Factor for internal boundary layer (IBL) depth in roughness change relation. Default is 0.9. See note 5.
- P_{40} Factor for upper kink in roughness change profile. Default is 0.3. See note 5.

- P_{41} Factor for lower kink in roughness change profile. Default is 0.09. See note 5.
- P_{42} Azimuthal resolution in BZ model. May be set to 1, 2, 3, 4, 5, 6, 9, 10, 12 or 15 degrees. Default is 5 degrees.
- P_{43} Display 1) sector-wise distribution of total energy, 2) WECS energy production if available, else total energy, or 0) do not display this column at all. Default is 2.
- P_{44} Lower limit of absolute value of latitude in surface Rossby number. Default is 10.0. See note 2.
- P_{45} Shelter model: limit for upwind separation slope. Default is 0.5.
- P_{46} Shelter model: limit for downwind separation slope. Default is 0.2.
- P_{47} Shelter model: lateral spreading angle of momentum deficit. Default is 12.0 degrees.
- P_{48} Screen video attribute of `working` text. Default is 231 (blinking video).
- P_{49} Screen video attribute. Default is 7 (normal video).
- P_{50} Window video attribute. Default is 112 (inverse video). Typical values of the video mode are: 7 (normal), 15 (bright), and 112 (inverse).
- P_{51} Depth of dy-variation over water. Default is 50. This parameter is not used if $P_{56} > 0$ (default).
- P_{52} Relative amplitude of dy-variation near surface. Default is 0.0. This parameter is not used if $P_{56} > 0$ (default).
- P_{53} Average offset over water from neutral at $z = P_{51}$. Default is 0.0. This parameter is not used if $P_{56} > 0$ (default).
- P_{54} Factor in height of minimum stability induced variance. Default is $2.0E - 3$. See note 6.
- P_{55} Factor in heat flux induced perturbation of u_* . Default is 1.65. See note 6.
- P_{56} Rms heat flux over land. Default is $100 \text{ [W m}^{-2}\text{]}$. See note 6.
- P_{57} Rms heat flux over water. Default is $30 \text{ [W m}^{-2}\text{]}$. See note 6.
- P_{58} Offset heat flux over land. Default is $-40 \text{ [W m}^{-2}\text{]}$. See note 6.
- P_{59} Offset heat flux over water. Default is $15 \text{ [W m}^{-2}\text{]}$. See note 6.
- P_{60} Factor on geostrophic height for stab envelope limiting. Default is 0.5. See note 6.
- P_{61} Form factor in heat flux distribution over land. Default is 0.6. See note 6.
- P_{62} Form factor in heat flux distribution over water. Default is 0.6. See note 6.

- P_{63} Switch for format of dump files: -1, 0, 1, 2, or 3. Default is 1. Set to 1 if dump file is used as input to the *PARK* program.
- P_{64} Minimum geostrophic wind in stability calculation. Default is 16 m s^{-1} .
- P_{65} Number of sub-sectors per sector in roughness map analysis. Default is 6.
- P_{66} Smallest allowed distance to first roughness change. Default is 50 m.
- P_{67} Maximum number of roughness changes per sector. Maximum is 10, default is 7.
- P_{68} Maximum rms-error in log(roughness) analysis. Default is 0.3.
- P_{69} Graphics on (1) or off (0). Default is 1.
- P_{70} Not used.
- P_{71} Number of scans/frame in time-series plot. Default is 4000, maximum is 8000.
- P_{72} Plot range for speed (integer part) and fractional divisions (fractional part). Default is 25.2, corresponding to a range of $0\text{--}25 \text{ m s}^{-1}$ and divisions every 5 m s^{-1} (0.2×25.0).
- P_{73} Plot range for direction (integer part) and fractional divisions (fractional part). Default is 360.083333, corresponding to a range of $0\text{--}360^\circ$ and divisions every 30° .
- P_{74} Plot mode: 1 for speed and direction, 2 for polar plot. Default is 1.

Note 1 BZ is a model based on neutral stratification. The purpose of including an inversion height z_i (P_6) and a strength parameter (P_7) is to enable an (admittedly extremely simple) modelling of the climatological effect of the stably stratified atmosphere above the boundary layer. Horizontal scales larger than z_i are “squeezed” to make the calculated velocity perturbations more horizontal and attenuate vertical motion. The softness parameter (P_7) governs the strength of this effect from maximum squeezing ($P_7 = 0$) to minimum ($P_7 = 1$) where the inversion has no effect at all.

Note 2 Initially, WASP uses a simplified drag law to calculate u_* from G , viz

$$u_* = G P_9 \left(\ln \frac{G}{|f|z_0} - A \right)^{-1} \quad (\text{B.16})$$

In the subsequent iteration the following classical expression is used

$$G = \frac{u_*}{k} \sqrt{\left(\ln \frac{u_*}{|f|z_0} - A \right)^2 + B^2} \quad (\text{B.17})$$

where u_* is the surface friction velocity, G the geostrophic wind speed, f the Coriolis parameter ($= 2\Omega \sin \phi$, where ϕ is the latitude and $|\phi| \geq P_{44}$), z_0 the surface roughness length, k the von Kármán constant and A and B are the parameters P_{10} and P_{11} , respectively.

Note 3 This parameter makes it possible to reduce the horizontal resolution of the BZ model in cases where this is too high compared to the accuracy of the digitized map. This can reduce spurious large variations in response across contour lines.

Note 4 Parameters 26–30 and 34 are geometrical factors determining the shape of the vertical perturbation profile calculated by the BZ model. The inner-layer depth ℓ is calculated from

$$\frac{\ell}{z_0} = P_{26} \left(\frac{L}{z_0} \right)^{P_{30}} \quad (\text{B.18})$$

where z_0 is the surface roughness length averaged upwind over a length of $P_{29} \times L$. L is the vertical decay length of the outer-layer perturbation. A relevant velocity scale is evaluated at $z = P_{27} \times L$.

Note 5 The height of the internal boundary layer, developing downstream of an abrupt change in surface roughness, is calculated from

$$\frac{h}{z_0} \left(\ln \frac{h}{z_0} - 1 \right) = P_{39} \frac{x}{z_0} \quad (\text{B.19})$$

where $z_0 = \max(z_{01}, z_{02})$. The perturbed profile is assumed to be logarithmic with roughness length z_{01} up to $z = P_{41} \times h$ and logarithmic with z_{02} above $z = P_{40} \times h$. Between these two heights the profile is assumed linear in $\ln z$.

Note 6 The background for these parameters is explained in detail in Chapter 8 of the European Wind Atlas (Troen and Petersen, 1989).

B.2 Graphics parameters

The graphics screen type and display characteristics are specified by the parameters in the file GRAPHICS.PAR:

- P_1 Screen driver. Default is HALOIBMV.DEV for IBM Enhanced Graphics (VGA). A list of graphics drivers shipped with WASP is given below.
- P_2 Mode. Default is 7, corresponding to a resolution of 640×480 in 16 colors.
- P_3 Foreground color. Default is 1 (blue).
- P_4 Line color. Default is 7 (white).
- P_5 Marking color. Default is 13 (red).
- P_6 Line width in pixels. Default is 1 pixel.
- P_7 Marked line width in pixels. Default is 1 pixel. Use 3 for monochrome displays without grey-scale capability.
- P_8 Cursor color. Default is 4 (red).
- P_9 Text background. Default is 1 (blue).
- P_{10} Text color. Default is 7 (white).
- P_{11} Maximum fraction of screen used for menu. Default is 0.25.
- P_{12} Plot file extension: PLT for SURFER/GRAPHER file or HPG for HP-GL file. Default is HPG.
- P_{13} Plotter steps in x -direction. Default is 11040.
- P_{14} Plotter steps in y -direction. Default is 7721.
- P_{15} Plotter scale factor. Default is 0.001.
- P_{16} Digitizer driver: 0 for none, 1 for HALO driver, 2 for HALO-compatible driver and 3 for the internal WASP ASCII driver (see Section B.4). Default is 0.
- P_{17} Interrupt number if $P_{16} = 1$. May take values between 1 and 8 (1 illegal on IBM-AT). Default is 8.
- P_{18} Printer enabled (1) or disabled (0). Default is 0 (printer disabled).

Graphics adapters supported

| 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 monochrome) | 640 × 400 | HALOINDA.DEV | 6 |

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 screen video modes (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 below.

Special considerations

Hercules Graphics Card The Hercules monochrome graphics adapter must be initialized to *full page graphics mode* by typing HGC FULL at the DOS prompt before running WAP.

Monochrome displays The default values in GRAPHICS.PAR are not suitable for monochrome monitors. As an example, consider the LCD-display of a laptop computer with an IBM Color Graphics card (CGA). In this case the parameters in GRAPHICS.PAR could take the following values:

```
HALOIBMG.DEV % 1. Screen driver
1             % 2. Mode
0             % 3. Foreground color
15           % 4. Line color
15           % 5. Marking color
1            % 6. Line width
3            % 7. Marked line width
15           % 8. Cursor color
0            % 9. Text background
15           % 10. Text color
0.25         % 11. Max fraction of screen for menu
HPG          % 12. Plot file: PLT or HPG
11040        % 13. Plotter steps in x-direction
7721         % 14. Plotter steps in y-direction
0.001        % 15. Plotter scale factor
0            % 16. Digitizer: 0=none, 3=internal
8            % 17. Interrupt number if digitizer=1
0            % 18. Printer enabled (1) or disabled (0)
```

B.3 Printer parameters

It is possible to make a screen-dump of eg the orographic map or the resulting Weibull distribution 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. This file further contains the following parameters or printer attributes:

Printer driver. Default is HALOLJTP.PRN. The list of printer drivers shipped with WASP is given below.

- P_0 Printer attribute 0. Width of output in dots. $P_0 > 0$ specifies the printer width. Default is -75 (normal).
- P_1 Printer attribute 1. Height of output in dots. $P_1 > 0$ specifies the printer height. Default is -1 (normal).
- P_2 Printer attribute 2. Image orientation: 0 for normal and 1 for landscape. Default is -1 (normal).
- P_3 Printer attribute 3. Black/White reversal: 0 for black/white reversal and 1 for no black/white reversal. Default is 1 (no B/W reversal).
- P_4 Printer attribute 4. Dither flag: 0 for dithering and 1 for no dithering. Default is -1 (perform dithering).
- P_5 Printer attribute 5. Form feed flag. 0: perform form feed after image; 1: do not perform form feed. Default is -1 (perform form feed).
- P_6 Printer attribute 6. BIOS/DOS flag. 0: Print through BIOS; 1: print through DOS. Default is -1 (print through BIOS).
- P_7 Printer attribute 7. Dots per inch. Default is 3, corresponding to 300 dpi.
- P_8 Printer attribute 8. Number of copies: 0 for one copy; $P_8 > 0$ for P_8 copies. Default is -1 (one copy).
- P_9 Printer attribute 9. Centering. 0 perform centering; 1 do not perform centering. Default is -1 (perform centering).
- P_{10} Printer attribute 10. x -offset in dots. 0: no offset or specify dots in x -offset. Default is -1 (no offset).
- P_{11} Printer attribute 11. y -offset in dots. 0: no offset or specify dots in y -offset. Default is -1 (no offset).
- P_{12} Printer attribute 12. Printer ID. Default is -1 (not supported).
- P_{13} Printer attribute 13. COM port. Default is -1 (not supported).
- P_{14} Printer attribute 14. Process ID for EMS. Default is -1 (not supported).
- P_{15} Printer attribute 15. Bold printing. Default is -1 (not supported).

P_{16} Printer attribute 16. Parallel port. 0 for LPT1, 1 for LPT2 and 2 for LPT3. Default is -1 (LPT1).

Printers supported

| 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+ | HAL00290.PRN |
| Okidata Microline 392C, 393C & 394C | HAL00390.PRN |

Special considerations

HALOCNA2.PRN Dots per inch is not supported and P_7 must be set to -1.

HALOEPSN.PRN Dots per inch may be 0 for 120H × 72V (normal) or 1 for 120H × 72V (wide). Number of copies and y -offset are not supported and must be set equal to -1. Printer ID may take the following values: 0 for Epson, 1 for Okidata, 2 for Gemini and 3 for IBM ProPrinter.

HALOLJTP.PRN Dots per inch may be 0 for 75H × 75V, 1 for 100H × 100V, 2 for 150H × 150V and 3 for 300H × 300V.

HALOPJET.PRN Dots per inch may be 0 for 90H × 90V or 1 for 180H × 180V. Number of copies and y -offset are not supported and must be set equal to -1.

HALOTJET.PRN Dots per inch is not supported and P_7 must be set to -1. Number of copies and y -offset are not supported and must be set equal to -1.

HALOKLSR.PRN Dots per inch may be 0 for 75H × 75V, 1 for 100H × 100V, 2 for 150H × 150V and 3 for 300H × 300V.

HALOFUSU.PRN Dots per inch may be 0 for 60H × 180V, 2 for 90H × 180V, 4 for 120H × 180V and 6 for 180H × 180V. The corresponding resolutions in wide format are 1, 3, 5, and 7, respectively. Number of copies and y -offset are not supported and must be set equal to -1.

HALOOKIP.PRN Dots per inch may be 0 for 60H × 60V, 2 for 72H × 72V, 4 for 120H × 120V and 6 for 144H × 144V. The corresponding resolutions in wide format are 1, 3, 5, and 7, respectively. Number of copies and y -offset are not supported and must be set equal to -1.

HAL00290.PRN As HALOOKIP.PRN.

HAL00390.PRN Dots per inch may be 0 for 60H × 180V, 2 for 90H × 180V, 4 for 120H × 180V and 6 for 180H × 180V. The corresponding resolutions in wide format are 1, 3, 5, and 7, respectively. y -offset is not supported and must be set equal to -1.

B.4 Digitizer parameters

The parameter file DIGIT.PAR is used only when the internal WASP digitizer driver has been chosen, ie when P_{16} has been set equal to 3 in the file GRAPHICS.PAR. The default configuration given below is valid for a CalComp DrawingBoard emulating 2000 ASCII, but any digitizer can be emulated provided it can send a fixed format ASCII string. For the CalComp DrawingBoard the format of the ASCII output string – also called the report string – is as follows:

XXXX,YYYY,C<CR><LF>

The report string consists of 11 characters (XXXX,YYYY,C) and two terminator characters (<CR>: *carriage return* and <LF>: *line feed*). Notice, that the DrawingBoard must first be set to provide ASCII output and the mode on the digitizer must be set to RUN.

The parameter file contains the following 16 parameters:

- P_1 Serial communications port on the PC: 1 or 2. Default is 1.
- P_2 Number of characters in report string (excluding terminators). Default is 11.
- P_3 Number of terminator characters in report string. Default is 2.
- P_4 Baud rate: -1, 2 (300 baud), 4 (1200 baud), 5 (2400 baud), 6 (4800 baud) or 7 (9600 baud). Default is 7, corresponding to 9600 baud.
- P_5 Parity: -1, 0 (no), 1 (odd), 2 (even). Default is 2.
- P_6 Data bits: -1, 0 (5 bits), 1 (6 bits), 2 (7 bits) or 3 (8 bits). Default is 2.
- P_7 Stop bits: -1, 0 (1 stop bit) or 1 (2 stop bits). Default is 0.
- P_8 x -value start location in report string. Default is 1.
- P_9 x -value end location in report string. Default is 4.
- P_{10} y -value start location in report. Default is 6.
- P_{11} y -value end location in report. Default is 9.
- P_{12} Button-identifier start location in report string. Default is 11.
- P_{13} Button-identifier end location in report string. Default is 11.
- P_{14} Character string reported for active button. Default is 1.
- P_{15} Character string reported for released buttons. Default is 0.
- P_{16} Decimal value of first terminator character. Default is 13, corresponding to (<carriage return>).

As another example, consider the SummaGraphics MicroGrid II. The format of the ASCII output string in this case is:

```
+XXXXX,+YYYYY,FF,T<CR><LF>
```

This report string consists of 18 characters: (+XXXXX,+YYYYY,FF,T) and two terminator characters. The DIGIT.PAR file corresponding to this report string should look like:

```
1 % Com port (1 or 2)
18 % Number of characters in report string (excl.terminators)
2 % Number of terminator characters
7 % Baud rate -1 or (2=300,4=1200,5=2400,6=4800,7=9600)
2 % Parity -1 or (0=no,1=odd,2=even)
2 % Databits -1 or (0=5,1=6,2=7,3=8)
0 % Stopbits -1 or (0=1,1=2)
1 % x value start location in report
6 % x value end location in report
8 % y value start location in report
13 % y value end location in report
16 % button identifier start location in report
16 % button identifier end location in report
1 % character string reported for active button
0 % character string reported for released buttons
13 % decimal value of first terminator character
```

HALO digitizer driver

If parameter #16 in GRAPHICS.PAR is set equal to 1 the HALO digitizer driver is invoked and the DIGIT.PAR file becomes inactive. In this case the communication with the digitizer is faster because of the binary format. The following digitizer pads are supported by the inclusion of HALO drivers on the WASP diskette:

| 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 |

The proper Halo driver is installed by typing its name and any optional parameters at the DOS prompt, before invoking WASP, eg:

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

In this case the driver corresponding to the Summagraphics MM1201 format is installed with a CalComp DrawingBoard tablet, see HALOMM.BAT. The optional parameters are described briefly below. – How to chose the binary output format corresponding to the drivers above should be explained in the digitizer manual.

-Xn and -Yn Maximum *x*- and *y*-ranges, ie the range of coordinates that the locator is capable of supplying to WASP. Digitizers may come in different sizes but all use the same driver, so these parameters would be useful for adjusting the size for these digitizers.

- Pn and -Bn Communications port number (-P) and configuration (-B). Digitizers that communicate with the computer by means of the serial port use these parameters to configure the port.
- In Interrupt number – this should correspond to parameter #17 in GRAPHICS.PAR. May take values between 1 and 8 (1 illegal on IBM-AT).
- Ln, -Mn and -Rn Left, middle and right button masks. These parameters are used to define which keys, buttons, etc. can be detected while the locator is in use. Set $n = -1$ for all three buttons, or use the values given below, see HALOMM.BAT.

The default values of the parameters for the different drivers are:

| Driver file name | -X | -Y | -P | -B | -I | -L | -M | -R |
|------------------|-------|-------|----|-----|----|----|----|----|
| HALOBPOI.COM | 2048 | 2048 | 1 | 234 | 1 | -1 | -1 | -1 |
| HALOGTCI.COM | 10000 | 10000 | 1 | 227 | 1 | -1 | -1 | -1 |
| HALOHIPI.COM | 10000 | 10000 | 1 | 218 | 1 | 4 | 8 | -1 |
| HALOKBDI.COM | 720 | 720 | - | - | 1 | 4 | 2 | 1 |
| HALOSDTI.COM | 5850 | 5850 | 1 | 235 | 1 | 1 | 2 | -1 |

The communications port parameter value (-Bn) can be determined using the following formula:

$$n = \langle \text{baud rate} \rangle \times 32 + \langle \text{parity} \rangle \times 8 + \langle \text{stop bits} \rangle \times 4 + \langle \text{data bits} \rangle$$

where $\langle \text{baud rate} \rangle$, $\langle \text{parity} \rangle$, $\langle \text{stop bits} \rangle$ and $\langle \text{data bits} \rangle$ take the following values according to their setting:

| Value | $\langle \text{baud rate} \rangle$ | $\langle \text{parity} \rangle$ | $\langle \text{stop bits} \rangle$ | $\langle \text{data bits} \rangle$ |
|-------|------------------------------------|---------------------------------|------------------------------------|------------------------------------|
| 0 | 110 | no | 1 | - |
| 1 | 150 | odd | 2 | - |
| 2 | 300 | even | - | 7 |
| 3 | 600 | - | - | 8 |
| 4 | 1200 | - | - | - |
| 5 | 2400 | - | - | - |
| 6 | 4800 | - | - | - |
| 7 | 9600 | - | - | - |

Hence, in the example above, the communications port parameter value was calculated as follows:

$$n = 7 \times 32 + 1 \times 8 + 0 \times 4 + 3 = 235$$

The output from the digitizer can be checked by the utility program RHALO.EXE, eg:

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

C The files of WASP

WASP uses several different categories of disk files that the user should also be familiar with, since this will save a lot of typing in of data. The files are used to store information that is required by WASP during execution. Some of the files can be generated by dumping the information typed in during a session, while others must be prepared beforehand. To avoid confusion and enhance systematics WASP assumes a default file extension with each of the nine file types:

| File type | Extension |
|-------------------------------------|-----------|
| Time-series data | .DAT |
| Histogram data | .TAB |
| Site-specific roughness description | .RDS |
| Digital terrain map | .MAP |
| Obstacle list | .OBS |
| Wind atlas data | .LIB |
| Wind turbine power curve | .POW |
| Wind resource file | .RSF |
| Dump files | .DMP |

However, the user may specify the name completely and thereby override the default choice (file names without an extension must be ended by a punctuation mark). A short description of these files is given below, with reference to the Section in the manual where they are introduced.

Caution! Note that these files are *not* stored automatically. You must explicitly invoke the relevant DUMP options to store the .TAB, .RDS, .OBS, .LIB and, possibly, .MAP files. Leaving WASP without saving the results means that you will have to type the information or run the models again.

Sample files The WASP diskette contains examples of each of the files mentioned above, as well as a list (WASP.TOC) of all the files distributed on the diskette.

Temporary file WASP occasionally uses the file WASPWORK.TMP for temporary storage of data during execution. This file is deleted after use.

C.1 Time-series data

Meteorological time-series data are stored in ASCII or binary files with the default extension .DAT. This type of file must be prepared before running WASP. The format of the file is not fixed and almost any format can be processed. An example of a binary data file is provided on the WASP diskette as WASPDALE.BIN. The corresponding ASCII file, WASPDALE.DAT, is also provided. The processing of time-series data files are described in Section 6.1 on page 48.

C.2 Histogram data

Histogram or table data are stored in ASCII files with the default extension .TAB. This type of file may be prepared beforehand from an existing climatological table or may be generated by processing a time-series. See Section 6.2 on page 57.

| Line | Contents |
|------|---|
| 1 | Character string identifying the histogram |
| 2 | Latitude, Longitude and height a.g.l. of anemometer |
| 3 | Number of sectors, scaling factor for wind speed, offset for wind direction and optional format parameter |
| 4 | Sector-wise frequencies of occurrence [%] |
| 5 | Upper limit for speed class 1, sector-wise frequencies of class 1 |
| 6 | Upper limit for speed class 2, sector-wise frequencies of class 2 |
| 7-n | As line 5 and 6, but for speed class 3 to n |

Table 6. Contents of a histogram file, cf. WAsPDALE.TAB on the WAsP diskette. The frequencies in line 5-n are given in [per mille].

C.3 Site-specific roughness description

The site-specific roughness description, containing the roughness rose and user-specified correction factors, is stored in an ASCII file. This type of file is typically generated by dumping the site description entered during a WAsP session, but can also be prepared beforehand using an ASCII text editor. See Chapter 3 on page 27.

| Line | Contents |
|------|--|
| 1 | Character string identifying the site description |
| 2 | Height of WAsP calculations [m] |
| 3 | User-specified correction factors for wind speed |
| 4 | User-specified correction angles for direction [deg] |
| 5 | Number of roughness changes in each sector |
| 6 | Roughness lengths [m] in sectors 1-6 |
| 7 | Roughness lengths [m] in sectors 7-12 |
| 8 | Distances [m] to first roughness change, sector 1-6 |
| 9 | Distances [m] to first roughness change, sector 7-12 |
| | Roughness lengths and distances written in a similar way as in line 6-9 are repeated as many times as the maximum number of roughness changes specified. |

Table 7. Contents of a site-specific roughness description file, cf. AIRPORT.RDS on the WAsP diskette.

C.4 Terrain maps

Terrain maps, containing digitized height contour lines and/or roughness change lines, are stored in ASCII or binary files with the default extension .MAP. Map files can be prepared before invoking WASP, or may be digitized directly from WASP. See Chapter 7 on page 60.

Cartesian coordinates

The contents of a map file in Cartesian coordinates is given below. The + in column one of the first line designates "Cartesian" and is mandatory. If the coordinates provided are metric and absolute (like UTM), line 2-3 may be replaced by one line containing non-numeric input. Line 5 (and similar records) may take either of the three forms shown according to their meaning.

| Line | Contents |
|------|---|
| 1 | Character string identifying the file: + ... |
| 2 | Fixed point # 1 in user and metric [m] coordinates: $X_1^{\text{user}} \ Y_1^{\text{user}} \ X_1^{\text{metric}} \ Y_1^{\text{metric}}$ |
| 3 | Fixed point # 2 in user and metric [m] coordinates: $X_2^{\text{user}} \ Y_2^{\text{user}} \ X_2^{\text{metric}} \ Y_2^{\text{metric}}$ |
| 4 | Scaling factor and offset for height scale (z). $z_{\text{metric}} = \text{scaling factor} \times (z_{\text{user}} + \text{offset})$ |
| 5 | Contour line: height of line and number of points in line: $Z \ n$ (eg: 100.0 43) |
| 5 | Roughness line: roughness lengths to the left and right of the line, respectively, and number of points in line: $z_{0l} \ z_{0r} \ n$ (eg: 0.03 0.40 117) |
| 5 | Roughness and contour line: roughness lengths to the left and right of the line, respectively, height of line and number of points in line, eg: $z_{0l} \ z_{0r} \ Z \ n$ (eg: 0.0 0.05 0 221) |
| 6- | $X_1 \ Y_1 \ [\dots \ X_n \ Y_n]$ $X_{n+1} \ Y_{n+1}$: where [] embrace optional parameters and $n \geq 1$. |
| | The pattern from line 5 and onward is repeated as many times as there are contour/roughness lines in the map. |

Table 8. Contents of a map file in Cartesian coordinates, cf. WASPDALE.MAP on the WASP diskette.

Polar coordinates

The contents of a map file in polar coordinates is given below. The * in column one of the first line designates "polar" and is mandatory. Line 5 (and similar records) may take either of the three forms shown according to their meaning.

In the third line of the map file you may specify an optional fifth parameter: the conversion from user angle units to the 360° meteorological system used by WASP. The conversion is applied in the following manner:

| Line | Contents |
|------|---|
| 1 | Character string identifying the file: * ... |
| 2 | Fixed point in user and metric [m] coordinates: $X_1^{\text{user}} \ Y_1^{\text{user}} \ X_1^{\text{metric}} \ Y_1^{\text{metric}}$ |
| 3 | Distance and angle in user and metric units: $D^{\text{user}} \ \theta^{\text{user}} \ D^{\text{metric}} \ \theta^{\text{absolute}}$ |
| 4 | Scaling factor and offset for height scale (z). $z_{\text{metric}} = \text{scaling factor} \times (z_{\text{user}} + \text{offset})$ |
| 5 | Contour line: height of line and number of points in line: $Z \ n$ (eg: 100.0 43) |
| 5 | Roughness line: roughness lengths to the left and right of the line, respectively, and number of points in line: $z_{0l} \ z_{0r} \ n$ (eg: 0.03 0.40 117) |
| 5 | Roughness and contour line: roughness lengths to the left and right of the line, respectively, height of line and number of points in line, eg: $z_{0l} \ z_{0r} \ Z \ n$ (eg: 0.0 0.05 0 221) |
| 6- | $r_1 \ \theta_1 \ [\dots \ r_n \ \theta_n]$ $r_{n+1} \ \theta_{n+1}$ \vdots where [] embrace optional parameters and $n \geq 1$. |
| | The pattern from line 5 and onward is repeated as many times as there are contour lines in the map. |

Table 9. Contents of a map file in polar coordinates. The * in column one of the first line designates "polar" and is mandatory. The angles in line 3 are both given in degrees from N.

$$\theta_{360} = (\theta^{\text{user}} + \Delta\theta) \times \langle \text{factor} \rangle$$

where $\Delta\theta = \theta^{\text{absolute}} - \theta^{\text{user}}$, ie $-\Delta\theta$ is the value in the user system of the North direction. Hence, to convert from the 400° system commonly used in surveying to a standard meteorological 360° system, the factor should be set to 0.9 ($= \frac{360}{400}$). When transforming from a standard mathematical polar coordinate system to the meteorological system the factor is -1 and $\Delta\theta = -90^\circ$.

C.5 Obstacle list

The obstacle description is stored in an ASCII file with the default extension .OBS. The information is entered from the keyboard during a WASP session and can subsequently be stored. See Chapter 5 on page 44.

| Line | Contents |
|------|--|
| 1 | Character string identifying the obstacle list |
| 2 | Characteristics of obstacle # 1: Angle and distance to first corner of obstacle, angle and distance to second corner, height of obstacle, depth of obstacle, porosity of obstacle |
| 3 | Characteristics of obstacle # 2. |
| n | Characteristics of obstacle # $n - 1$. ($n \leq 51$) |

Table 10. Contents of an obstacle list file, cf. AIRPORT.OBS on the WASP diskette.

C.6 Wind atlas data

Wind atlas data are stored in ASCII files with the default extension .LIB. The result of running the wind atlas model may be stored in the user's "library" of wind atlas data. Wind atlas data are generated by invoking the GENERATE option of the ATLAS menu and stored by the DUMP option of the same menu. See Chapter 8 on page 71.

| Line | Contents |
|-------|--|
| 1 | Character string identifying the table |
| 2 | Number of roughness classes, heights and sectors |
| 3 | The standard roughness lengths (classes): 0.00, 0.03, 0.10 and 0.40 [m] |
| 4 | The standard heights: 10, 25, 50, 100, 200 [m] a.g.l. |
| 5 | The frequencies of occurrence: roughness class 0 |
| 6 | Weibull A parameters for 10 m [ms^{-1}] |
| 7 | Weibull k parameters for 10 m |
| 8-9 | Weibull A and k parameters for 25 m |
| 10-11 | Weibull A and k parameters for 50 m |
| 12-13 | Weibull A and k parameters for 100 m |
| 14-15 | Weibull A and k parameters for 200 m |
| 16-26 | As line 5-15, but for roughness class 1 |
| 27-37 | As line 5-15, but for roughness class 2 |
| 38-48 | As line 5-15, but for roughness class 3 |

Table 11. Contents of a wind atlas file, cf. WASPDALE.LIB on the WASP diskette.

C.7 Wind turbine power curve

The wind turbine power curve data is stored in an ASCII file. Must be prepared beforehand using a text editor. See Chapter 9 on page 76.

| Line | Contents |
|------|---|
| 1 | Text identifying the WECS |
| 2 | Wind turbine hub height [m] |
| 3 | Conversion factors for wind speed f_U and power f_P : Wind speed in [m/s] = $f_U \times$ (column 1) Power production in [W] = $f_P \times$ (column 2) |
| 4- | Column 1: wind speed, Column 2: power production |

Table 12. Contents of a wind turbine power curve file, cf. WECS200.POW on the WASP diskette.

C.8 Wind resources

The wind resources in one or several points, calculated using the RESOURCEFILE option in the main menu, are stored in ASCII files with the default extension .RSF. The results for each point are stored in one file record.

| Column | Contents |
|---------|--|
| 1-10 | Character string (label) identifying the site |
| 11-20 | X-coordinate of the site [m] |
| 21-30 | Y-coordinate of the site [m] |
| 31-38 | Z-coordinate (altitude) of the site [m] |
| 39-43 | Height above ground level [m] |
| 44-48 | Weibull A-parameter for the total distribution [m/s] |
| 49-54 | Weibull k-parameter for the total distribution |
| 55-69 | Energy content – or power production if WECS loaded |
| 70-72 | Number of sectors |
| 73-76 | Frequency of occurrence: sector 1 [%] |
| 77-80 | Weibull A-parameter for sector 1 [m/s] |
| 81-85 | Weibull k-parameter for sector 1 |
| 86-98 | As 73-85, but for sector 2 |
| ⋮ | ⋮ |
| 216-228 | As 73-85, but for sector 12 |

Table 13. Contents of a wind resources file, cf. WASPDALE.RSF on the WASP diskette. Notice, that the numbers refer to the column of the file.

C.9 Dump file formats

The formats of the different dump files were described in detail in Chapter 10.

D Sample forms

The following four pages contain sample forms that may be useful when describing a site. These are:

1. Site Description Form
2. Obstacle Description Form
3. Roughness Classification Form: 12 sectors
4. Roughness Classification Form: 8 sectors

The very last page of this manual is a Software Report Form. Use this form to report software bugs, documentation errors, or suggested enhancements to WASP. The form should be mailed to Risø National Laboratory:

Meteorology and Wind Energy Department
Risø National Laboratory
P.O. Box 49
DK-4000 Roskilde
Denmark

Phone (+45) 42 37 12 12
Telex 43 116
Telefax (+45) 46 75 56 19
e-mail: gylling@risoe.dk
Omnet: risoe.meteo

Site characteristics:

Name: _____

Map reference: _____ Altitude: _____

Latitude: _____ Longitude: _____

Data characteristics:

Anemometer height: _____ Period: _____

Instrumentation: _____

Averaging period: _____ Sampling period: _____

Site coordinates in digitized map:

X: _____ Y: _____ Z: _____

Further information:

Station: _____ Date: _____

| # | α_1 | R_1 | α_2 | R_2 | h | d | Porosity |
|---|------------|-------|------------|-------|-----|-----|----------|
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α is given in degrees from north and R , h and d in metres.

Further information:

Station: _____ Date: _____

| Sector | z_{01} | X_1 | z_{02} | X_2 | z_{03} | Remarks |
|--------|----------|-------|----------|-------|----------|---------|
| 1 | 0 | | | | | |
| 2 | 30 | | | | | |
| 3 | 60 | | | | | |
| 4 | 90 | | | | | |
| 5 | 120 | | | | | |
| 6 | 150 | | | | | |
| 7 | 180 | | | | | |
| 8 | 210 | | | | | |
| 9 | 240 | | | | | |
| 10 | 270 | | | | | |
| 11 | 300 | | | | | |
| 12 | 330 | | | | | |

 z_0 and X are given in metres.

Further information:

Station: _____ Date: _____

| Sector | z_0 | X_1 | z_0 | X_2 | z_0 | Remarks |
|--------|-------|-------|-------|-------|-------|---------|
| 1 | 0 | | | | | |
| 2 | 45 | | | | | |
| 3 | 90 | | | | | |
| 4 | 135 | | | | | |
| 5 | 180 | | | | | |
| 6 | 225 | | | | | |
| 7 | 270 | | | | | |
| 8 | 315 | | | | | |

 z_0 and X are given in metres.

Further information:

WASP

Software Report Form

Name: _____

Street: _____

City: _____ Zip code: _____

State/country: _____

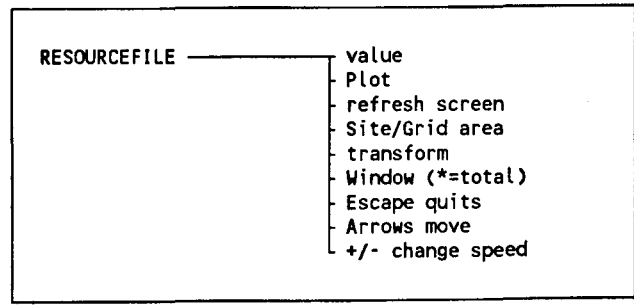
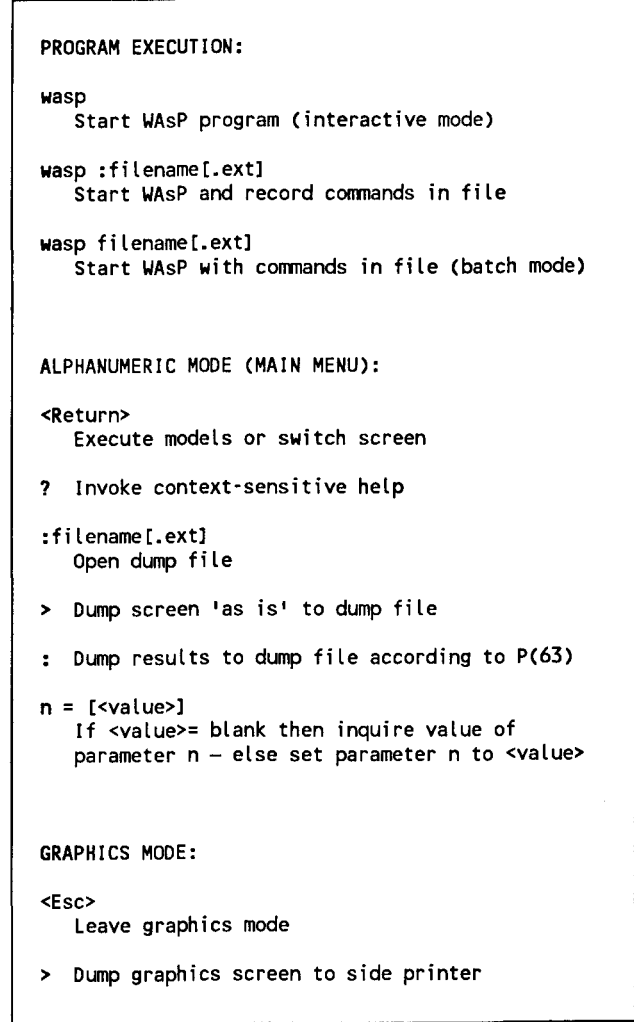
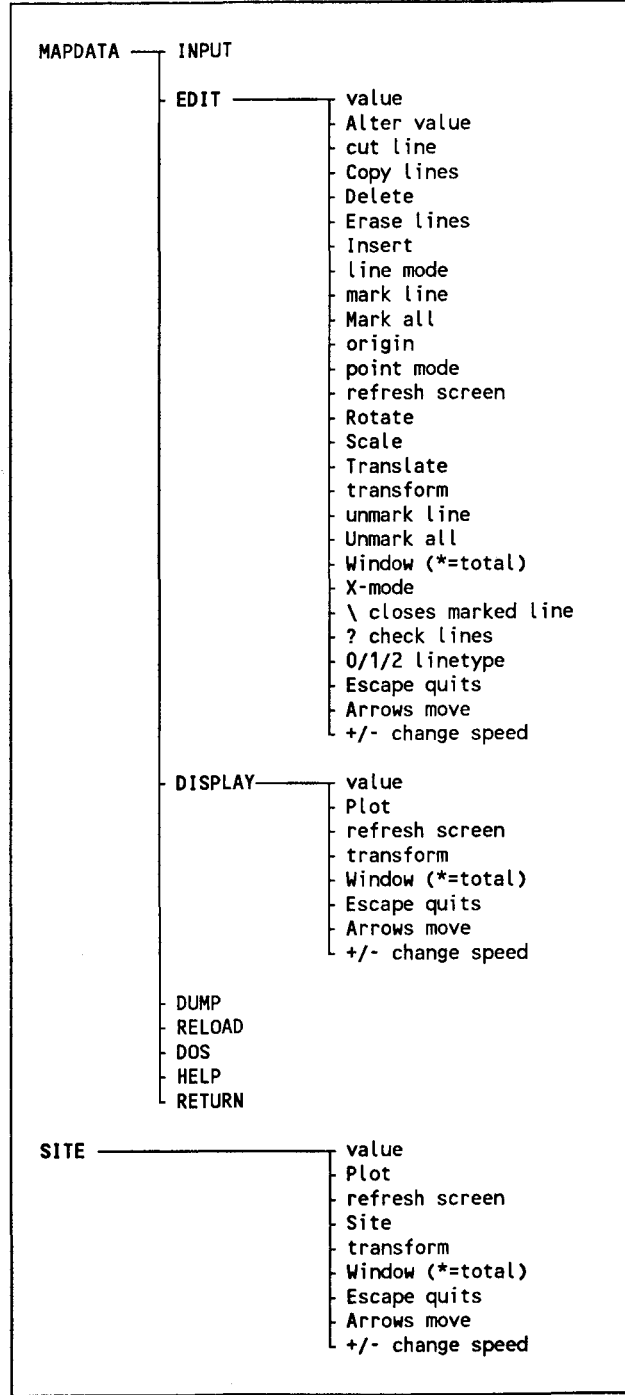
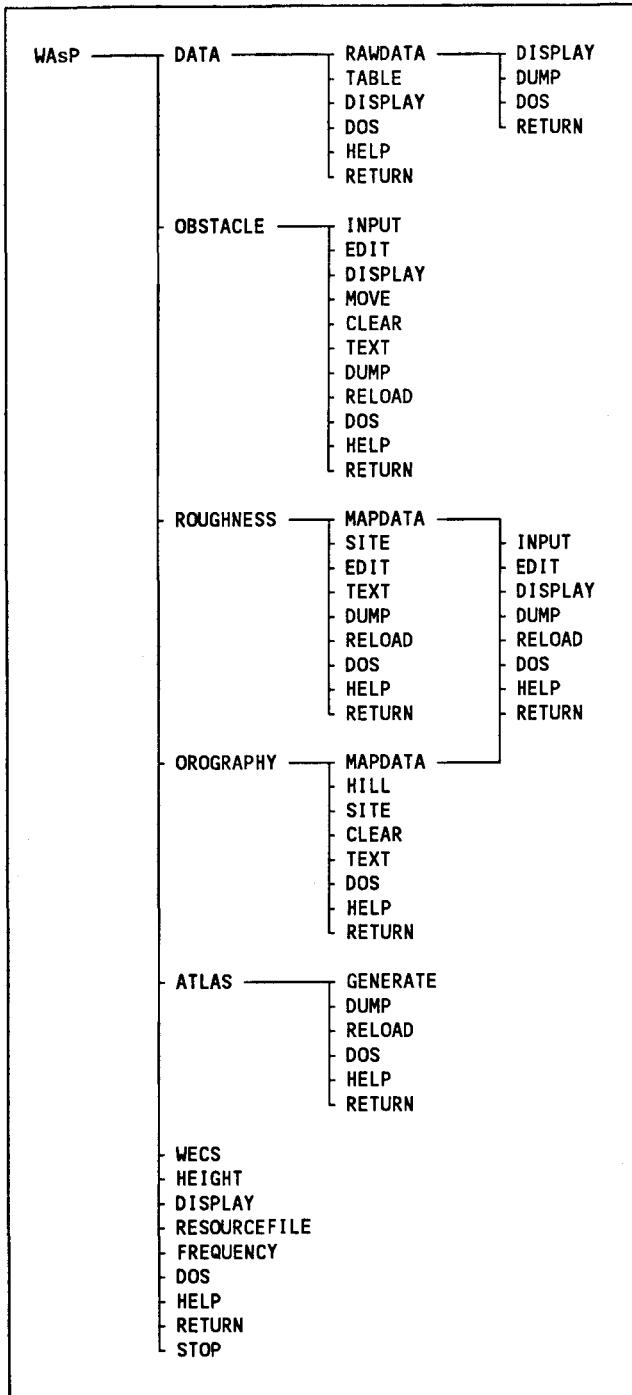
WASP serial #: _____ Version: _____

Computer make/model: _____

DOS version: _____

Description of error condition:

Suggestions for WASP updates:



Bibliographic Data Sheet**Risø-I-666(EN)(v.2)**

Title and author(s)

Wind Atlas Analysis and Application Program (WASP).
Vol. 2: User's Guide

Niels G. Mortensen, Lars Landberg, Ib Troen and Erik Lundtang Petersen

ISBN

87-550-1789-4

ISSN

Dept. or group

Meteorology and Wind Energy

Date

January 1993

Groups own reg. number(s)**Project/contract No.**

Pages

133

Tables

13

Illustrations

60

References

14

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 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.

Descriptors INIS/EDB

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

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