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The Vindeby Project: A Description

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Abstract The Vindeby monitoring project has been established to provide information on the world's first offshore wind farm at Vindeby, Denmark. The project will consider all aspects of offshore meteorology which are relevant to offshore wind energy production in addition to turbine loading and behaviour in offshore conditions. This report contains a description of the site, including obstacles, roughness and fetch. The instrumentation used on each mast is described. Details of the data acquisition and the structure of the data bases holding the observations are given. Possible distortion of the wind flow at both land and sea masts has also been also considered.

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1 Introduction

Offshore siting of wind turbines will become more attractive as the availability of good land sites decreases. It is generally assumed that higher wind speeds offshore will at least partially offset increased siting costs. However, there is little information available about offshore wind speeds and many technical questions remain unanswered. There is therefore considerable interest in monitoring of the world's first offshore wind farm at Vindeby in Denmark. Structural measurements are being carried out in this low turbulence environment to supplement previous measurements on turbines in wind farms in different terrain types, from very rough complex terrain in California (Pedersen et al., 1991) to flat coastal terrain in the Nørrekær Enge wind farm (Højstrup et al., 1993). Additionally meteorological data will be obtained which will be useful in developing and testing models of the offshore and coastal wind climate. Specific campaigns are also planned to investigate spectra, profiles and fluxes and roughness due to wind-wave interaction.

2 Site description

Vindeby wind farm, located off the northwestern coast of the island of Lolland, consists of 11 Bonus 450kW turbines arranged in two rows oriented along an axis of 325-145°. Figure 1 shows the location of the wind farm. The most southerly turbine in the array is approximately 1.5km from land and the turbine spacing is 300m both along and between the rows. The water depth is between 2.1 and 5.1m. Electricity generation to the grid started in July 1991. For more details of the construction and operation of the wind farm see Olsen and Dyre (1993). One interesting problem detailed in this paper was the setting of the pitch of the blades. Initial pitching was set as on similar turbines on land and this had to be corrected due to over-production, the cause was thought to be lower turbulence offshore.

In order to study the meteorological aspects of the wind farms, and to provide information on wind flow in the coastal zone, three meteorological masts have been erected, one on land and two offshore. The land mast is located nearly 2km south of the most southerly turbine in the array. The two offshore masts are placed at distances equal to the turbine spacing (300m), one to the west and one to the south of the first row. The locations of the masts with respect to the wind turbines are shown in Figure 2. The minimum distances from land to sea mast south (SMS) and sea mast west (SMW) are approximately 1270m and 1630m respectively.

The topography at Vindeby is very flat and lies close to sea level. No topographic enhancement of the wind speed is expected. To the south of the land mast the terrain is mainly open farmland with a few scattered houses and trees, with open sea to the north. The coastline runs approximately along the line of 285-105°.

3 Instrumentation

Instruments have been installed at the same heights (with reference to sea level) on all three 45m masts providing wind speed from four levels, wind direction at two heights, temperature differences and absolute temperature. Additional instrumentation has been provided on the sea masts to give a more detailed view of the meteorology offshore. Instrumentation details are given in Table 1. Samples are taken at the rate of 20Hz and stored as half-hourly means together with selected higher-resolution time-series. Details of the data acquisition system are given in Section 4. Further instrumentation is being utilised during specific campaigns which will be reported separately.

Two turbines (4W and 5E) have been instrumented for basic structural measurements. The objective of the turbine instrumentation is to make simultaneous measurements of the mechanical loads on the two turbines and the upstream turbulence for a variety of situations which basically fall into two classes:

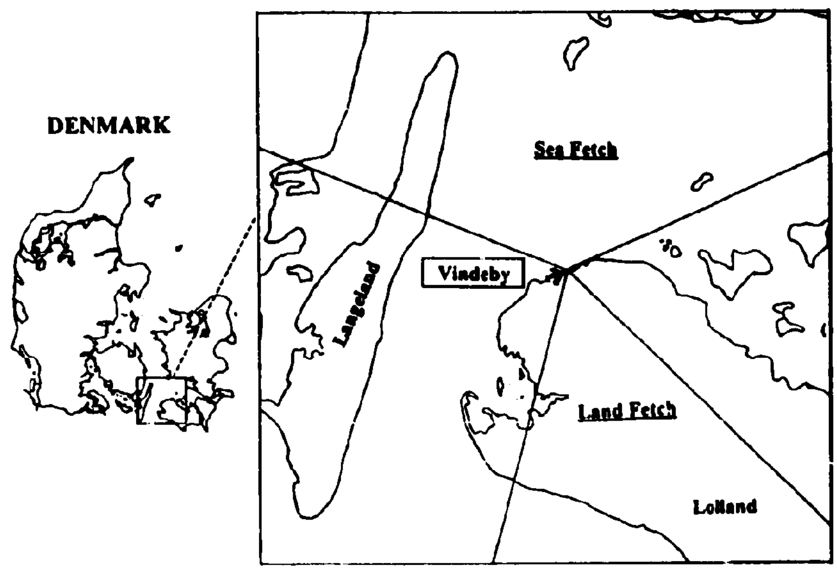


Figure 1. Location of Vindeby, Denmark

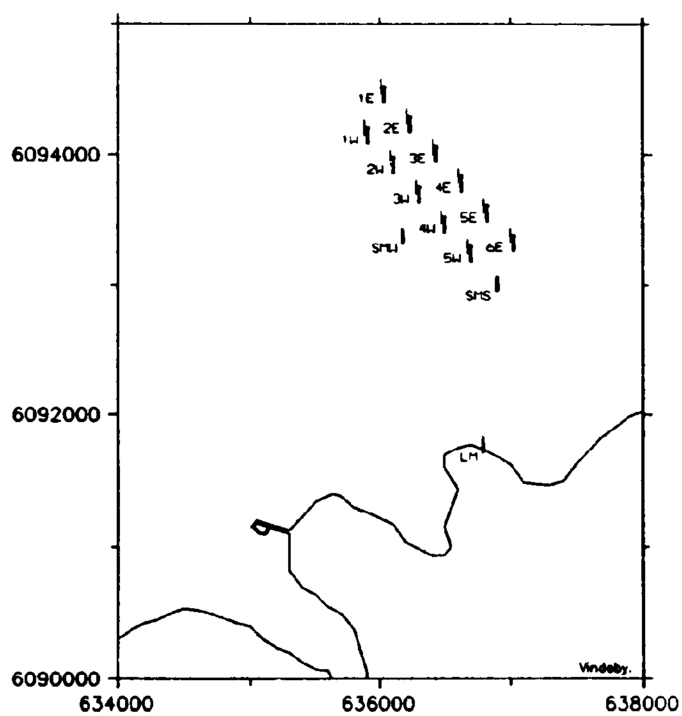


Figure 2. The configuration of the wind farm and positions of the masts at Vindeby.

- in the unobstructed low turbulence flow
- in the wake or one or more turbines

For a number of cases it will be possible to directly compare loads on one undisturbed turbine with measurements on the other turbine in a wake situation. Roughly 10% of representative time-series will be stored to supplement the on-line data reduction.

3.1 The land mast

The position of the land mast is 54° 57' 7.7" N, 11° 08' 11"E, grid reference 32UPF368917. The mast is approximately 16m from the coastline and stands about 2m above sea level on a concrete plinth. The actual height of measurements above sea level (i.e. from the north) is therefore about 2m higher than measurements from the land fetch. The data collection hut is nearly 10m (9.7m) east of the mast. Data collection began in January 1993 but due to severe flooding, comprehensive measurements began on 30th April 1993. A plan of the instrumentation is shown in Figure 3. The booms are oriented in a north-south direction along the line of 350 - 170°. Most of the anemometers are placed on the southern boom, with an additional anemometer at 37.5m height on the northern boom for comparison. In addition to the standard set of instruments on the mast (see Figure 3) pressure and radiation are measured and a precipitation detector has been installed.

3.2 Sea Mast South

Data collection began at SMS on 8th September 1993. A plan of the instrumentation is shown in Figure 4 and the instruments are fully described in Table 1. In addition to measurements of wind speed at four standard heights, wind direction at two heights, temperature and temperature differences, there are three extra anemometers for more detailed study of the wind speed profile. The booms on SMS are oriented in the direction 173-353°.

Initial data analysis suggests two instrument problems:

1) Wind direction sensor at 43m is not functioning correctly.
2) Temperature sensor at 10m is consistently reading lower than at the other masts.

3.3 Sea Mast West

Data collection began at SMW on 5th November 1993. A plan of the instrumentation is shown in Figure 5 and the instruments are fully described in Table 1. In addition to having the same instrumentation as SMS, SMW is equipped with three 3D fast response sonic anemometers and has a downward looking IR thermometer for water surface temperature measurements. Additional instrumentation is being installed in March 1994 to measure water temperature at different depths, wave heights (with an ultrasonic wave height sensor) and an electromagnetic current meter. The booms at SMW are oriented in the direction 46-226°.

Initial data analysis suggests that the wind speed measurements at 37.5m maybe wrongly labelled i.e. wind speeds recorded as SMW_WS_38 may be SMW_WS_38N and vice versa.

3.4 Turbines 4W & 5E

On each turbine, one blade-root has been instrumented with strain gauges for bending moments in two directions. Additional strain gauges are mounted on the tower. Measurements of rotor position, turbine electrical output and yaw angle are also available. These measurements were started at Turbine 4W on 19 November 1993, only the flap and power output measurements are yet to be included in the data base.

Table 1. Instrumentation on the masts

Height (m) above sea level (southern boom unless indicated as N)	Description	Make/Type	Details	Comments
LM 46,37.5,37.5N*,20,7 SMS 48,43,37.5,37.5N*,29,20,15,7 SMW 48,43,37.5,37.5N*,29,20,15,7	Wind speed	Cup anemometer Risø PT2244b	Range 0 to 60Hz Distant constant 2m Built to withstand wind speeds exceeding 50m/s Temperature range -25 to +50°C	1) Pulse type anemometer. 2) Højstrup (1993) describes the calibration procedure in full.
LM 37, 20 SMS 43N,20N SMW 43N,20N	Wind Direction	Risø P2021 resolver wind vane with wind direction transmitter P2058	Range 0-360° Accuracy typically 0.5° Maximum wind speed 40m/s Temperature range -25 to +50°C	High-level analogue output voltages proportional to the sine and cosine of the wind direction. Direction is calculated on-line.
SMW 45,18,5.7	Vector wind speed/direction fluctuations Temperature fluctuations	F2360a GILL 3 Axis Ultrasonic anemometer	Wind speed range 0 to 60m/s Resolution 0.01m/s Tres= ???	
LM 10N SMS 10N SMW 10N	Absolute temperature	Riso P2039 PT 100 Sensor P2029 Radiation Shield P1740 Temperature Transmitter	-30 to +60°C Calibration error <0.1% of span or 0.1°C Linearity error <0.1% of span	

LM (45-10)N,(20-10)N SMS (47.5-10)N, (24-10)N SMW (47.5-10)N, (24-10)N	Temperature difference	Riso P2040 Pt 500 P2029 Radiation Shield P1867 Temperature Transmitter	Maximum temperature difference ±10°C Temperature range ±30°C Temperature drift (typical) Sensitivity ±15ppm/°C Offset ±30uV/°C	Output as analogue voltages. ±5V gives ±10°C. Can resolve to 2.4mV.
LM 3 (in the hut)	Barometric Pressure	Aneroid Barometer Multur BA Pressure Sensor BA 1000 Pressure Transmitter	Temperature range -10 to +70°C Drift 1mbar/year (typically) Accuracy ±1mbar Working temperature 0 to +60°C	Output as analogue voltage. ±5V gives 900-1100mbar?
SMW 5	Water surface temperature	F2362 HEIMANN KT15.82 IR Radiation Pyrometer	Spectral sensitivity 8-14μm Temperature range 0 to 60°C Accuracy ±0.5°C[1] Drift better than 0.1% of the absolute measuring temperature in K/month	Accuracy depends on the correct setting of the emissivity of the surface to be measured. [1] plus 0.7% of the temperature difference between the housing containing the measuring instruments and the object to be measured in the range of ambient temperature 15 to35°C. In the range 0 to 15°C and 35 to 60°C an additional inaccuracy of 0.15/K deviation of the ambient temperature from the range 15 to35°C.

SMW	Wave height	AWR Acoustic Wave Recorder	<u>Acoustic</u> Transmit Frequency 200kHz Beam Width 1° Pulse length 0.2ms <u>Memory</u> Lifetime 10 years <u>Program</u> On Time 20min Cycle Rate 3 hours Sample Rate 8Hz <u>Hydraulic</u> Max Wave height 15m Wave Period 1-25s <u>Accuracy</u> ±1.5% full scale.	
SMW	Current	GMI Current Registration System	<u>Current Speed</u> Type Electro-magnetic. 2 Axis Range 0 to 200cm/s Accuracy 1% FSD <u>Direction</u> Range 0-360° Accuracy <2° Operating Temperature -5 to +45°C	

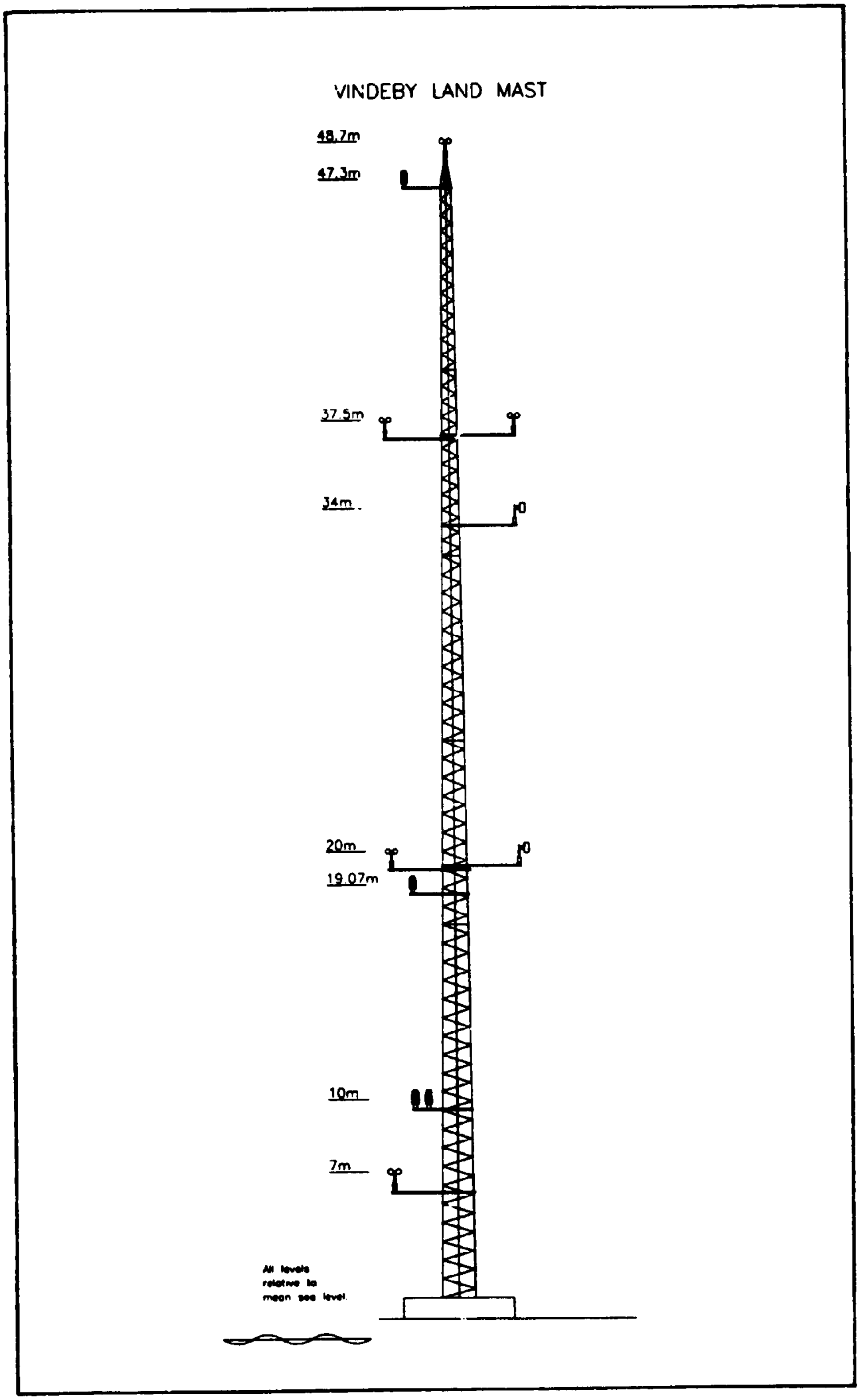


Figure 3. Instrumentation on the land mast

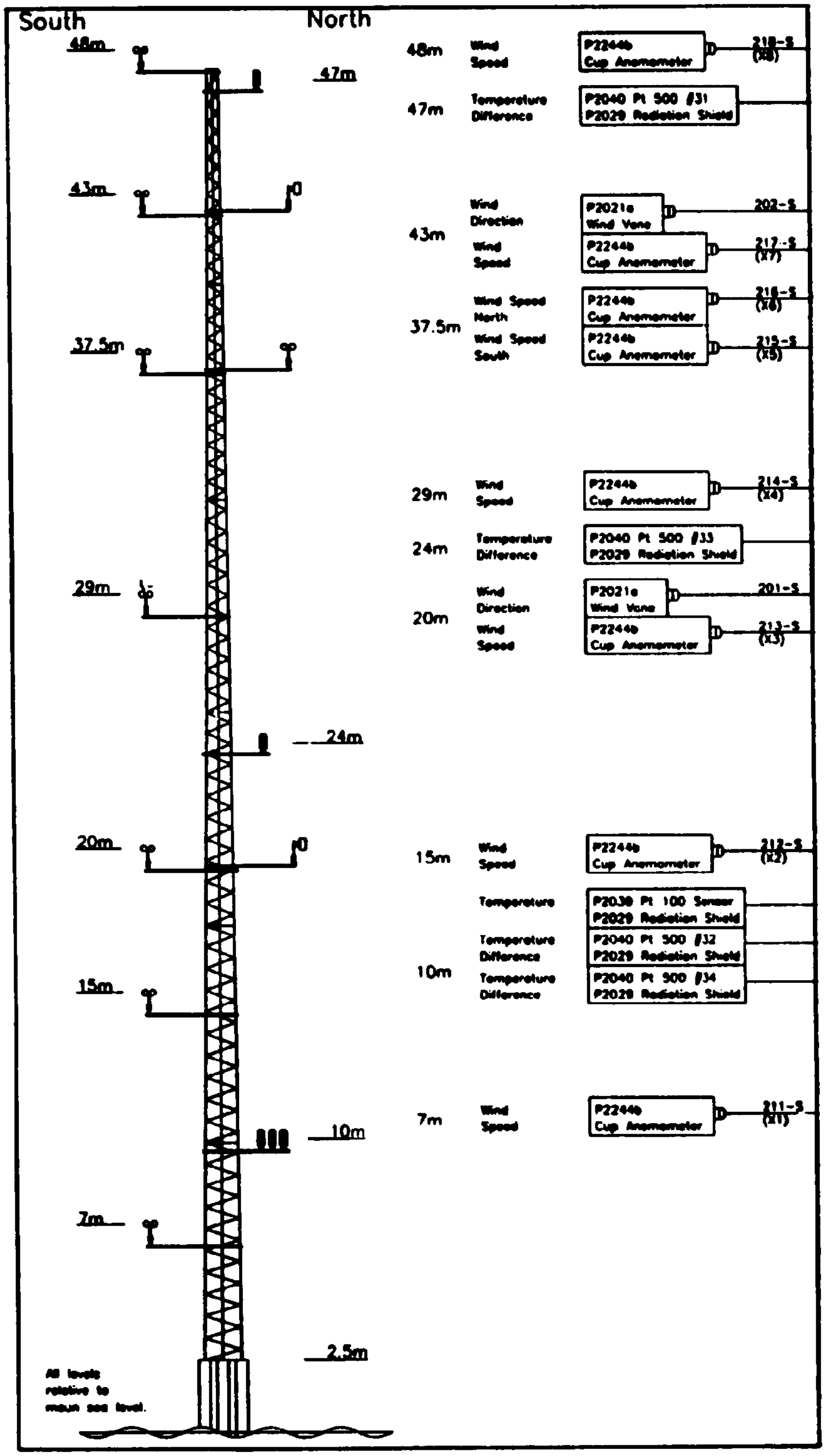


Figure 4. Instrumentation on sea mast south

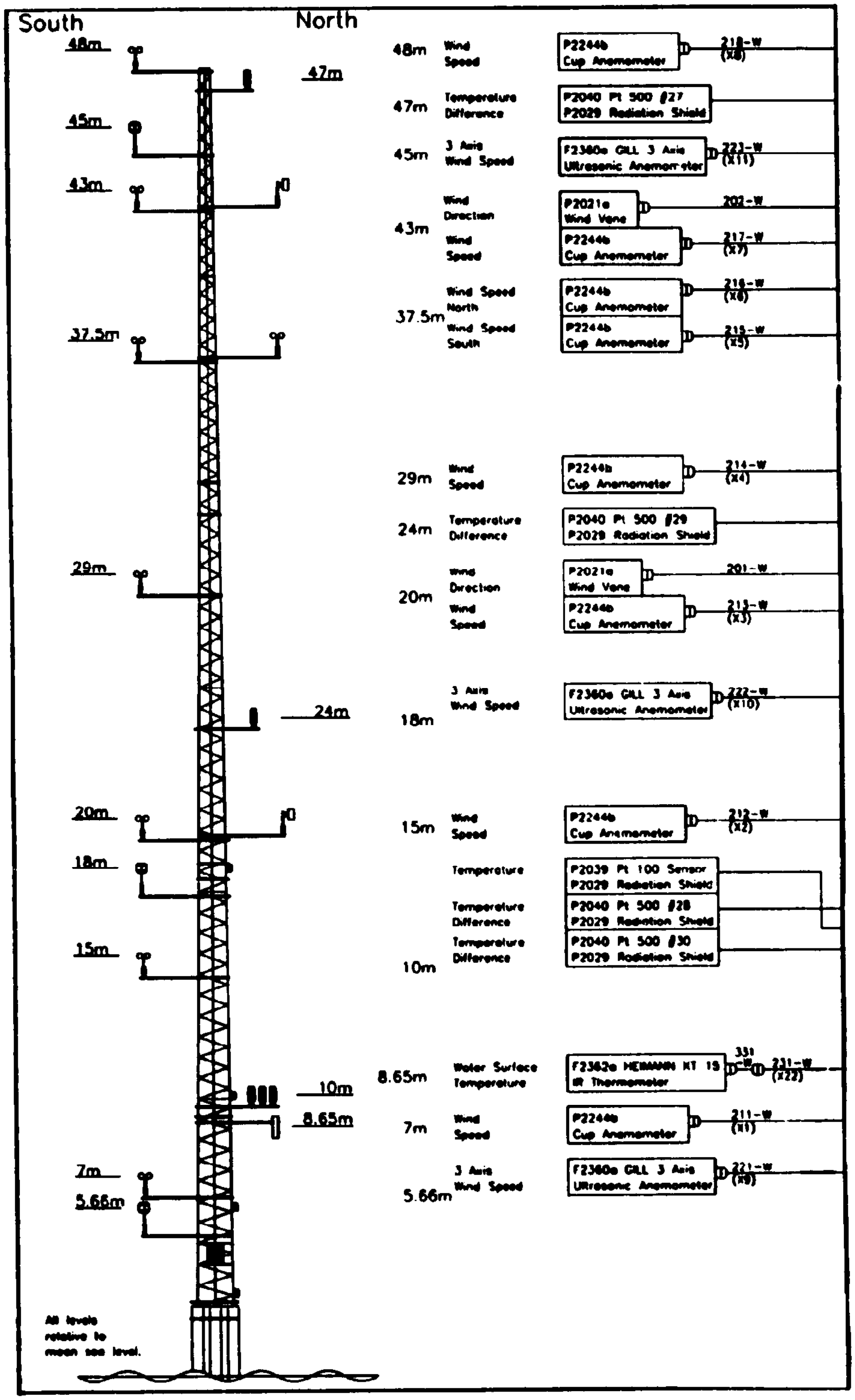


Figure 5. Instrumentation on sea mast west

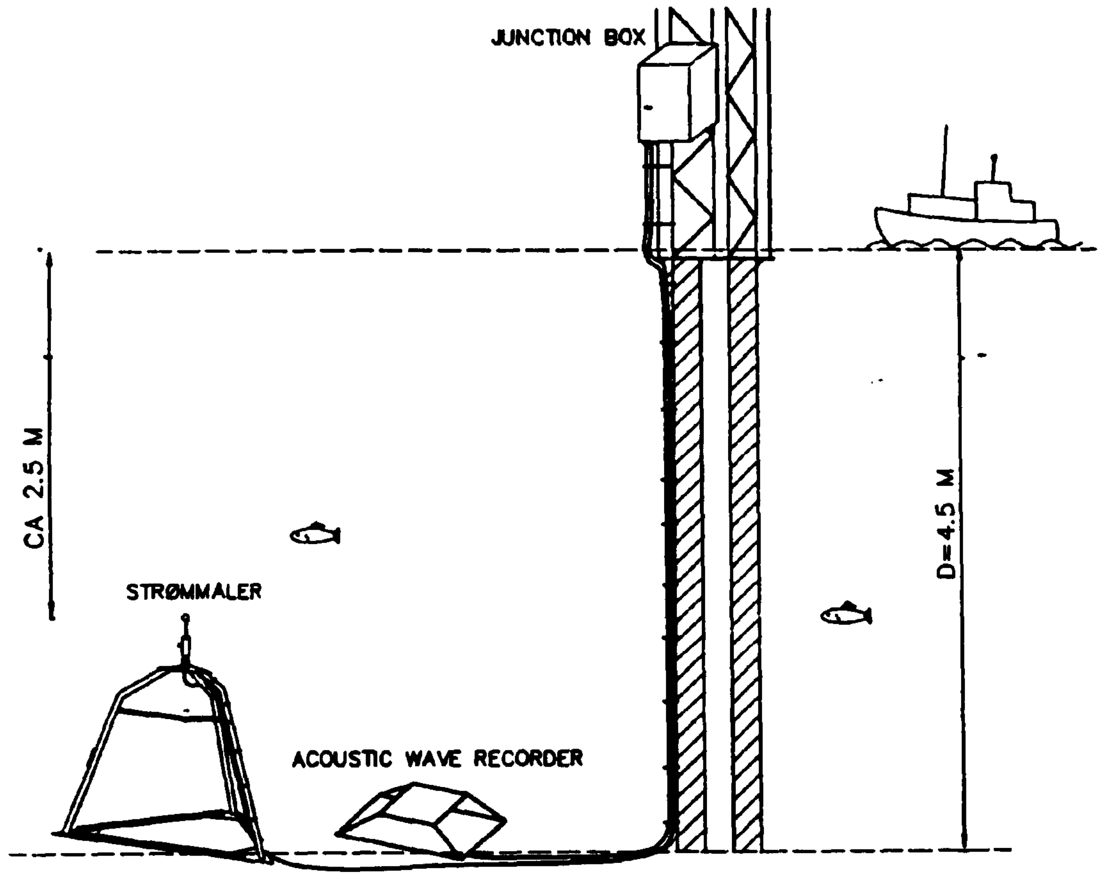


Figure 6. Current and wave height recorder

4 Data Acquisition System

The data acquisition system logs over 100 simultaneous signals from 6 different locations with physical separations of up to 3 km. This is achieved using 4 PCs, one in each of turbines 4W, 5W and 5E and one in the measuring hut at the foot of the land mast. Data from the sea masts and turbine signals are acquired by the turbine PCs and transmitted to the land mast on a fibre optic link. The land mast PC, in addition to acquiring all the local meteorological signals, simultaneously receives the serial signals from 4W, 5W and 5E. In this way, all the signals are available at the land mast and synchronisation is ensured. No data are logged on the turbine PCs; their function is simply to transmit the acquired data onward to the land mast. All 4 PCs run the Risø PC-DAQ data acquisition software.

Whilst the 4 systems have many similarities, there are sufficient differences to warrant a somewhat detailed description of each. First however we will describe the conversion methods for the major signal types.

4.1 Data Acquisition Conversion Methods

4.1.1 Cup anemometers

Risø cup anemometers output two pulses per revolution. The conversion method is to measure the time for each rotation, the instantaneous cup speed being derived from the reciprocal of the rotation time and the instrument calibration constants.

The period measurement is made using the Metrabyte CTM-05 (or equivalent Computer Boards CRT-05) counter timer card. This PC card is based on the AM9513 system timing controller chip. Signal conditioning (pulse forming, debouncing and synchronising to the timer source clock) is achieved using the purpose built Risø P2117 counter-timer interface. The accuracy of the period measurement is dependent only on the accuracy of the source clock frequency, derived from a quartz crystal. This is specified to an accuracy of ±0.1% with a temperature coefficient of about 1 ppm/°C and an ageing characteristic of less than 3 ppm/year. The pulse period accuracy is therefore at least an order of magnitude better than the cup calibration accuracy (see Hojstrup, 1993).

A source frequency of 62.5kHz and a 16 bit counter are used for the period measurement, giving a resolution of 0.7mm/s at 7 m/s and 7mm/s at 22 m/s. The price for this exceptional resolution is that for wind speeds under 1 m/s, the counter will over-run (exceed 65536) and no measurement is possible. This condition is detected and the reported wind speed is set to zero. On each mast, one anemometer (38N) is measured using a source frequency of 3.9kHz, giving a much lower resolution but allowing detection of cup speeds to below the instrument's start speed.

4.1.2 Analogue signals

Analogue signals are measured using one of two different analogue to digital converter (ADC) PC cards, DT2814 or CIO-AD08PGL. These are described below.

<u>Data Translation DT2814</u>

This is a 12 bit ADC, with a conversion time of about 15μsec and an accuracy of ±0.03% FSR (3mV for the ±5V range used). All input signals pass first through the DT709 signal conditioning board which converts the signals to single-ended (common signal ground) and subsequently passes the signal through a first order RC filter with a 3dB frequency of 160Hz. The conditioned signals (up to 16) are then passed to the DT2814 for sampling.

Calibration of the DT2814 is straightforward. A number of reference voltages are applied in turn to the inputs of the DT709, the resulting digital values recorded and the volts to digital gain and offset calculated using a linear regression routine. The individual channels are sufficiently similar to allow the calibration to be calculated for a single channel, providing that all the channels are subsequently verified with this common calibration.

The DT709 has a gain error of 0.1%. The thermal characteristics are:

Zero Drift	±20µV/°C
Gain Drift	10ppm of FSR/°C
Reference Voltage Drift	25ppm/°C

Computer Boards CIO-AD08PGL

This is a 12 bit ADC with channel selectable gain. The combined channel select and sample time is of the order of 100 µsec and the accuracy is specified as 0.01% of reading ±1 bit. Input channels may be chosen to be either unipolar (in the range 0-10V to 0-1.25V) or bipolar (in the range ±10V to ±0.625V). This choice is made on a per-channel basis.

Whilst the AD08PGL has only 8 (double-ended) input channels, it is employed in conjunction with a number of external CIO-MUX16 and CIO-MUX32 multiplexer boards. These extend the capacity of the AD08 in units of 16 and 32 respectively up to a maximum of 128 channels. The multiplexer boards have provision for pre-amplification (not used in the current experiment) and optional low pass filtering (3 dB frequency of 8 Hz). This filtering is only used for signals with no high frequency content, for example absolute and difference temperatures.

Calibration of this ADC system must take account of the different range settings for the individual channels and for the pre-amplification on the MUX boards. Blocks of 8 channels share a pre-amplifier and its associated offset potentiometer. In practice, each channel must be calibrated individually by applying a number of calibration voltages appropriate to the channel range, recording the resulting digital values and calculating a volts-to-digital gain and offset with a linear regression routine.

4.1.3 Serial signals

A number of instruments output data digitally, in a serial stream of either binary or ASCII data. This includes the sonic anemometer, Ophir hygrometer, wave height and current sensors and the serial data streams transmitted from the remote data acquisition systems. Serial instruments may be freely mixed in the channel list of the DAQ system. At each scan, the serial input buffers are checked and if the number of bytes representing a complete block of data are present, the block is removed, decoded and the data passed to DAQ. For more than one complete block present, all the blocks before the most recently arrived block are discarded. If there is less than one complete block present in the input buffer, no data are removed and the data decoded for the last completed block are returned to DAQ.

4.2 Description of the Data Acquisition Systems

4.2.1 Land Mast

The data acquisition system at the Land Mast (LM) collects all the signals from the 3 remote systems and in addition samples the local meteorological signals. It is here that data (statistics and time series) are stored on disk and it is from here that the data are transferred onwards to Risø. The PC is built up on a 12 slot industrial chassis with a 33 Mhz 80486DX CPU card and a 240 Mbyte hard disk. A CIO-AD08PGL is used for sampling the local analogue signals and a CTM-05 timer/counter card is used for the cup anemometer signals. An intelligent Digiboard serial card provides for up to 4 channels of serial input.

For remote-control, the PC is equipped with a high speed (19.2 kbps) analogue modem. This is used for monitoring of the data acquisition and provides a data transfer backup. Data are normally transferred using an ISDN (digital) telephone line, the PC being equipped with a (Lasat) ISDN adapter. This permits data transfer rates of approximately 90 kbps, equivalent to 38 Mbytes per hour. A third telephone line together with a remote monitoring and control system (Televagt) enables the PC to be remotely re-booted (turned on and off).

4.2.2 Wind Turbine 4W

This system samples all the signals from SMW and the local turbine signals. The PC is built up on a 12 slot industrial chassis with a 33 MHz 80486DX CPU card. Since no data are logged, the PC has no hard disk. Local (SMW and 4W) analogue signals are measured using a CIO-AD08PGL ADC in conjunction with 2 MUX32 multiplexer boards. Two CTM-05 timer cards are used for the cup anemometer pulse signals. Two Digiboard intelligent serial cards provide for up to 16 serial channels.

SMW signals are transmitted to 4W via an underwater signal cable with capacity for up to 50 double-ended signals. Transient protection is provided at each end of this cabie.

4.2.3 Wind Turbine 5E

Only 5E turbine signals are sampled by this system. The PC is built using a 5 slot chassis with a 25 Mhz 30386SX CPU card. There is no hard disk. Analogue signals are sampled using a DT2814 ADC together with a DT709 signal conditioning board. There are no pulse signals. Data are transmitted to 5W for subsequent re-transmission into the Land Mast. Direct transmission is not possible as there are only 2 optical fibre cables available for data transmission.

4.2.4 Wind Turbine 5W

This system samples all the signals from SMS. At present no 5W turbine signals are measured although power measurements (turbine and park aggregate) are planned. The PC is built using a 6 slot chassis with a 25 Mhz 30386SX CPU card. There is no hard disk. Analogue signals are sampled using a DT2814 ADC together with a DT709 signal conditioning board. (This may be changed to a CIO-AD08PGL / MUX32 if the present 16 channel capacity is insufficient for the planned power measurements). Pulse signals from the cup anemometers are sampled using 2 CTM-05 timer cards. The serial data stream from 5E is sampled using a standard COM port equipped with a 16550 UART (with buffering). All data (local plus 5E) are transmitted to the Land Mast.

SMS signals are transmitted to 5W via an underwater signal cable with capacity for up to 30 double-ended signals. Transient protection is provided at each end of this cable.

5 Interference to the wind flow

5.1 Roughness and Fetch

The topography at Vindeby is very flat (Figure 7) and lies close to sea level. No topographic enhancement of the wind speed is expected. The roughness classified according to Wieringa (1986) is given in Figure 8. To the south of the mast the terrain is mainly open farmland with a few scattered houses and trees, with open sea to the north. Roughness lengths estimated from maps and a description of the fetch in each 10° bin are given in Table 2.

The coastline runs approximately along the line of 285-105°. Moving to the mesoscale, the definition of the terrain becomes more complicated due to the nature of the coastline. After examination of the fetch in the nearest 10km to the mast, directions between 290 and 65° can be classified as having sea fetch, while those between 135 and 195° have land fetch (shown in Figure 1). The remaining direction have mixed fetch and it is not yet clear how they should be categorised further.

Mean wind speed profiles recorded at the land mast from May to September 1993 in each of the four fetch classifications are shown in Figure 9. Roughness lengths have been determined by a 'best-fit' logarithmic line. It is shown that while the roughness lengths are similar to those estimated from map data for the land and mixed fetch areas, the predicted roughness length over sea is much lower than expected. This will be the subject of further investigation. Figure 10 shows the directions to each of the masts and the wind farm and describes the research potential of the remaining wind directions with possible problems caused by the nature of the fetch.

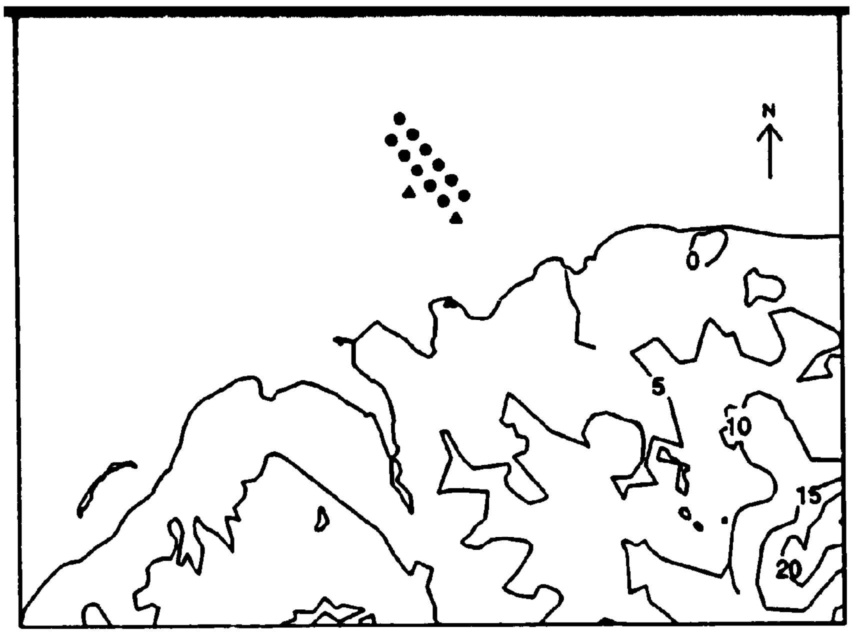
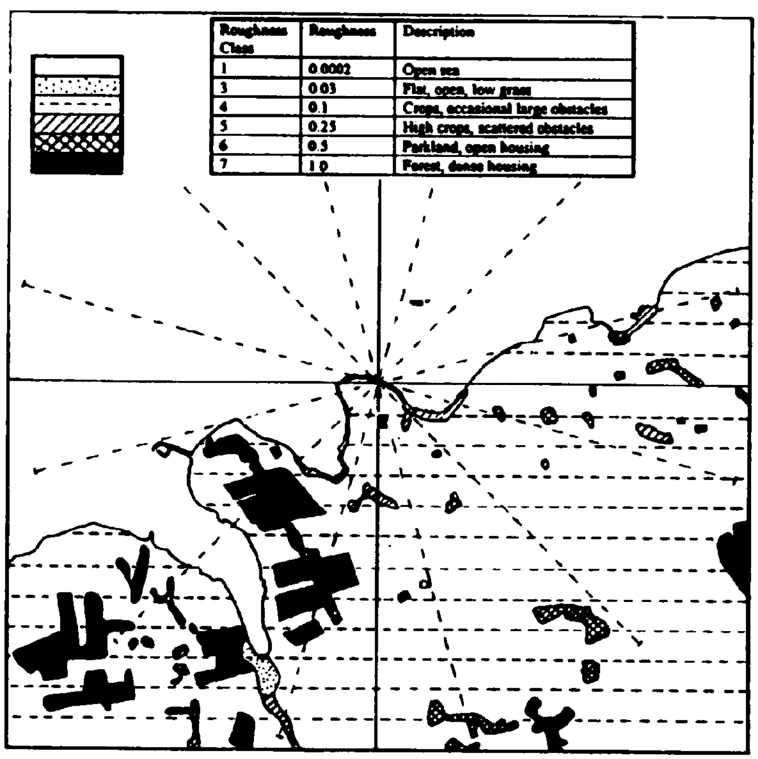


Figure 7. Topograpy at Vindeby



Roughness Class	Roughness	Description
1	0.0002	Open sea
3	0.03	Flat, open, low grass
4	0.1	Crops, occasional large obstacles
5	0.25	High crops, scattered obstacles
6	0.5	Parkland, open housing
7	1.0	Forest, dense housing

Figure 8. Roughness classification of the terrain around the land mast estimated from maps (according to Wieringa, 1986)

Table 2. Roughness and fetch description by sector.

Dir Bin	Dir (°)	Fetch distance (km)	Fetch	z_0 (m)	Comments
0	355-5	39-44	S	0.0002	21.5km to Ømo at 0-5°, 3km land then 15km sea to Sjælland.
1	5-15	30-39	S	0.0002	27km to Agersø at 5-11°, 3km land then 6km over sea to Sjælland
2	15-25	29	S	0.0002	29km to Sjælland
3	25-35	33	S	0.0002	30km to fjord, 0.5-2km land, 1km sea then Sjælland
4	35-45	36-38	S	0.0002	35-38° 34km to fjord then 0.5-2km land then 1km sea fetch 39-45° sea to Sjælland
5	45-55	38-41	S	0.0002	45-52° sea to Sjælland 52-55° sea to Enø, complicated mixed fetch for 5.5km before Sjælland
6	55-65	43	S	0.0002	43km sea, 1km land, sea 1-5km (Dybsø fjord) then Sjælland
7	65-70 70-75	34-42	S SLS	0.0002 0.0018	64-70° sea 34-42km to Knudshoved Odde, peninsula approx 0.4-2km wide. Sea (Avnø fjord) 6.5km at 64° to 1km at 75° then Sjælland 70° to 75° sea 1-1.5km, land 500m then sea approx 35km
8	75-85		SLM	0.0612	sea <1km, land 5-9km then sea-land-sea-land-sea-land
9	85-95		SLM	0.0612	sea <1km, land 9-10km then sea-land-sea-land
10	95-105		SLM	0.0612	sea<1km, land 11-16km then sea-land-sea-land
11	105-115		SLM	0.0762	sea <1km, land 16-23km, water fetch for 2-18km then Lolland
12	115-125		ML	0.0762	sea <1km, land for 50km+
13	125-135	48	L	0.0762	land fetch for 40km+
14	135-145	41	L	0.1116	land fetch for 40km+
15	145-155	37	L	0.1080	land fetch for 35km+
16	155-165	27	L	0.1000	land fetch for 28km+
17	165-175	25	L	0.1200	land fetch for 24-26km
18	175-185	23	L	0.1100	land fetch for 23km
19	185-195	11	L	0.1080	land 11km to Nakskov fjord, fjord 2-5km then land fetch 5-9km
20	195-205	11	L	0.1080	land 10-12km to Nakskov fjord, fjord 5km then land 4-5km
21	205-215		M	0.05	land 500m, sea 500m, land 1km, sea 500m, land fetch 10km, fjord small island and peninsula then Langelandsbælt
22	215-225		M	0.05	land 500m, sea 750m, land 1km, sea 750m, land fetch 10km then sea fetch except Albuen peninsula (1-1.5km land) at 18km 215-219°
23	225-235		M	0.03	land 500m, sea 800m, land 1km, sea 750m, land fetch 7-9km, sea fetch 18-25km, land fetch 3-8km then sea fetch
24	235-245		M	0.03	land 500m, sea 1km, land 1km, sea 500m, land 2-6km, sea 16-18km, land for 8-12km then sea
25	245-255		M	0.0006	land 500m, sea 1km, land 1km, sea 500m, land 2km sea for 16-18km, land for 6-10km, then sea/land
26	255-265		M	0.0003	land 500m, sea 18-20km, land 7-10km, then sea/land
27	265-275		M	0.0003	land 500m, sea 16-18km, land 6-8km, then sea land.
28	275-285		M	0.0003	land 500m, sea 17km, land 5-6km, sea 4-10km, then sea/land coastline runs approx 285°.
29	285-295	16	S	0.0002	sea 16km, land 4-5km, sea 8km, then land.
30	295-305	15	S	0.0002	sea 15km, land 4km, sea 7km, then land
31	305-315	17	S	0.0002	sea 17km, land 4km, sea 7-8km then land
32	315-325	18-20	S	0.0002	sea 18-21km, land 4-5km, sea 8-10km, then land
33	325-335	21-25	S	0.0002	sea 21-25km, land 2-4km, sea 10-16km, then land
34	335-345	60	S	0.0002	sea 60km+
35	345-355	60+	S	0.0002	sea (Storebælt)

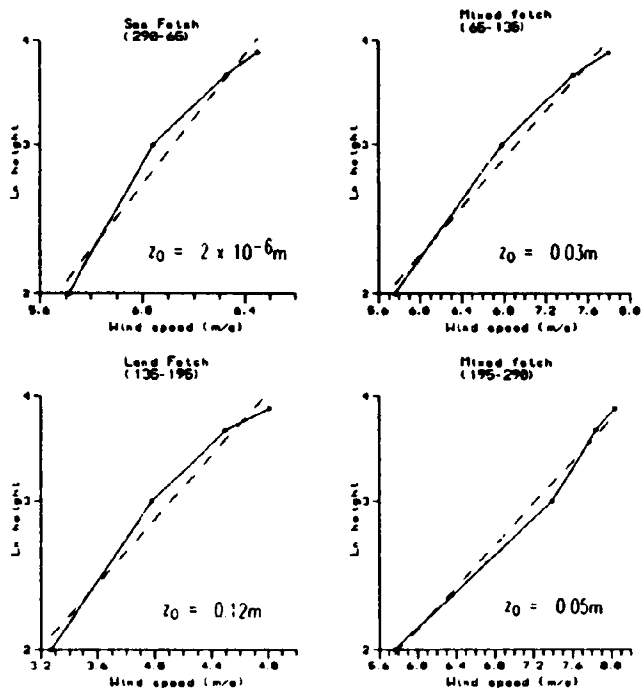
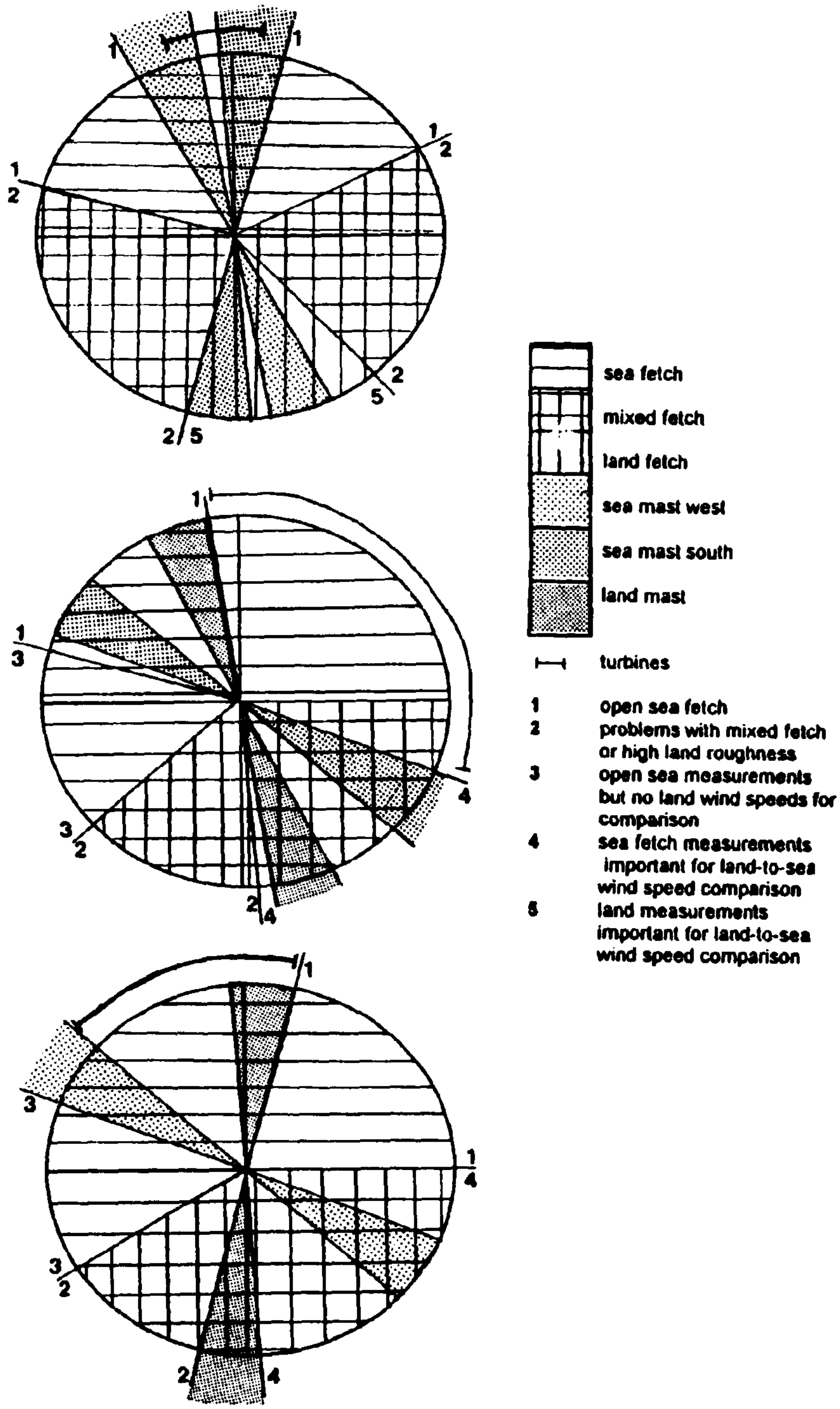


Figure 9. Roughness in four fetches estimated from wind speed profile data

Figure 10a shows an analysis of the fetch from different directions to the land mast. It is clear that considerable care will be needed to examine wind speeds from southwesterly and easterly directions due to the nature of the fetch. The complicated coastline will lead to the development of multiple internal boundary layers from some directions while an area of high roughness to the west/southwest may have some impact. However, to the south is an area of relatively simple terrain while both northeast and northwest directions have clear sea fetch. The wind farm and sea masts are placed to the north of the land mast.

A consideration of the fetch in the vicinity of SMS is shown in Figure 10b. The north/northwest sectors contain the wind farm and measurements from this direction will therefore be most useful for study of array effects. To the northeast is relatively open sea fetch from which measurements will be useful for comparison with observations at SMW which will contain array effects from this direction. The southeast quadrant will contain data for inter-comparison with observations from the land mast, showing the increase (if any) between land and sea measurements at this distance under different stability conditions. The southwest quadrant is similar but the fetch to the land mast is more complicated and contains some area of high roughness length which will probably cause internal boundary layer development. The inter-comparison will therefore have to be carefully assessed. From the west there is also open sea fetch but there are no wind speeds with straightforward land fetch for comparison. SMW is also in this direction.

Figure 10c shows an assessment of the fetch and research potential of wind directions to SMW. There are obvious similarities to SMS except that the mast will be in the wake of the wind farm when the wind direction is between 350 and 110°. Measurements from the northwest and southeast will be especially useful for comparison with data from the other two masts.



a) LM

b) SMS

c) SMW

Figure 10. Research potential of each direction at the masts

5.2 Internal Boundary Layers (IBL)

The measurements at all three masts have been compared with a simple model for the downstream development of velocity spectra after a two dimensional roughness/heat flux change (Højstrup, 1981) in Højstrup et al. (1994). The model gave good results for the wind profiles and reasonable results for the standard deviations. Here we use simple formulae to address two initial questions concerning the development of IBL's moving both on and offshore. The analysis undertaken here uses the results from a number of studies predicting IBL heights both empirically and theoretically. The equations which have been used for neutral conditions are:

1) Bergström et al. (1988)

$$h = 0.2x^{0.8} \qquad (1)$$

2) Hanna (1987)

$$h = 0.1x \qquad (x<2000m) \qquad (2)$$

3) Van Wijk et al. (1990)

$$h \ln\left(\frac{h}{z_{o2}}\right) = 2k^2 x \qquad (3)$$

4) Elliott (1958)

$$\frac{h}{z_{o2}} = A\left(\frac{x}{z_{o2}}\right)^{0.8} \qquad (4)$$

where:

$$A = 0.75 - 0.03\ln\left(\frac{z_{o2}}{z_{o1}}\right)$$

In all these equations:

h is the internal boundary layer height
z_{o1} is the upwind roughness
z_{o2} is the downwind roughness,
k is the von Karman constant (0.4), and
x is the fetch i.e. distance from the roughness change

In convective conditions the IBL will grow more quickly i.e. the height increases over shorter distances while in stable conditions the growth of the IBL may be retarded. An extension of Bergström et al.'s equation (1988) has been used here to predict IBL heights in different stability conditions:

$$h = 0.2x^{(0.78-0.33z/L)} \qquad (5)$$

where:
z is the height
L is the Monin-Obukhov length

The following questions can then be addressed:

1) is the lowest anemometer on the land mast (7m) sufficiently high to be recording 'marine' wind speeds when the wind blows from the north?

The minimum distance between the mast and the coastline is 16m. It can be seen from Figure 11 that in summer the vegetation at the coast cannot be ignored. From the sea to approximately 4.5m inland the reeds are about 0.7m high, increasing to

1.5m height between 4.5m and the mast structure. It may be more accurate to consider this belt of reeds as a displacement height.

Equations (1) to (3) predict an IBL height of around 1.8m at 16m fetch in neutral conditions with a roughness change from 0.0002 to 0.1m while (4) gives 3.2m. In neutral conditions it is expected that the anemometer at 7m will therefore still be representative of conditions over sea when the wind is blowing from the north. When the angle is more oblique giving a longer land fetch, the IBL height will reach 7m (as predicted by equations (1) to (3)) at a fetch of 90m. Examination of the map of the site (Figure 11) suggests that this will occur at angles less than 295° and greater than 105° which does not include the sea fetch areas.

Using equation (5) the limiting value of z/L can be determined at which the IBL height is 7m when the fetch is 16m. This is found to be around -1.5 i.e. unrealistically unstable conditions. It is apparent that under most conditions and within the sea fetch specified, the lowest anemometer will record speeds which are representative of marine atmosphere but a combination of the two effects, with a longer fetch across the coastal band and unstable conditions may cause the lowest anemometer to record wind speeds within the IBL.

2) how stable would conditions have to be before the IBL height is lower than the top anemometer at the sea masts when winds are blowing from the land?

The shortest distances between the land and SMS and SMW are approximately 1270m and 1630m respectively. In neutral conditions the equations (1) to (4) have been used to predict IBL heights at the two masts which are shown in Table 3. It is shown that under neutral conditions the measurements at all heights on both masts should be within the marine boundary layer. In stable conditions, the IBL grows more slowly. Equation (5) has been used to predict limiting behaviour. That is to determine at what value of z/L the IBL height is the same at the top anemometer (48m) at the nearest sea mast. The value was found to be approximately 0.04, which represents very slightly stable conditions. It is clear that great care must be employed when using the sea mast data in stable conditions since the wind speeds recorded at the top of the mast may be excluded from the marine boundary layer.

The problems caused by IBL development at multiple roughness length changes at the land mast will be further investigated. Initial evaluation suggests that this should not be a significant problem in the land fetch as defined above since the area to the south of the mast is relatively uniform for several hundred meters.

Table 3. Predicted IBL heights at SMS and SMW in neutral conditions

Equation	Predicted IBL height at SMS (m)	Predicted IBL height at SMW (m)
1	61	74
2	127	163
3	63	68
4	55	78

5.3 Distortion of the flow around objects at the land mast

It is not yet clear whether obstacles close to the mast should be considered as individual items or included in the roughness description. A plan of the area surrounding the mast is shown in Figure 11. Table 4 contains a brief description of the obstacles in each 30° sector used as input into an analysis of the reduction of the wind speed with WA^{S}P (Mortensen et al., 1993). The results using the default wind climate are shown in Table 5. Sectors where no obstacle interference is predicted are not given. It is clear that the obstacles in the easterly sectors have a significant impact on the wind speed below 20m and this should be considered when using wind speeds from the lowest anemometer. The farm to the south also presents a major disturbance to the wind flow in the southerly sector and this is significant to 33m height.

Table 4. Obstacles at Vindeby (Obstacle description as required by WA^{S}P)

	Angle to first corner (°)	Distance to first corner (m)	Angle to second corner (°)	Distance to second corner (m)	height (m)	depth (m)	estimated porosity	Description
1	104	10.0	115	9.7	2.4	3.1	0	hut
2	116	14.6	123	14.7	3.4	1.5	0.7	tree
3	122	11.3	128	11.5	3.0	1.0	0.8	dead tree
4	116	96.0	137	125.0	5.0	24.0	0.5	house and garden
5	286	17.0	291	17.0	2.0	14.0	0.7	low hedge
6	286	54.0	288	54.0	2.5	10.0	0.7	hedge and small trees
7	286	81.0	288	81.0	4.5	33.0	0.5	block of trees
8	283	127.0	285	127.0	3.0	7.0	0.7	small trees
9	176	275.0	183	280.0	10.0	75.0	0.5	house and trees

Table 5. Predicted percentage reduction in wind speeds caused by obstacles in each sector from WA^{S}P

30° sector		Height		Height where wind speed reduction decreases to less than -0.5% (m)
	5m	10m	20m	
90	-1.0	-0.1	0.0	6
120	-12.6	-5.1	-0.5	20
150	-1.6	-1.1	-0.1	14
180	-2.4	-2.4	-1.7	33
270	-0.7	-0.2	0.0	7
300	-1.0	-0.3	0.0	8

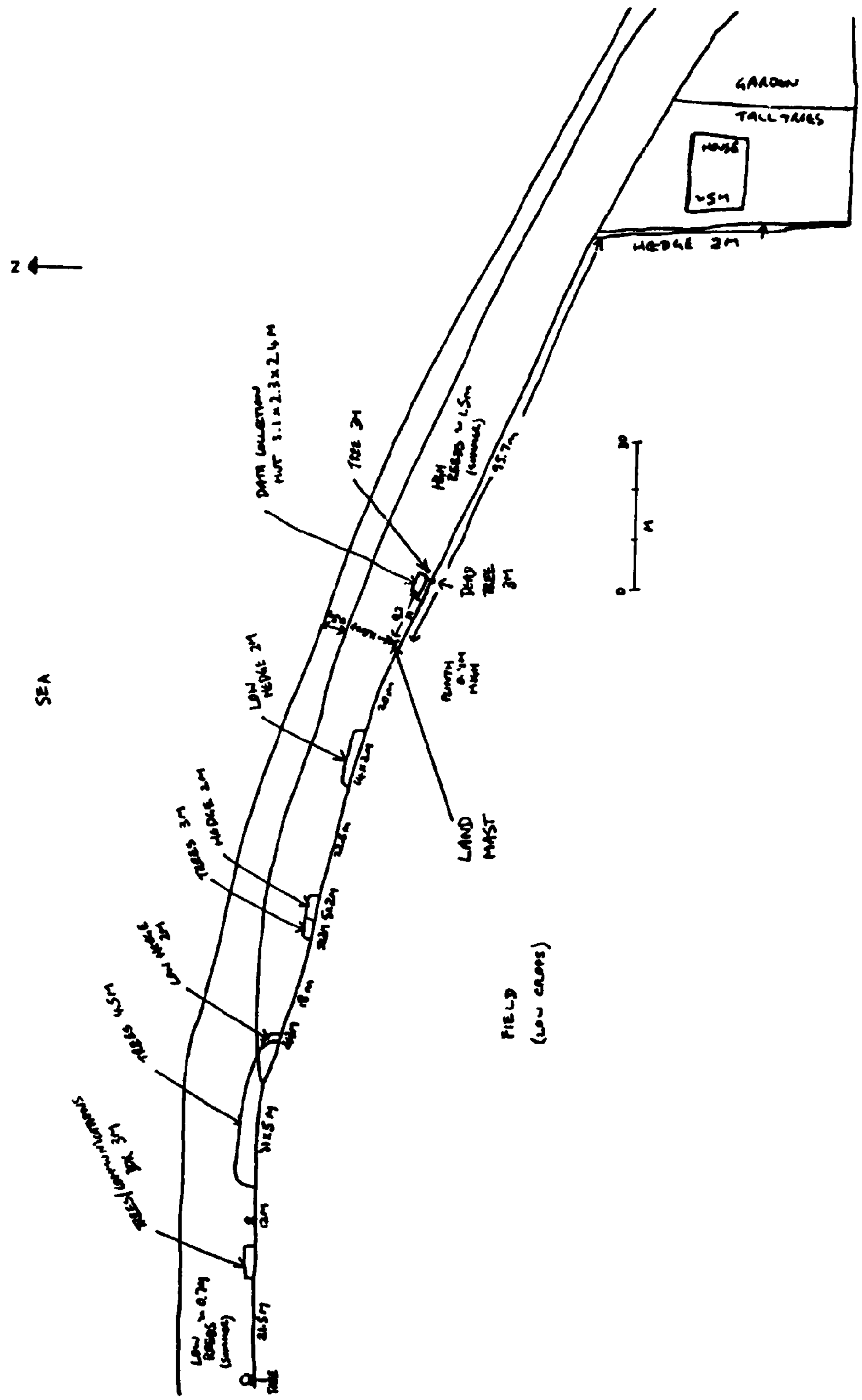


Figure 11. Plan of the area around the land mast showing obstacles

5.4 Boom orientation

The orientation of the land-sea boundary is approximately 285°-105°, with the angle between the land and sea mast west being about 20° (along 340-160°). The angle between the land mast and sea mast south is 5° (along the axis 5°-185°). The present orientation of the booms on the land mast and SMS is 350° - 170° with major instrumentation on the southern end of the boom (Figure 12).

Due to the triangular construction of the mast there were three possible orientations of the booms and therefore six possible permutations (of 4 and 1 anemometers). The ideal configuration of the booms and anemometers obviously depends on the major purpose of the research. It is necessary to align the anemometers to minimise the distortion of the wind flow by the mast in the directions which are most important. However, the distribution of the wind direction must also be considered. The solution chosen was to orient the main wind speed instrumentation towards the south, thus the major distortion of the wind flow is from the north-northeast direction which has a relatively low frequency.

The booms on SMS are arranged in a similar way, while on SMW the boom is arranged along the axis 46°-226 with the major instrumentation oriented to towards 226°.

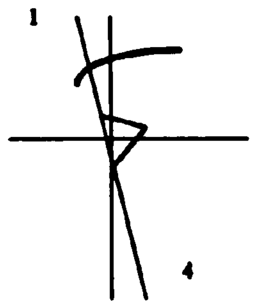
5.5 Distortion of the wind flow by the boom

The boom itself also causes distortion to the measured wind speed/direction depending on:

1) boom diameter (50mm)
2) height of the cup/vane centre above the boom (600mm)
3) distance of the instrument to the centre of the mast
   (Figure 13 gives this information for the two sea masts.)
4) distance of the instrument from the mast structure (2.4m)

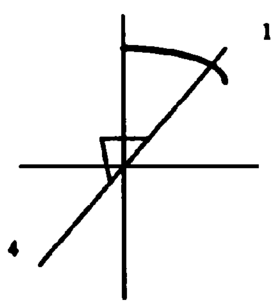
5.6 Analysis of mast interference effects at the land mast

Major interference presumably introduced by the flow round the mast is experienced between 160 and 180° where the wind speed as measured on the south anemometer exceeds that of the north anemometer and between 340 and 0° where the wind speed on the north anemometer is greater. This was examined closely using data from May to August 1993 so that the correct directional wind speed at 37.5m could be selected. At the other heights where measurements are located on the south it possibly means excluding bins (between 340 and 0°) where interference at 37.5m exceeds a prescribed limit (say 0.25m/s). However, the relatively narrow band of distortion seen in these two directions suggests that interference to the wind flow is limited except where the wind flows directly at the mast before reaching the instruments. Figure 13 shows the average, minimum and maximum difference between wind speeds recorded at 37m (south-north) by 10° sector. With the exception of the above mentioned directions the average difference is less than 0.1m/s in each sector bin. This does not present a problem at 46m or 37.5m since the top anemometer is free from obstruction and at 37.5m measurements from either instrument can be selected. However, it is clear that at 20m and 7m heights considerable interference will be experienced to the measured wind speeds in the sectors 0, 34 and 35 where the wind speeds may be reduced by up to 0.5m/s on average (Table 3) and more on individual measurements. Similar behaviour is expected at the two sea masts since the masts have identical structures (bearing in mind different instrumentation and boom orientation).



Major flow distortion 345-35°

a) at the land mast and SMS



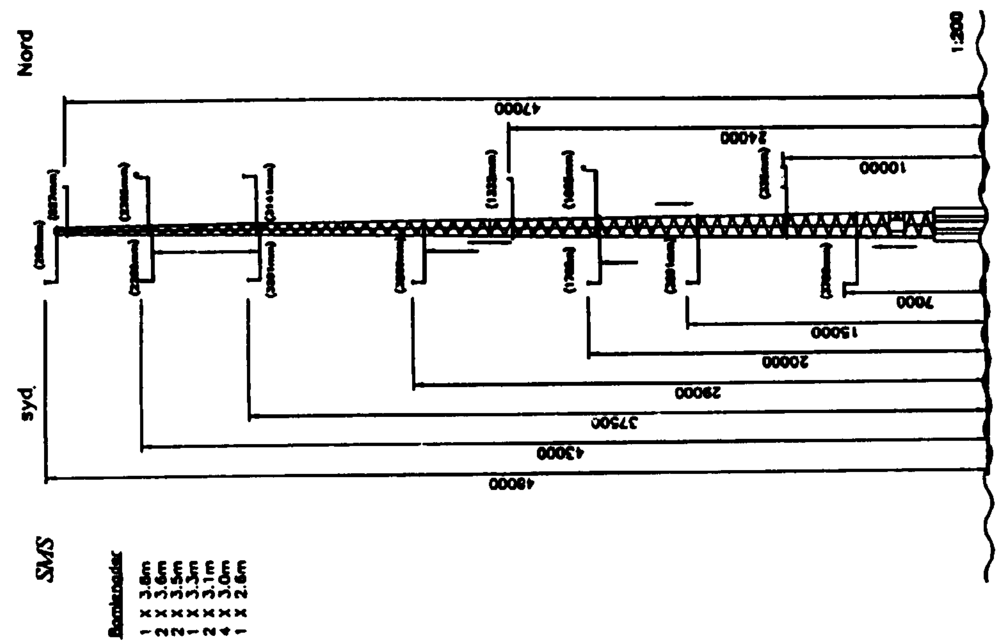
Major flow distortion 0-50°

b) at SMW

Figure 12. Arrangements of the boom and anemometers at Vindeby

5.7 Directions between masts and turbines

The directions between the masts and individual turbines are given in Table 7 and also shown approximately in Figure 14. It is intended that this information will be useful for examination of the data for array effects. Note that from about 320° SMS is in the wake of the westerly row of wind turbines while SMW will be recording the undisturbed wind flow. By way of contrast data from SMW will be more useful for consideration of wake effects from single or pairs of turbines, particularly those in the easterly quadrant where the wind flow to SMS will be undisturbed.



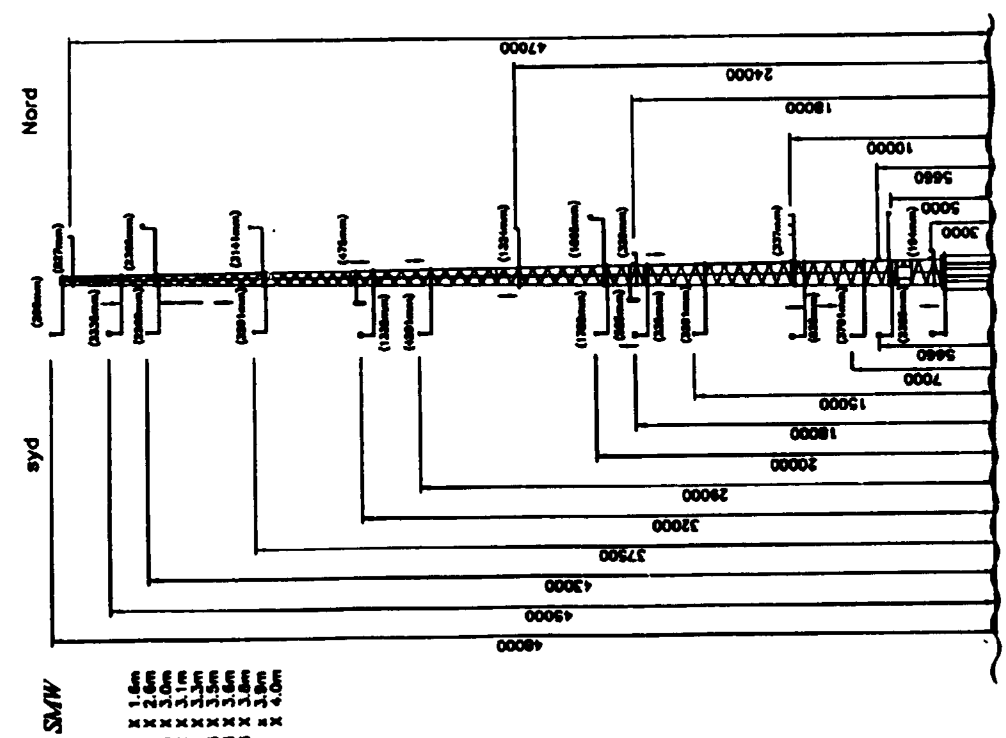


Figure 13. Boom lengths at the Sea Masts

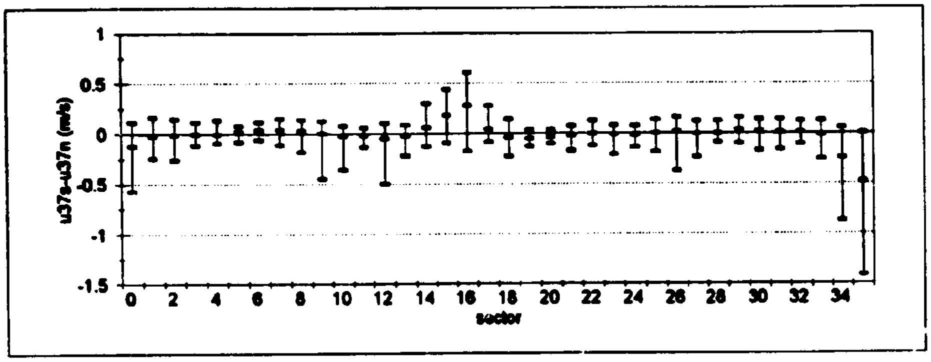


Figure 14. Difference between wind speeds at 38m height measured on the north and south sides of the land mast by 10° sector bin (m/s)

Table 6. Difference between wind speeds at 37.5m height measured on the north and south sides of the land mast

Sector	Direction (°)	Average wind speed difference at 37.5m (south-north) (m/s)
0	355-5	-0.12
17	165-175	0.18
18	175-185	0.28
34	335-345	-0.25
35	345-355	-0.48

Table 7. Directions between masts and from masts to turbines (° from grid north)

	From LM	From SMS	From SMW
LM	-	185	160
SMS	5	-	108
SMW	340	298	-
1W	340	320	339
2W	342.5	320	351.5
3W	346	320	22
4W	351	320	75
5W	356	320	106
1E	344.5	329	351.5
2E	348	332	3
3E	351	335	22
4E	355.5	340	48.5
5E	1.5	352.5	75
6E	9	23	95

6 Preliminary estimates of wind speeds at Vindeby

Table 8 gives mean wind speeds at 10m height estimated using various methods for the land mast site, a land site with no roughness change (z_0=0.03m) and for offshore areas (z_0=0.0002m) at Vindeby. No obstacles or topography were included in the analysis. The predicted mean 10m wind speeds at the wind farm and at the land mast are therefore expected to be in the region of 7m/s and 6-6.5m/s respectively. Mortensen et al. (1994) have applied WA^{s}P to prediction of potential wind energy output offshore in the Vindeby region.

Table 8. Preliminary estimates of wind speeds at Vindeby

Method	Predicted wind speed (m/s)		
	With roughness change	Land site	Offshore
European Wind Atlas (Troen and Petersen, 1989)	5.8-7.1	5.5-6.7	6.7-7.4
WA^{s}P[1] (Mortensen et al., 1993)	6.1	5.2	7.4
Borresen (1987)	not applicable	not applicable	7.1-7.9

[1]Simple roughness change, no obstacles.

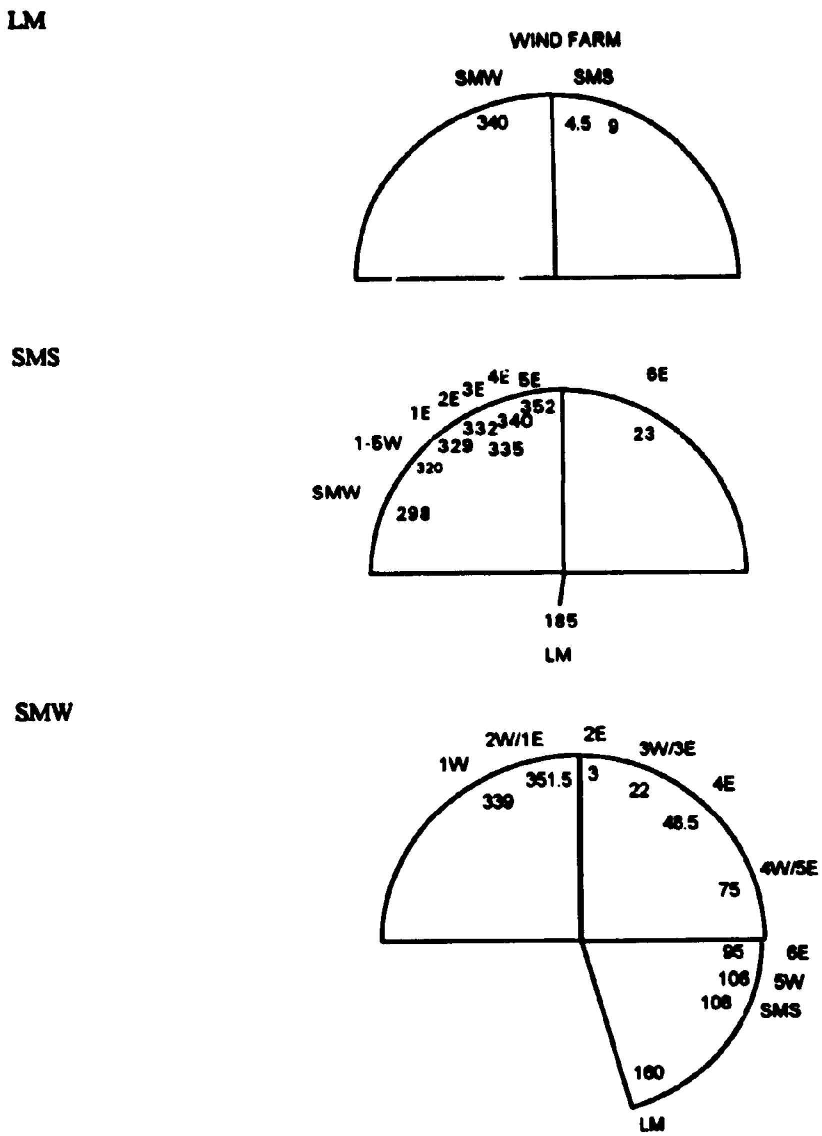


Figure 15. Wind directions between masts and turbines (° from grid north)

7 Data Bases

The data are organised in Paradox data bases which contain half-hourly averages, identified by a specific run name. Selected time-series are also stored. The data bases which are being updated and maintained on an weekly basis are listed in Table 9 and their contents are listed in Table 10. Quality control procedures are applied to remove erroneous or suspect data wind speed from the databases. The major problem to date has been the presence of 'spikes' in the wind speed data, mainly at SMS, possibly caused by turbine cut-in. These spikes (which are defined as a half-hourly value where the maximum wind speeds exceed the mean wind speed plus five times the standard deviation) are removed from the mean and standard deviation databases but left in the CUP_EXTR database.

Note that standard deviations of the wind direction are calculated:

$$\text{WD\_STDEV} = \sqrt{1 - \overline{\sin\theta}^2 - \overline{\cos\theta}^2}$$

Table 9. List of Paradox databases

LM	mean values for all parameters collected at the land mast
SMS	mean values for all parameters collected at SMS
SMW	mean values for all parameters collected at SMS
4W	mean values for all parameters collected at 4W
LM_STDV	standard deviations of wind speed and direction at the land mast
SMS_STDV	standard deviations of wind speed and direction at SMS
SMW_STDV	standard deviations of wind speed and direction at SMS
4W_STDV	standard deviations of all parameters collected at 4W
RUN_DEF	date and time of measurements identified by a run name
CUP_EXTR	minimum and maximum wind speeds at all masts

Table 10. Contents of Paradox tables

LM	**SMS**	**SMW**
Name	**Name**	**Name**
LM_WS_46	**SMS_WS_07**	**SMW_WS_07**
LM_WS_38	**SMS_WS_15**	**SMW_WS_15**
LM_WS_38N	**SMS_WS_20**	**SMW_WS_20**
LM_WS_20	**SMS_WS_29**	**SMW_WS_29**
LM_WS_07	**SMS_WS_38**	**SMW_WS_38**
LM_Sx_12	**SMS_WS_38N**	**SMW_WS_38N**
LM_Sy_12	**SMS_WS_43**	**SMW_WS_43**
LM_Sz_12	**SMS_WS_48**	**SMW_WS_48**
LM_ST_12	**SMS_WD_20**	**SMW_WD_20**
LM_SN_12	**SMS_WD_43**	**SMW_WD_43**
LM_WD_38	**SMS_T_10**	**SMW_T_10**
LM_WD_20	**SMS_dT_47_10**	**SMW_dT_47_10**
LM_T_10	**SMS_dT_24_10**	**SMW_dT_24_10**
LM_dT_47_10		**SMW_WT_00**
LM_dT_24_10		**SMW_SX_45**
Barometer		**SMW_SY_45**
Precip		**SMW_SZ_45**
Radiation		**SMW_ST_45**
		SMW_SU_45
		SMW_SD_45
		SMW_SX_18
		SMW_SY_18
		SMW_SZ_18
		SMW_ST_18
		SMW_SU_18
		SMW_SD_18
		SMW_SX_06
		SMW_SY_06
		SMW_SZ_06
		SMW_ST_06
		SMW_SU_06
		SMW_SD_06

LM_STDV	**SMS_STDV**	**SMW_STDV**
Name	**Name**	**Name**
LM_WS_46_stdev	**SMS_WS_07_stdev**	**SMW_WS_07_stdev**
LM_WS_38_stdev	**SMS_WS_15_stdev**	**SMW_WS_15_stdev**
LM_WS_38N_stdev	**SMS_WS_20_stdev**	**SMW_WS_20_stdev**
LM_WS_20_stdev	**SMS_WS_29_stdev**	**SMW_WS_29_stdev**
LM_WS_07_stdev	**SMS_WS_38_stdev**	**SMW_WS_38_stdev**
LM_Sx_12_stdev	**SMS_WS_38N_stdev**	**SMW_WS_38N_stdev**
LM_Sy_12_stdev	**SMS_WS_43_stdev**	**SMW_WS_43_stdev**
LM_Sz_12_stdev	**SMS_WS_48_stdev**	**SMW_WS_48_stdev**
LM_ST_12_stdev	**SMS_WD_20_stdev**	**SMW_WD_20_stdev**
LM_SN_12_stdev	**SMS_WD_43_stdev**	**SMW_WD_43_stdev**
LM_WD_38_stdev		
LM_WD_20_stdev		

4W	4W_STDV	5E*	5E_STDV*
Name	Name		
4W_Flap*	4W_Flap_stdev*		
4W_Edge	4W_Edge_stdev		
4W_RPos	4W_RPos_stdev		
4W_Yaw	4W_Yaw_stdev		
4W_TB_Mx	4W_TB_Mx_stdev		
4W_TB_My	4W_TB_My_stdev		
4w_Power*	4w_Power_stdev*		

RUN_DEF	CUP_EXTR	
run name	Name	
abs time	LM_WS_46_min	SMW_WS_07_min
year	LM_WS_46_max	SMW_WS_07_max
week	LM_WS_38_min	SMW_WS_15_min
date	LM_WS_38_max	SMW_WS_15_max
hour	LM_WS_38N_min	SMW_WS_20_min
min	LM_WS_38N_max	SMW_WS_20_max
sec	LM_WS_20_min	SMW_WS_29_min
duration	LM_WS_20_max	SMW_WS_29_max
param 1	LM_WS_07_min	SMW_WS_38_min
param 2	LM_WS_07_max	SMW_WS_38_max
param 3	SMS_WS_07_min	SMW_WS_38N_min
param 4	SMS_WS_07_max	SMW_WS_38N_max
param 5	SMS_WS_15_min	SMW_WS_43_min
byte 1	SMS_WS_15_max	SMW_WS_43_max
byte 2	SMS_WS_20_min	SMW_WS_48_min
byte 3	SMS_WS_20_max	SMW_WS_48_max
byte 4	SMS_WS_29_min	
byte 5	SMS_WS_29_max	
	SMS_WS_38_min	
	SMS_WS_38_max	
	SMS_WS_38N_min	
	SMS_WS_38N_max	
	SMS_WS_43_min	
	SMS_WS_43_max	
	SMS_WS_48_min	
	SMS_WS_48_max	

* missing
Name and run name are identical for each run.

Table 11. Description of the parameters in the run definition file

Run_name	Defining exclusively each half hour run as YYMMDDHHII (start time). YY - Year MM - Month DD - Day HH - Hour II - Minutes
abs time	Hours since Jan 1 1988 0000
year	Defining the precise start time of the run
week	"
date	"
hour	"
min	"
sec	"
duration	Duration of the run in seconds
param1	LM_WS_38
param 2	LM_WS_38_stdev
param 3	LM_WD_38
param 4	LM_WD_38_stdev
param 5	LM_dT_47_10
byte 1	Saved time series =1, else =0
byte 2	Sector bin (Truncated WD/2.0)
byte 3	Speed bin (Mean WS from 38m height at all masts)
byte 4	Rain=1, else=0
byte 5	not used

8 Specific Campaigns

The measurements from Vindeby have wide application. In addition to the ongoing data collection a number of intensive field campaigns are planned, the first will take place in April 1994 and the second in autumn 1994. During these periods extra instrumentation will be installed and time series will be collected continuously. These campaigns will be reported separately.

8.1 Sea Surface Temperatures (SST)

It is of interest to consider the temporal and spatial variability in SST. These variations will affect stability and hence wind speed, both vertically and spatially. Since SST is not routinely measured and certainly not on small spatial scales, we consider the possibility of using satellite data. Images are available twice daily from NOAA - providing 1km by 1km data twice daily at a cost of 800Kr per image. It is also possible to obtain 30m by 30m data but this is very expensive. Risø has the expertise to process images to obtain not only SST but also evaporation. Note that when there is cloud cover information is not extractable from these images.

Hansen et al. (1993) have looked at SST variability around Denmark. Under certain conditions cold Baltic Sea water flows to the south of Lolland and then up through Kattegat. This can give rise to large differences in temperature over relatively short distances. Hansen et al. (1993) also found the presence of 'cold spots'.

9 Conclusions

This report describes the basic instrumentation, data acquisition and storage of the Vindeby Project. A full site description is given, including roughness and fetch description, the location and size of obstacles near the land mast and the possible distortion of the wind flow by the mast structure and by obstacles. Since the project is ongoing it is not possible at the time of going to press for this report to be entirely complete.

10 Acknowledgements

Funding for the project has been provided by SK Power, the operators of the Vindeby wind farm, the European Commission, the Danish Ministry of Energy and ONR (Office of Naval Research).

We gratefully acknowledge the inspiration and help rendered in the definition and starting phases of the project by Søren Larsen, Peter Hauge Madsen, Sten Frandsen and Peter Hjuler Jensen.

Many people have been involved in establishing and running this project. In particular we would like to thank the technicians of the Meteorology and Electronics Departments who have spent many hours, often in harsh conditions, erecting and maintaining instruments. All the electronics for the project have been carried out with great efficiency by Risø's Electronics Department under the guidance of Ole Frost Hansen.

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Appendix I

Channel List (for sensors in operation at the time of going to press of this report 15th March 1994)

Ind	P	Title	Type	Bord	Hex	Ch	B	Gain	Offset	Units	Blk	rcms<>
1		LM WS 46	cup	ctm5	300	1	-	1.211E+00	3.050E-01	m/s	4	011111
2		LM WS 38	cup	ctm5	300	2	-	1.213E+00	3.010E-01	m/s	4	011111
3		LM WS 38N	cup	ctm5	300	3	-	1.222E+00	2.940E-01	m/s	4	011111
4		LM WS 20	cup	ctm5	300	4	-	1.212E+00	3.350E-01	m/s	4	011111
5		LM WS 07	cup	ctm5	300	5	-	1.218E+00	2.840E-01	m/s	4	011111
6		LM sin 38	anal	AD08	308	2	-	2.447E-03	-5.010E+00	V	4	001111
7		LM cos 38	anal	AD08	308	1	-	2.447E-03	-5.010E+00	V	4	001111
8		LM WD 38	dir	AD08	308	0	-	2.000E-02	2.640E+02	°	4	011111
9		LM sin 20	anal	AD08	308	4	-	2.447E-03	-5.010E+00	V	4	001111
10		LM cos 20	anal	AD08	308	3	-	2.447E-03	-5.010E+00	V	4	001111
11		LM WD 20	dir	AD08	308	0	-	2.000E-02	3.540E+02	°	4	011111
12		LM T 10	anal	AD08	308	5	-	4.404E-02	-1.202E+02	°C	20	001111
13		LM dT 47-10	anal	AD08	308	6	-	4.893E-03	-1.002E+01	°C	20	001111
14		LM dT 24-10	anal	AD08	308	7	-	4.893E-03	-1.002E+01	°C	20	001111
15		Precip	anal	AD08	308	9	-	2.447E-03	-5.010E+00	???	20	001111
16		Barometer	anal	AD08	308	10	-	4.893E-02	8.998E+02	mbar	20	001111
17		Radiation	anal	AD08	308	8	-	2.447E-03	-5.010E+00	V	20	001111
18		LM SX 07	ser		308	1	-	1.000E-02	-1.000E+02	m/s	1	011111
19		LM SY 07	ser		308	2	-	1.000E-02	-1.000E+02	m/s	1	011111
20		LM SZ 07	ser		308	3	-	1.000E-02	-1.000E+02	m/s	1	011111
21		LM ST 07	ser		308	4	-	2.500E-03	-4.000E+01	m/s	1	011111
22		LM SU 07	extn		308	0	-	1.000E-02	-1.000E+02	m/s	1	001111
23		LM SD 07	extn		308	0	-	1.000E-02	-1.000E+02	°	1	001111
24		LM SC 07	ser		308	6	-	1.000E+00	0.000E+00		1	001111
25		LM VT 07	ser		308	1	-	1.250E-02	-2.000E+02	°C	20	011111
26		LM RH 07	ser		308	2	-	1.000E-01	-1.000E+03	%	20	011111
27		LM SX 12	ser		308	1	-	1.000E-02	-1.000E+02	m/s	1	011111
28		LM SY 12	ser		308	2	-	1.000E-02	-1.000E+02	m/s	1	011111
29		LM SZ 12	ser		308	3	-	1.000E-02	-1.000E+02	m/s	1	011111
30		LM ST 12	ser		308	4	-	2.500E-03	-4.000E+01	m/s	1	011111
31		LM SC 12	ser		308	6	-	1.000E+00	0.000E+00		1	001111
32		LM SU 12	extn		308	0	-	1.000E+00	0.000E+00	m/s	1	001111
33		LM SD 12	extn		308	0	-	1.000E+00	0.000E+00	°	1	001111
34		LM VT 10	ser	COM8	308	1	1	1.250E-02	-2.000E+02	°C	20	011111
35		LM RH 10	ser	COM8	308	2	1	1.000E-01	-1.000E+03	%	20	011111
36		SMS WS 48	ser	COM5	308	1	17	2.500E-03	0.000E+00	m/s	4	011111
37		SMS WS 43	ser	COM5	308	2	17	2.500E-03	0.000E+00	m/s	4	011111
38		SMS WS 38	ser	COM5	308	3	17	2.500E-03	0.000E+00	m/s	4	011111
39		SMS WS 38N	ser	COM5	308	4	17	2.500E-03	0.000E+00	m/s	4	011111
40		SMS WS 29	ser	COM5	308	5	17	2.500E-03	0.000E+00	m/s	4	011111
41		SMS WS 20	ser	COM5	308	6	17	2.500E-03	0.000E+00	m/s	4	011111
42		SMS WS 15	ser	COM5	308	7	17	2.500E-03	0.000E+00	m/s	4	011111
43		SMS WS 07	ser	COM5	308	8	17	2.500E-03	0.000E+00	m/s	4	011111
44		SMS sin 20	ser	COM5	308	9	17	2.440E-03	-4.998E+00	V	4	001111
45		SMS cos 20	ser	COM5	308	10	17	2.440E-03	-4.998E+00	V	4	001111
46		SMS WD 20	dir	COM5	308	0	17	1.200E-02	2.300E+01	°	4	011111
47		SMS sin 43	ser	COM5	308	12	17	2.440E-03	-4.998E+00	V	4	001111
48		SMS cos 43	ser	COM5	308	13	17	2.440E-03	-4.998E+00	V	4	001111
49		SMS WD 43	dir	COM5	308	0	17	1.200E-02	2.300E+01	°	4	011111
50		SMS T 10	ser	COM5	308	17	17	4.393E-02	-1.200E+02	°C	20	001111

51	SMS dT 47-10	ser	COM5	308	15	17	4.880E-03	-9.997E+00	°C	20	001111
52	SMS dT 24-10	ser	COM5	308	16	17	4.880E-03	-9.997E+00	°C	20	001111
53	SMW WS 48	ser	COM6	308	1	42	2.500E-03	0.000E+00	m/s	4	011111
54	SMW WS 43	ser	COM6	308	2	42	2.500E-03	0.000E+00	m/s	4	011111
55	SMW WS 38	ser	COM6	308	3	42	2.500E-03	0.000E+00	m/s	4	011111
56	SMW WS 38N	ser	COM6	308	4	42	2.500E-03	0.000E+00	m/s	4	011111
57	SMW WS 29	ser	COM6	308	5	42	2.500E-03	0.000E+00	m/s	4	011111
58	SMW WS 20	ser	COM6	308	6	42	2.500E-03	0.000E+00	m/s	4	011111
59	SMW WS 15	ser	COM6	308	7	42	2.500E-03	0.000E+00	m/s	4	011111
60	SMW WS 07	ser	COM6	308	8	42	2.500E-03	0.000E+00	m/s	4	011111
61	SMW sin 43	ser	COM6	308	9	42	2.440E-03	-4.993E+00	V	4	001111
62	SMW cos 43	ser	COM6	308	10	42	2.440E-03	-4.993E+00	V	4	001111
63	SMW WD 43	dir	COM6	308	0	42	1.200E-02	7.500E+01	°	4	011111
64	SMW sin 20	ser	COM6	308	12	42	2.440E-03	-4.993E+00	V	4	001111
65	SMW cos 20	ser	COM6	308	13	42	2.440E-03	-4.993E+00	V	4	001111
66	SMW WD 20	dir	COM6	308	0	42	1.200E-02	7.500E+01	°	4	011111
67	SMW SX 45	ser	COM6	308	31	42	1.000E-02	-1.000E+02	V	1	011111
68	SMW SY 45	ser	COM6	308	32	42	1.000E-02	-1.000E+02	V	1	011111
69	SMW SZ 45	ser	COM6	308	33	42	1.000E-02	-1.000E+02	V	1	011111
70	SMW ST 45	ser	COM6	308	34	42	2.500E-03	-4.000E+01	°C	1	011111
71	SMW SU 45	extn	COM6	308	0	42	1.000E-02	-1.000E+02	m/s	1	001111
72	SMW SD 45	extn	COM6	308	0	42	1.000E-02	-1.000E+02	°	1	001111
73	SMW SX 18	ser	COM6	308	35	42	1.000E-02	-1.000E+02	V	1	011111
74	SMW SY 18	ser	COM6	308	36	42	1.000E-02	-1.000E+02	V	1	011111
75	SMW SZ 18	ser	COM6	308	37	42	1.000E-02	-1.000E+02	V	1	011111
76	SMW ST 18	ser	COM6	308	38	42	2.500E-03	-4.000E+01	°C	1	011111
77	SMW SU 18	extn	COM6	308	0	42	1.000E-02	-1.000E+02	m/s	1	001111
78	SMW SD 18	extn	COM6	308	0	42	1.000E-02	-1.000E+02	°	1	001111
79	SMW SX 06	ser	COM6	308	39	42	1.000E-02	-1.000E+02	V	1	011111
80	SMW SY 06	ser	COM6	308	40	42	1.000E-02	-1.000E+02	V	1	011111
81	SMW SZ 06	ser	COM6	308	41	42	1.000E-02	-1.000E+02	V	1	011111
82	SMW ST 06	ser	COM6	308	42	42	2.500E-03	-4.000E+01	°C	1	011111
83	SMW SU 06	extn	COM6	308	0	42	1.000E-02	-1.000E+02	m/s	1	001111
84	SMW SD 06	extn	COM6	308	0	42	1.000E-02	-1.000E+02	°	1	001111
85	SMW T 10	ser	COM6	308	17	42	4.392E-02	-1.199E+02	°C	20	001111
86	SMW dT 47-10	ser	COM6	308	15	42	4.880E-03	-9.986E+00	°C	20	001111
87	SMW dT 24-10	ser	COM6	308	16	42	4.880E-03	-9.986E+00	°C	20	001111
88	SMW WT 00	ser	COM6	308	19	42	4.880E-02	-1.249E+02	°C	20	001111
89	4W Edge	ser	COM6	308	21	42	9.760E-03	-1.997E+01	mA	1	011111
90	4W RP sin	ser	COM6	308	24	42	2.440E-03	-4.993E+00	V	1	001111
91	4W RP cos	ser	COM6	308	23	42	2.440E-03	-4.993E+00	V	1	001111
92	4W RPos	dir	COM6	308	0	42	1.250E-02	0.000E+00	°	1	011111
93	4W Yaw sin	ser	COM6	308	26	42	2.440E-03	-4.993E+00	V	20	001111
94	4W Yaw cos	ser	COM6	308	25	42	2.440E-03	-4.993E+00	V	20	001111
95	4W Yaw	dir	COM6	308	0	42	1.250E-02	0.000E+00	°	20	011111
96	4W TB Mx	ser	COM6	308	27	42	2.440E-03	-4.998E+00	V	1	011111
97	4W TB My	ser	COM6	308	28	42	2.440E-03	-4.998E+00	V	1	011111

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Abstract (Max. 2000 characters)

The Vindeby monitoring project has been established to provide information on the world's first offshore wind farm at Vindeby, Denmark. The project will consider all aspects of offshore meteorology which are relevant to offshore wind energy production in addition to turbine loading and behaviour in offshore conditions. This report contains a description of the site, including obstacles, roughness and fetch. The instrumentation used on each mast is described. Details of the data acquisition and the structure of the data bases holding the observations are given. Possible distortion of the wind flow at both land and sea masts has also been considered.

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