

Annex A1 Specification of the holec WPS-30/3 wind turbine

Type	:	HAWT
Rotor	:	upwind
Number of blades	:	3
Blade material	:	steel
Rotor diameter	:	30.1 m
Blade root radius	:	1.14 m ¹⁾
Blade profiles	:	NACA 230xxx series
Mass of one blade	:	1800 kg
Mass of blade foot	:	1360 kg
Mass of rotor (incl. hub)	:	15400 kg
First flap-wise		
Own-frequency	:	3.35 Hz
Rotor rotation direction	:	clockwise (looking downwind)
Tilt angle	:	5.5°
Cone angle	:	0.0°
Tower material	:	steel
Tower diameter	-base	: 3.2 m
	-top	: 1.32 m
Tower height	:	35 m
Distance rotor-tower	:	1.67 m (at hub height)
Rated Power	:	310 kW
Rated wind speed	:	14 m/s
Cut-in wind speed	:	5 m/s
Cut-out wind speed	:	20 m/s
Generator	:	synchronous with DC link
Control	:	variable speed/ variable pitch

¹⁾ The blade root is defined to be the position of the outer bearing of the blade, see figure 5 the blade lay-out

Annex A2 Specification of the extra instrumentation on turbine T36

Channels

blades and hub

8 strain gauges on each blade

4 strain gauges on the hub

strain gauges on the joint between hub and blades

rest of turbine

torque on the main shaft

torque on the fast shaft

bending moments in N-S and E-W directions 6 m below the tower top

bending moments in N-S and E-W directions 4 m above the tower base

pitch angle

blade position

nacelle direction

Electrical and control signals

field voltage of the generator

field current of the generator

voltage of all 3 phases of the generator

current of all 3 phases of the generator

frequency of the generator

set point field current

set point DC current

set point pitch angle

DC voltage

DC current turbine

DC current converter

voltage of all phase of the 10 kV grid connection

All above signals are sampled at a 32 Hz rate

Annex A3 Data transformation and averaging

A3.1 Co-ordinate transformation

The various quantities are measured in a frame of reference fixed to the wind farm, having co-ordinates X, Y and Z. X is horizontal, Y is horizontal and perpendicular to X, and Z points vertically upwards. X, Y, Z form a right handed co-ordinate system.

Scalar quantities, vectors, as well as tensor quantities (Reynolds-stresses) are measured in the fixed frame of reference. For analysis purposes these quantities need to be transformed to the wind frame of reference U, V, W. U is in the direction of the average undisturbed wind speed, V is perpendicular to the wind and W is vertical. Again a right handed frame of reference is used. For a definition of the two coordinate systems see figure 3.2. The directions of X and U are at an angle δ . The transformation from the fixed co-ordinate system to the wind co-ordinate system is hence a simple rotation about the Z-axis over an angle δ . The transformation matrix is given by:

$$\Delta_{ij} = \begin{bmatrix} \cos \delta & -\sin \delta & 0 \\ \sin \delta & \cos \delta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Scalars are insensitive to a rotation of the frame of reference and thus need not to be transformed. However the components of a vector are affected by a rotation of the frame of reference. The components in the wind frame of reference are found by applying the following expression:

$$U_{wind, i} = \sum_{j=1}^3 \Delta_{ij} \cdot U_{x, j}$$

The components of a tensor are changed according to the following transformation formula

$$T_{ij}' = \sum_{k=1}^3 \sum_{l=1}^3 \Delta_{ik} T_{kl} \Delta_{lj}^T$$

A3.2 Merging of 1-minute records to obtain multiple-minute averages

The data-base consists of records with one-minute averages of the measured quantities. However, for further analysis it is necessary to use multiple-minute records (for instance 3-minutes averages as was done in this report). It is possible to obtain averages over several minutes, combining subsequent records without losing accuracy using the formulas given below.

A distinction is made between linear averaged quantities (wind speed, power, wind direction, etc.) and non-linear quantities, such as the variance of the given quantities.

Linear averaged quantities

Subsequent records are simply averaged arithmetically to obtain the multiple-minute averaged value:

$$\mu_M = \frac{1}{M} \sum_{m=1}^M \mu_m$$

μ_M denotes the overall mean, μ_m denotes the means of the separate records.

Quadratic averaged quantities

Co-variance and variance mean values cannot be found by simply averaging their record values, but should be corrected for the variance and covariance of the record means.

The overall covariance is found in the following way:

$$(u'_i u'_j)_M = \frac{1}{M} \sum_{m=1}^M (u'_i u'_j)_m = \frac{1}{M} \sum_{m=1}^M (\mu_{i,m} - \mu_{i,M}) (\mu_{j,m} - \mu_{j,M})$$

μ_m and μ_M are as defined before. $(u'_i u'_j)_M$ denotes the overall average of the co-variance. $(u'_i u'_j)_m$ denotes the average of the co-variance in record m.

Calculating the average variance is a special case of this expression and is found by taking equal i and j.

$$\sigma_{i,M}^2 = \frac{1}{M} \sum_{m=1}^M \sigma_{i,m}^2 + \frac{1}{M} \sum_{m=1}^M (\mu_{i,m} - \mu_{i,M})^2$$

$\sigma_{i,M}$ denotes the overall variance of the i-component, $\sigma_{i,m}$ denotes the variance of record m.

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

Annex A4 Figures

In this annex a comprehensive overview is given of the analysis results. The results are given in the following order:

1. Results of sensor a2
2. Results of sensor b1
3. Results of sensor b2h
4. Results of sensor b2
5. Results of sensor b2l
6. Results of sensor b3
7. Results of sensor c2
8. Vertical profiles
9. Horizontal profiles

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.1 Sensor a2

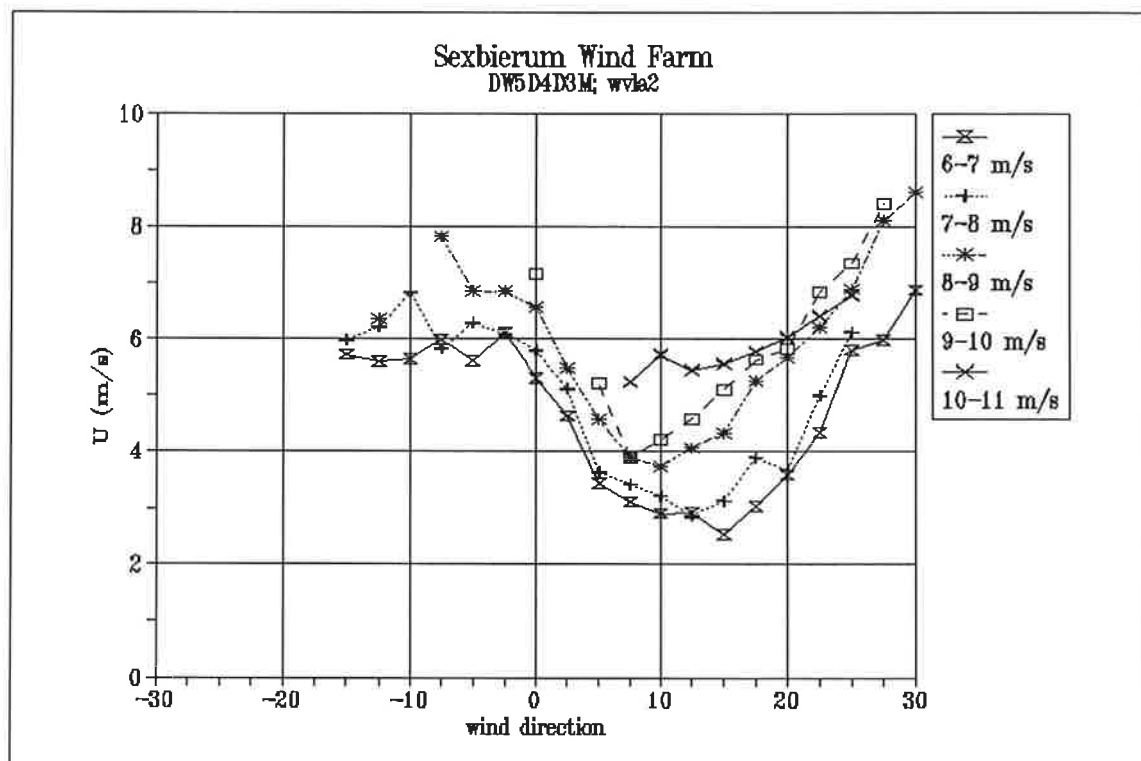


Figure 1 Horizontal wind speed U as a function of wind direction and wind speed bin

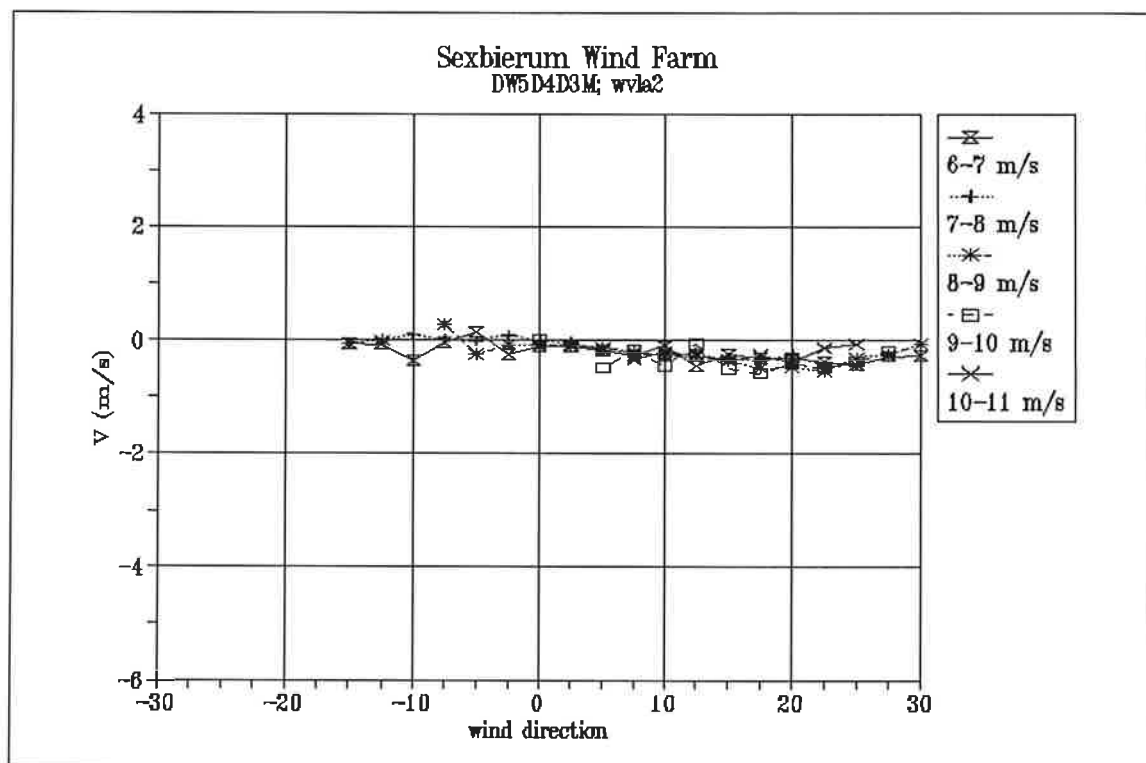


Figure 2 Lateral wind speed V as a function of wind direction and wind speed bin

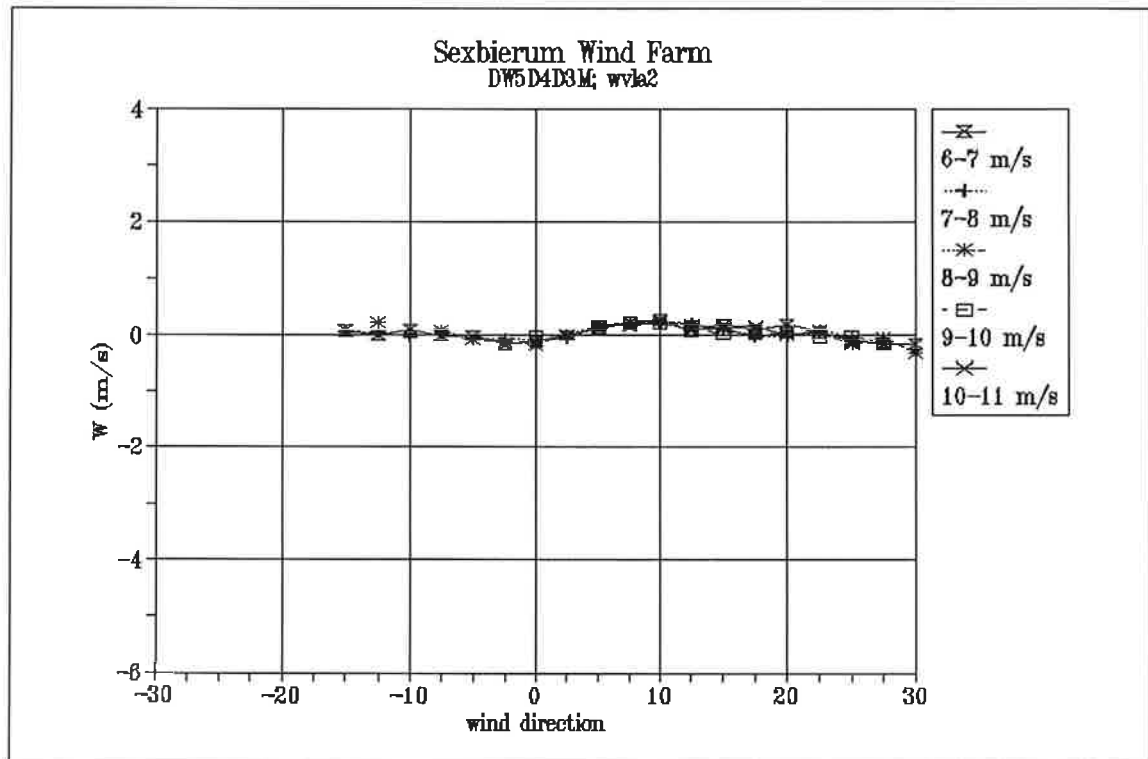


Figure 3 Vertical wind speed W as a function of wind direction and wind speed bin

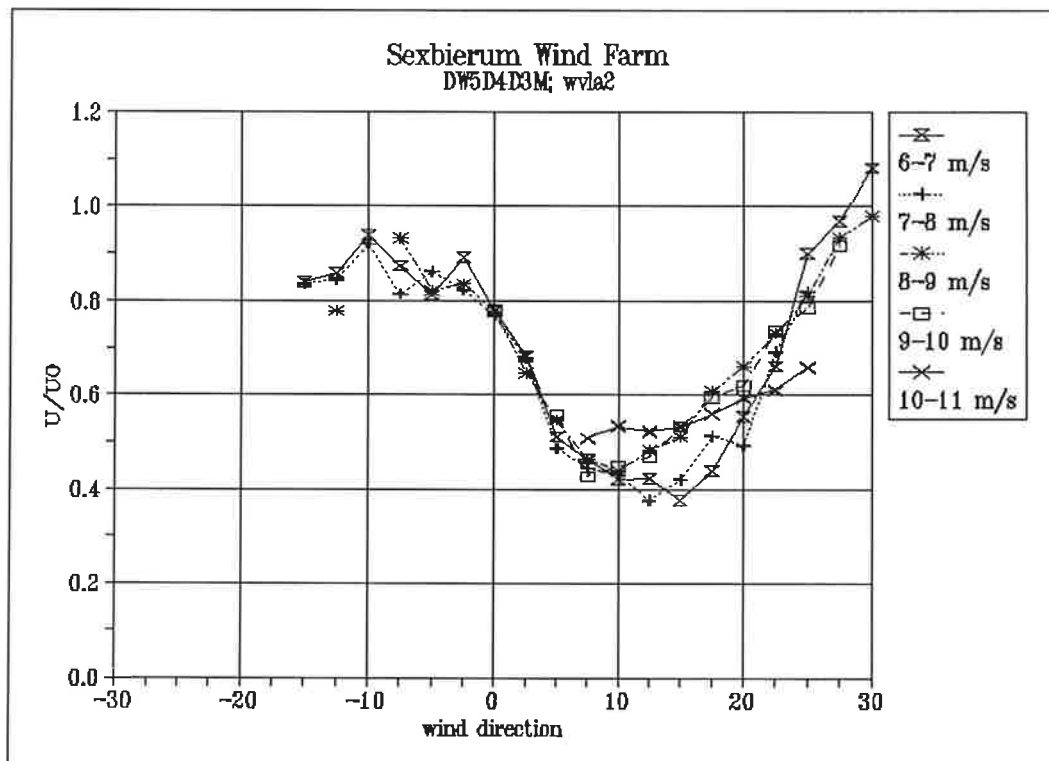


Figure 4 Wake deficit U/U_0 as a function of wind direction and wind speed bin

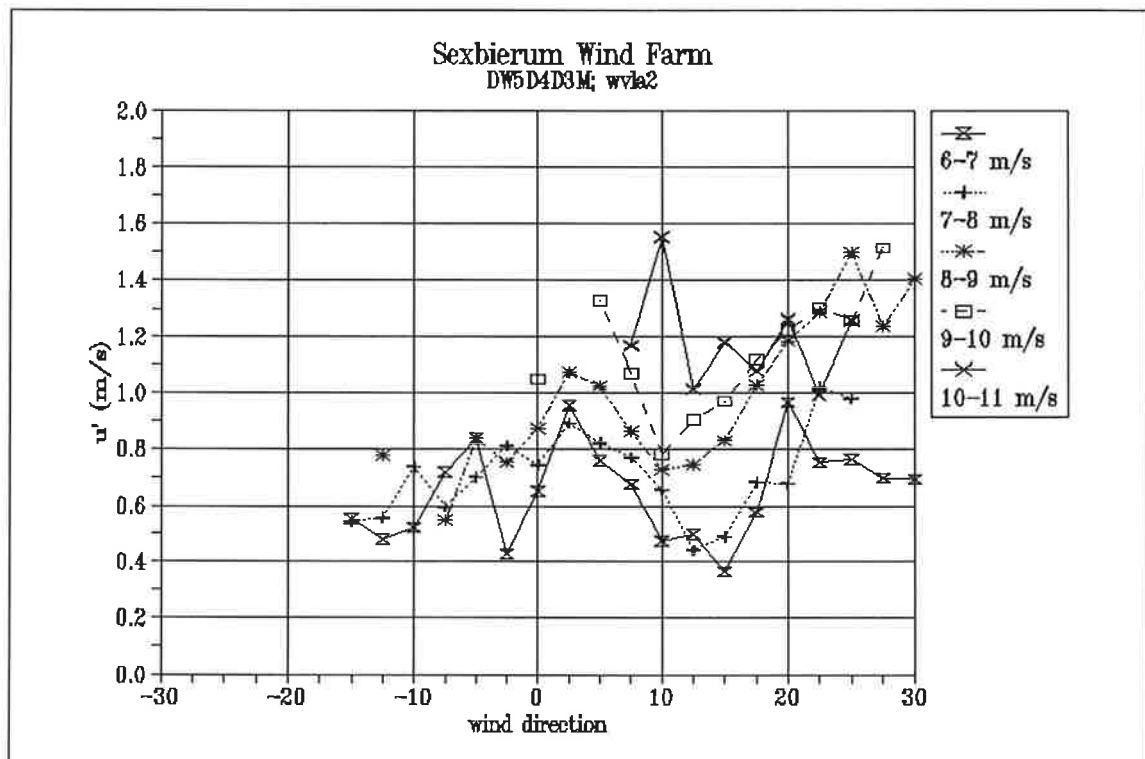


Figure 5 Longitudinal turbulent fluctuations u' as a function of wind direction and wind speed bin

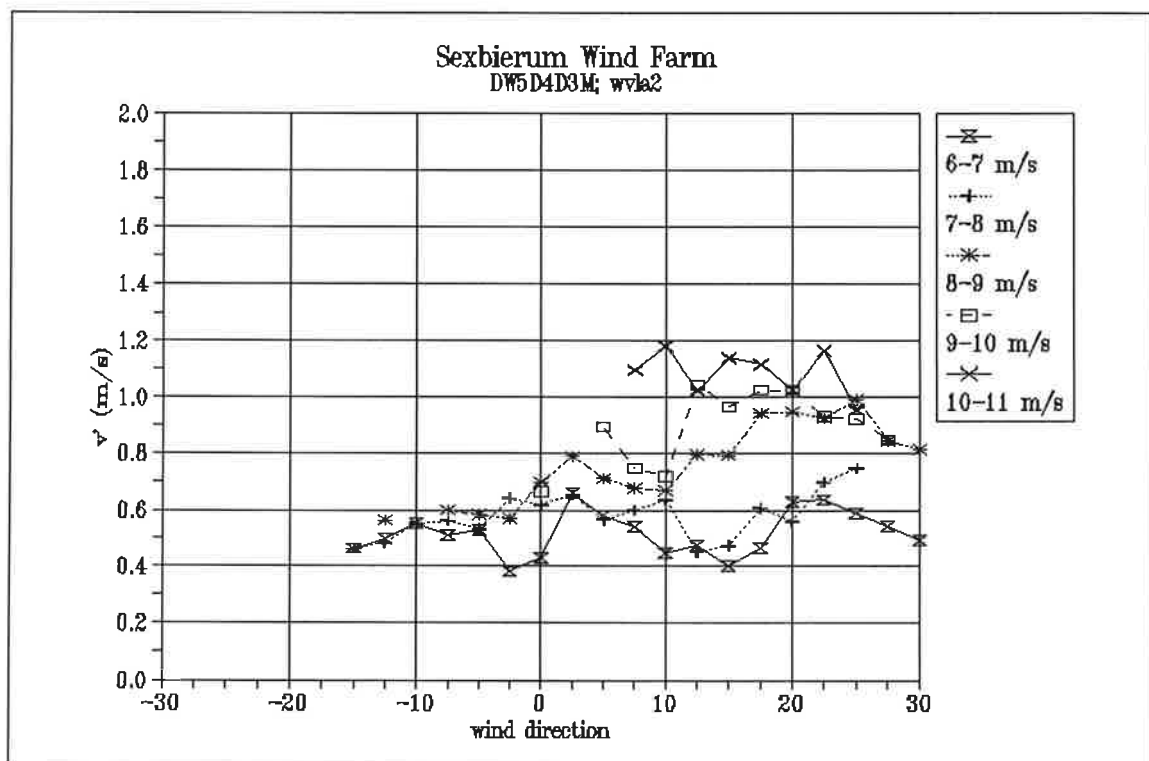


Figure 6 Lateral turbulent fluctuations v' as a function of wind direction and wind speed bin

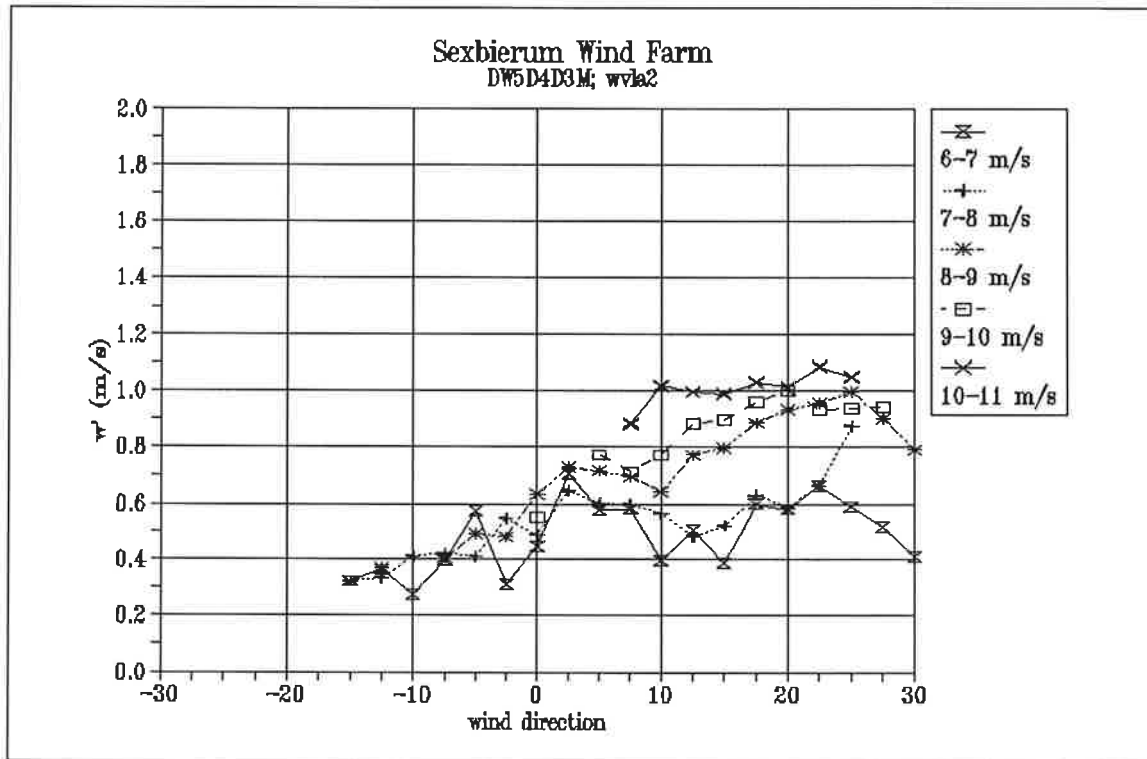


Figure 7 Vertical turbulent fluctuations w' as a function of wind direction and wind speed bin

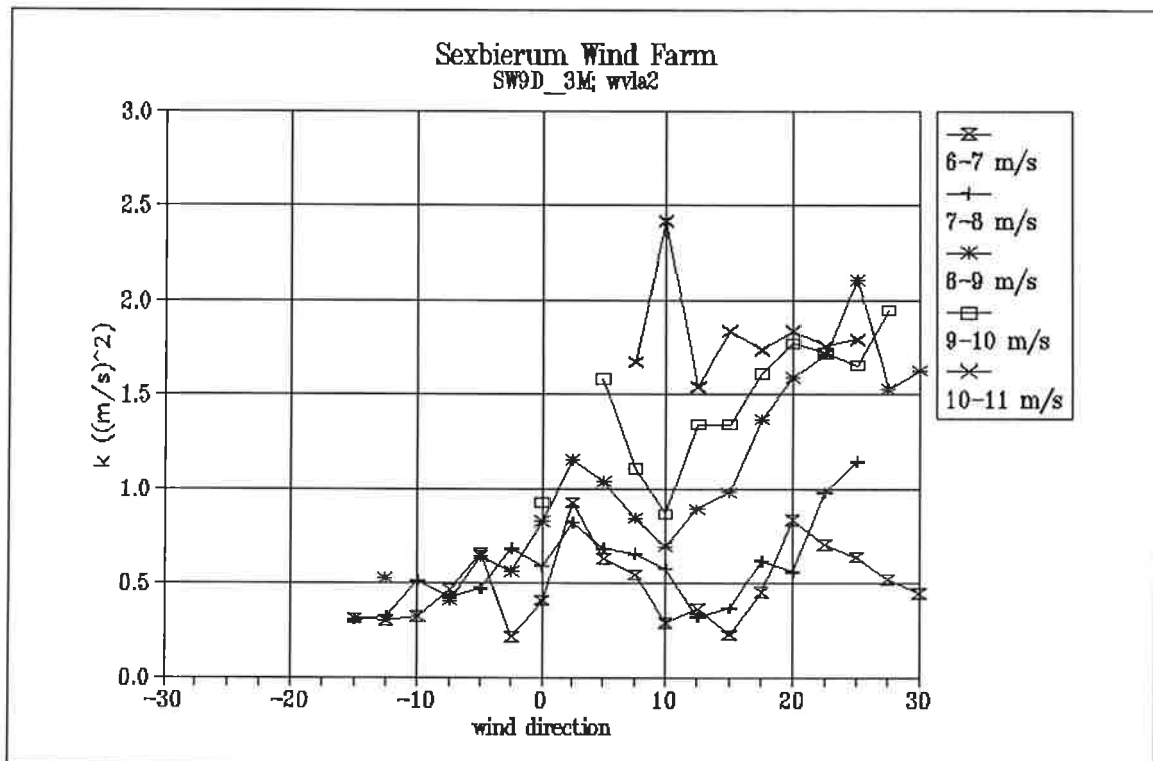


Figure 8 Turbulent kinetic energy per unit mass as a function of wind direction and wind speed bin

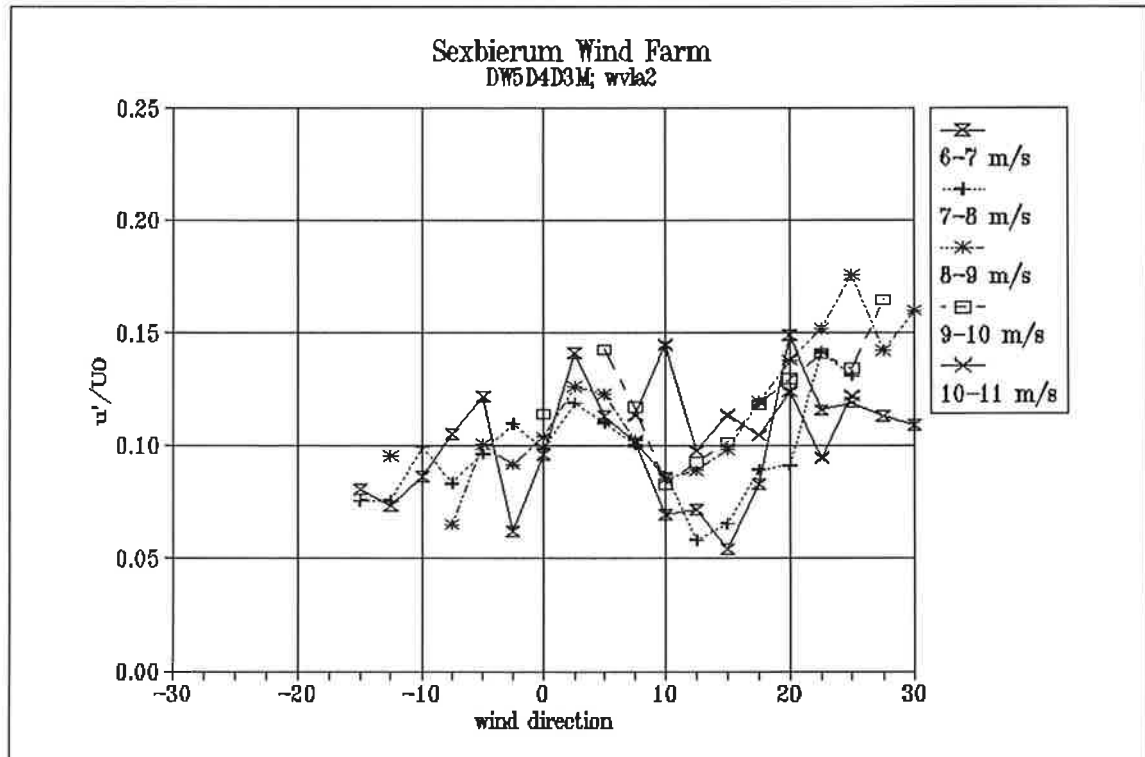


Figure 9 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

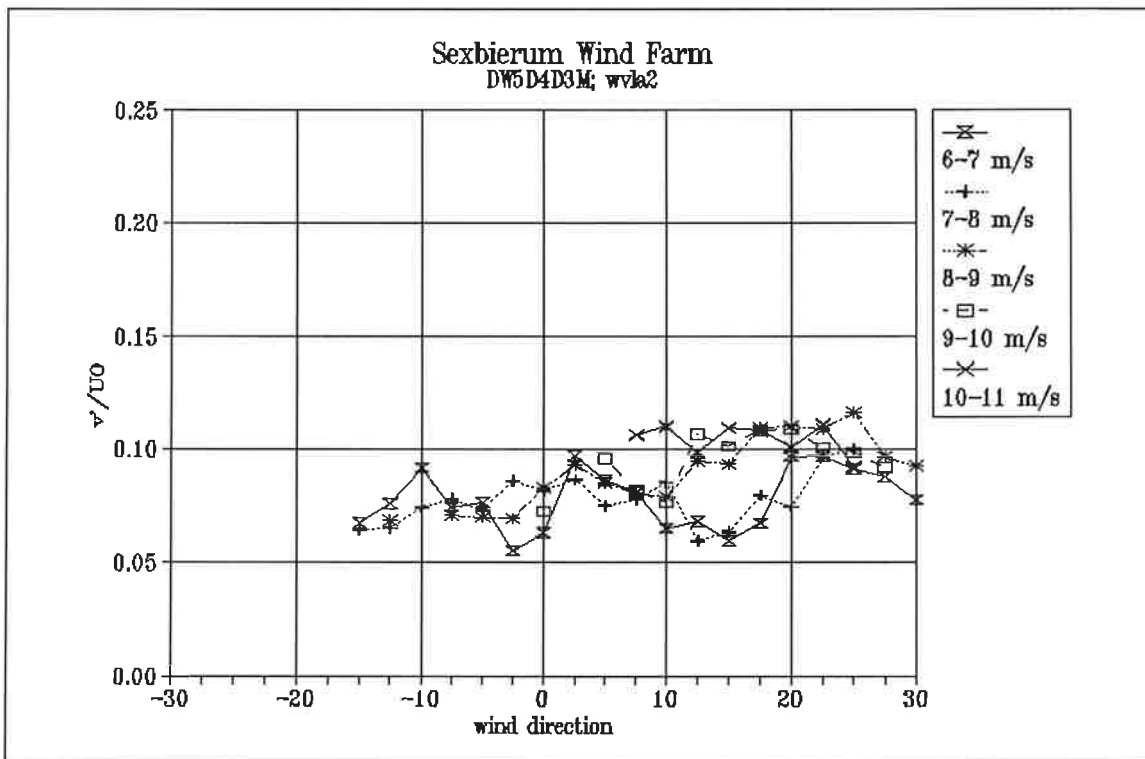


Figure 10 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction and wind speed bin

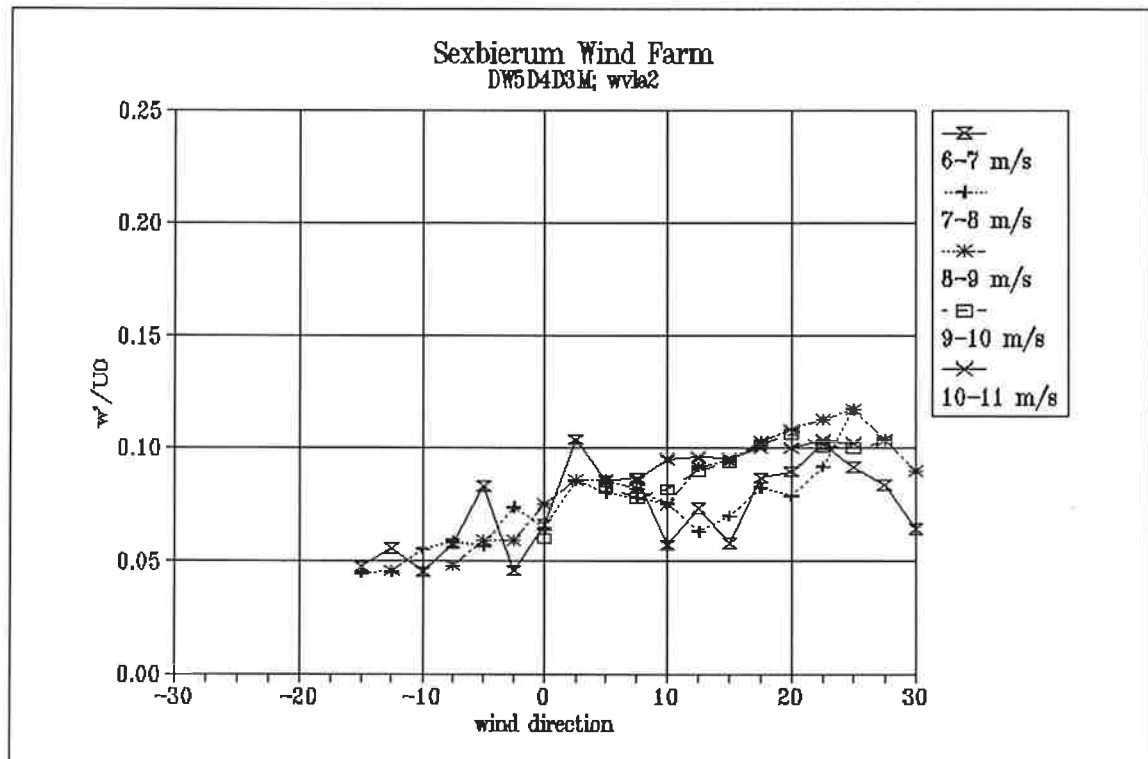


Figure 11 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction and wind speed bin

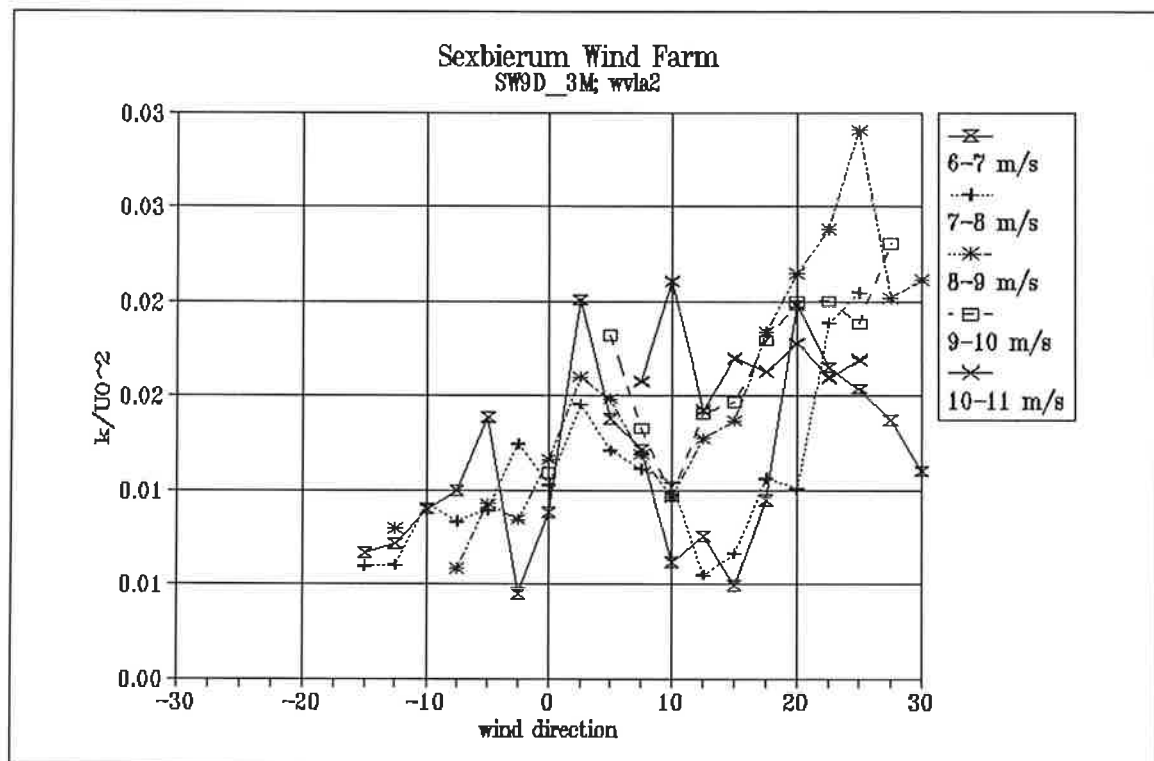


Figure 12 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction and wind speed bin

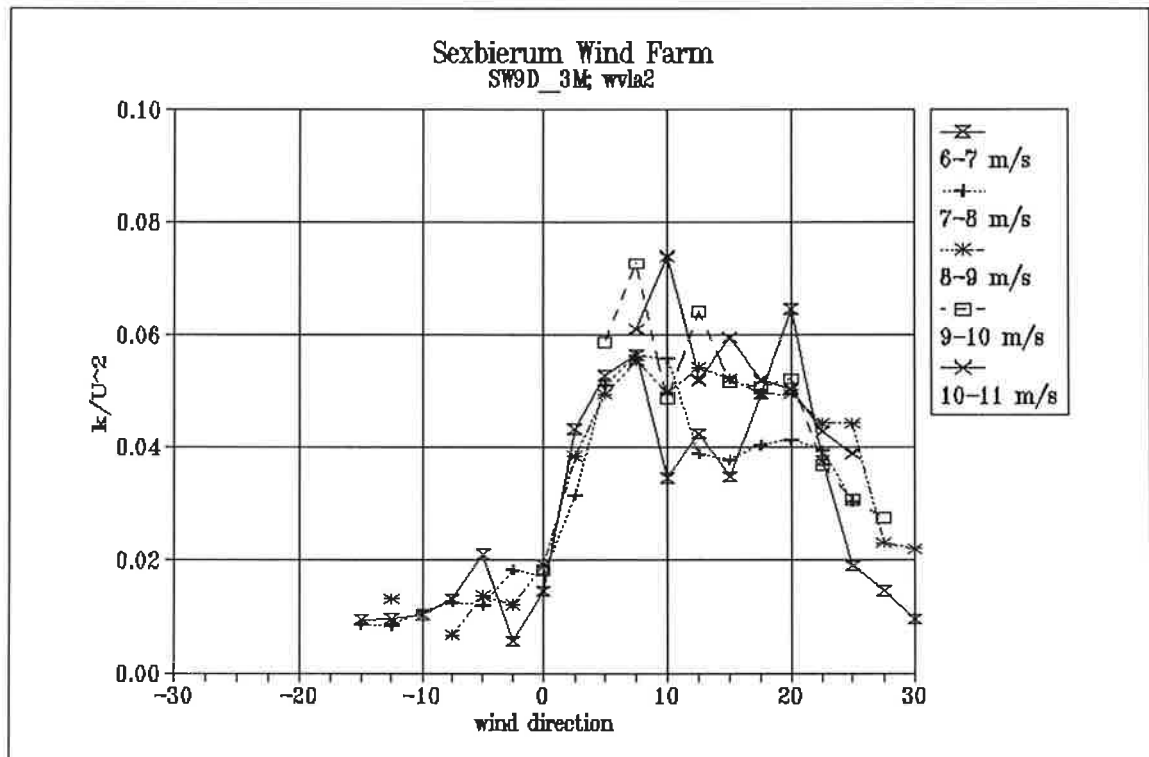


Figure 13 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction and wind speed bin

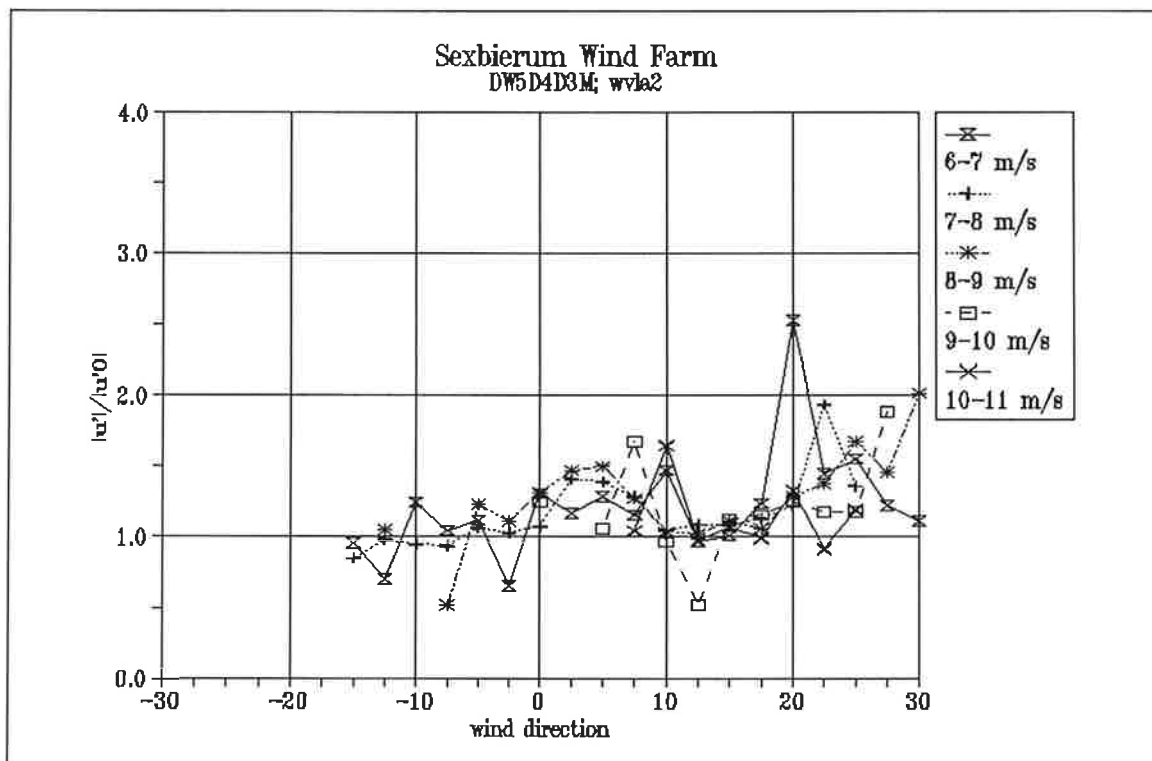


Figure 14 Longitudinal turbulence enhancement $u'u'/u_0^2$ as a function of wind direction and wind speed bin

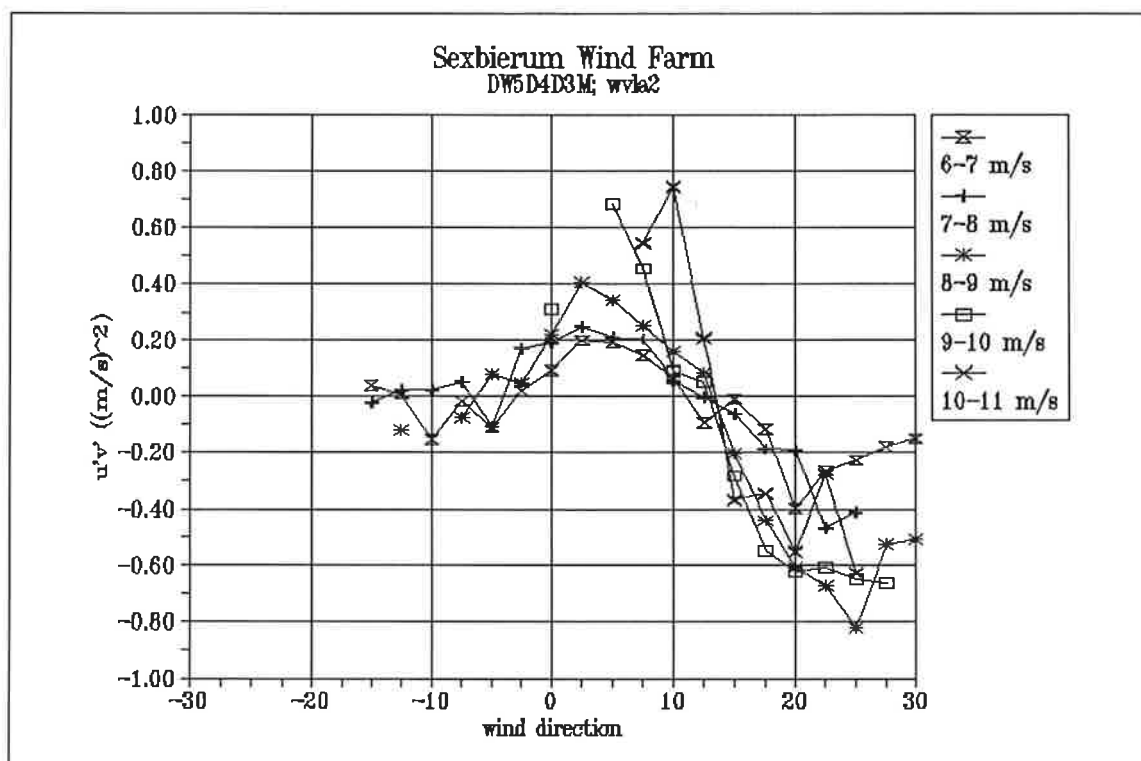


Figure 15 Shear stress $u'v'$ as a function of wind direction and wind speed bin

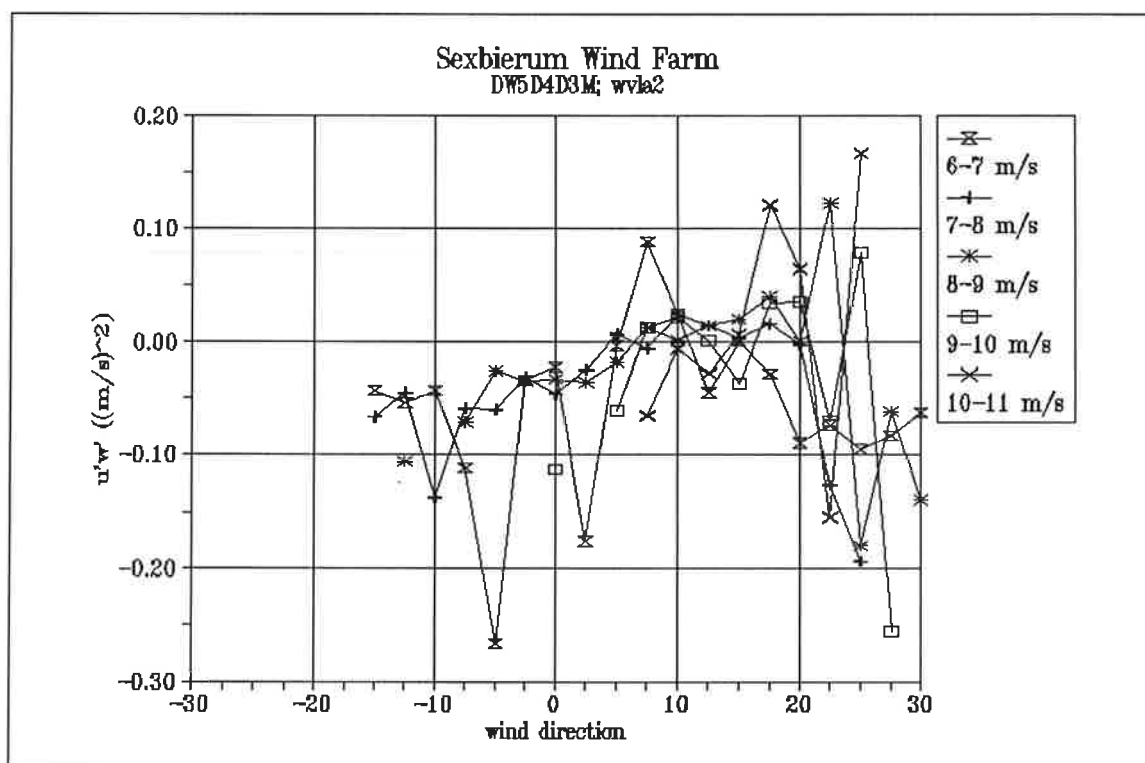


Figure 16 Shear stress $u'w'$ as a function of wind direction and wind speed bin

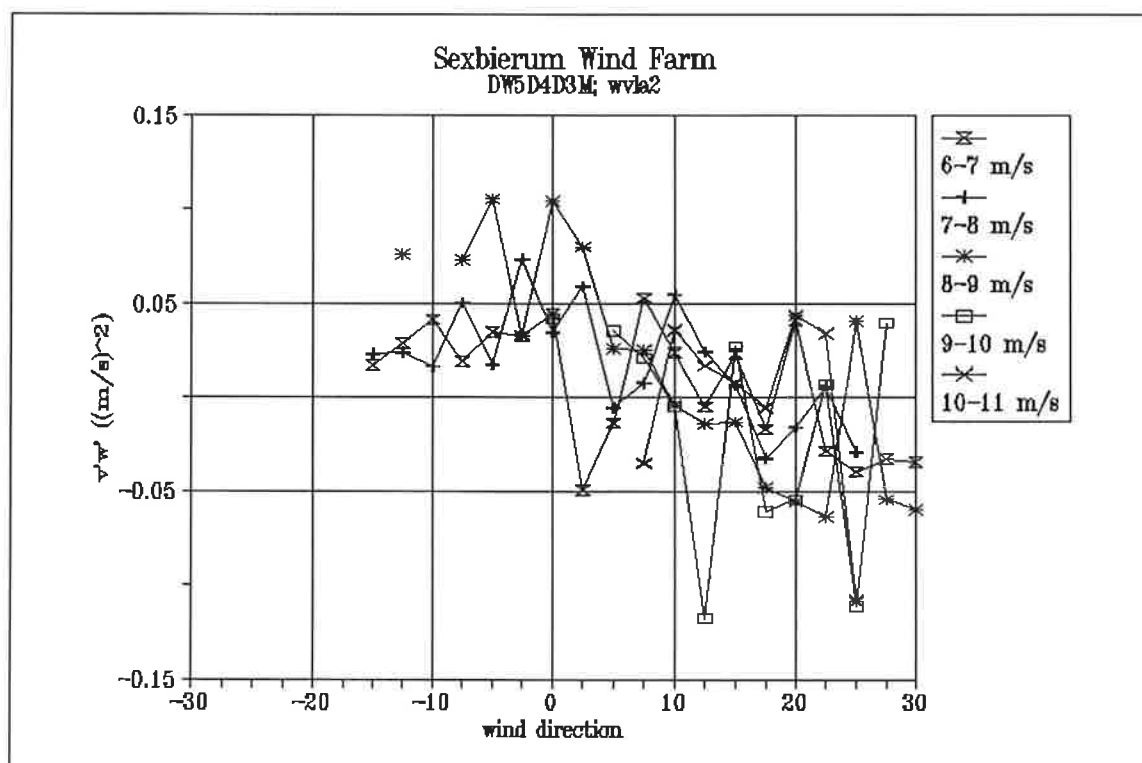


Figure 17 Shear stress $v'w'$ as a function of wind direction and wind speed bin

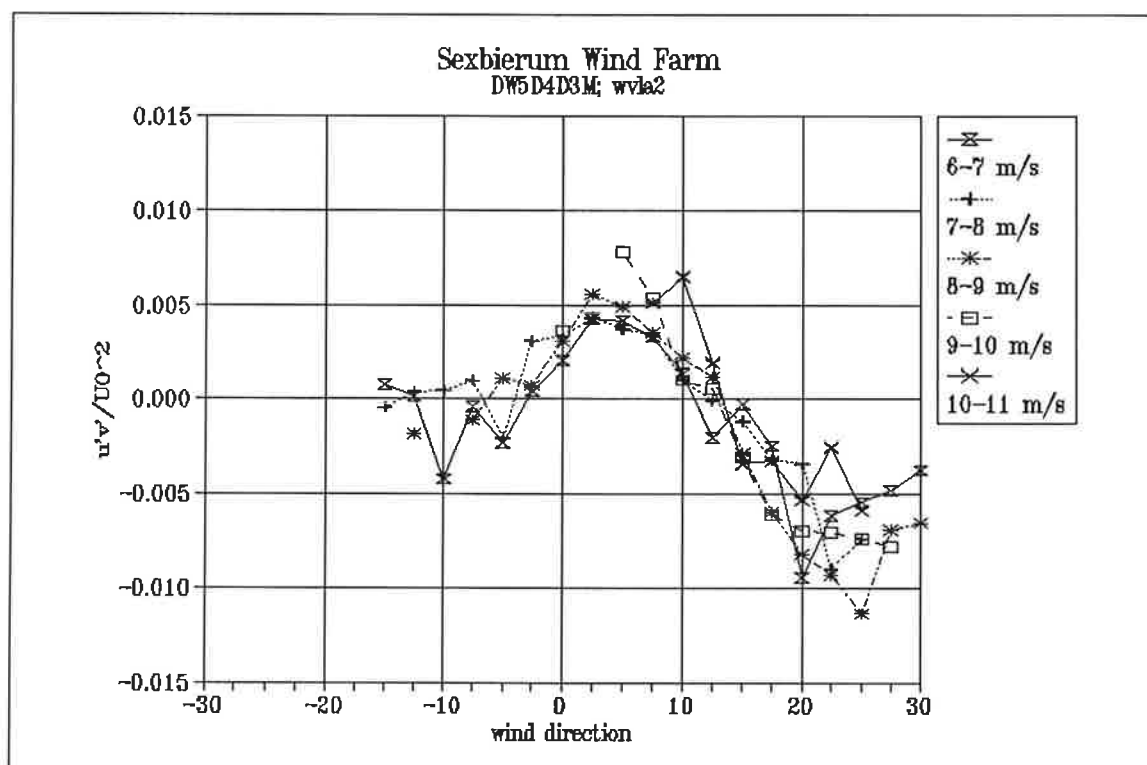


Figure 18 Non-dimensionalized shear stress $u'v'/U_0^2$ as a function of wind direction and wind speed bin

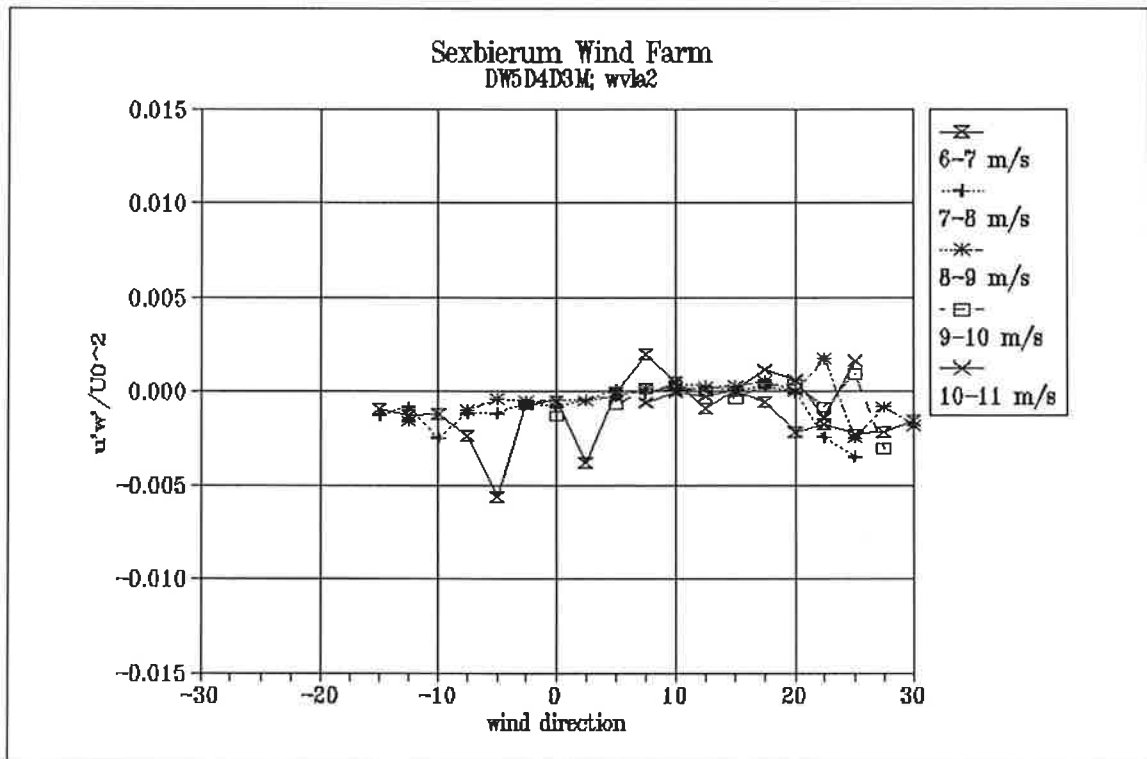


Figure 19 Non-dimensionalized shear stress $u'w'/U_0^2$ as a function of wind direction and wind speed bin

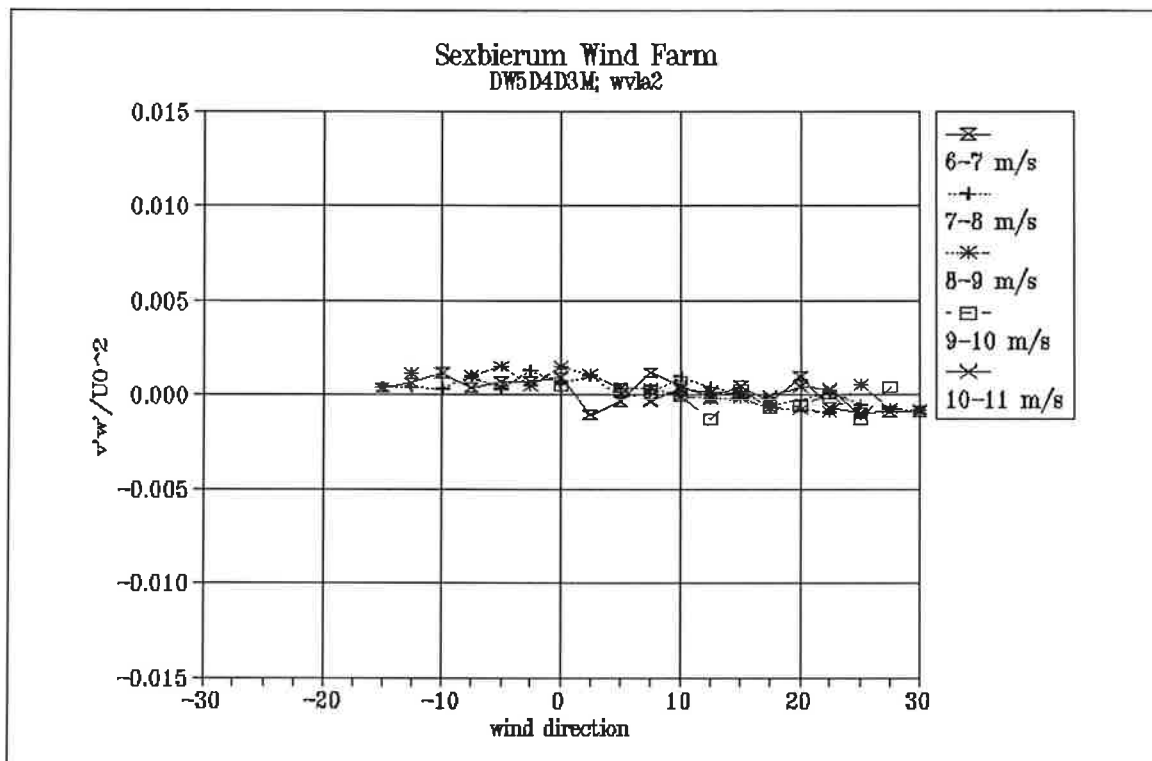


Figure 20 Non-dimensionalized shear stress $v'w'/U_0^2$ as a function of wind direction and wind speed bin

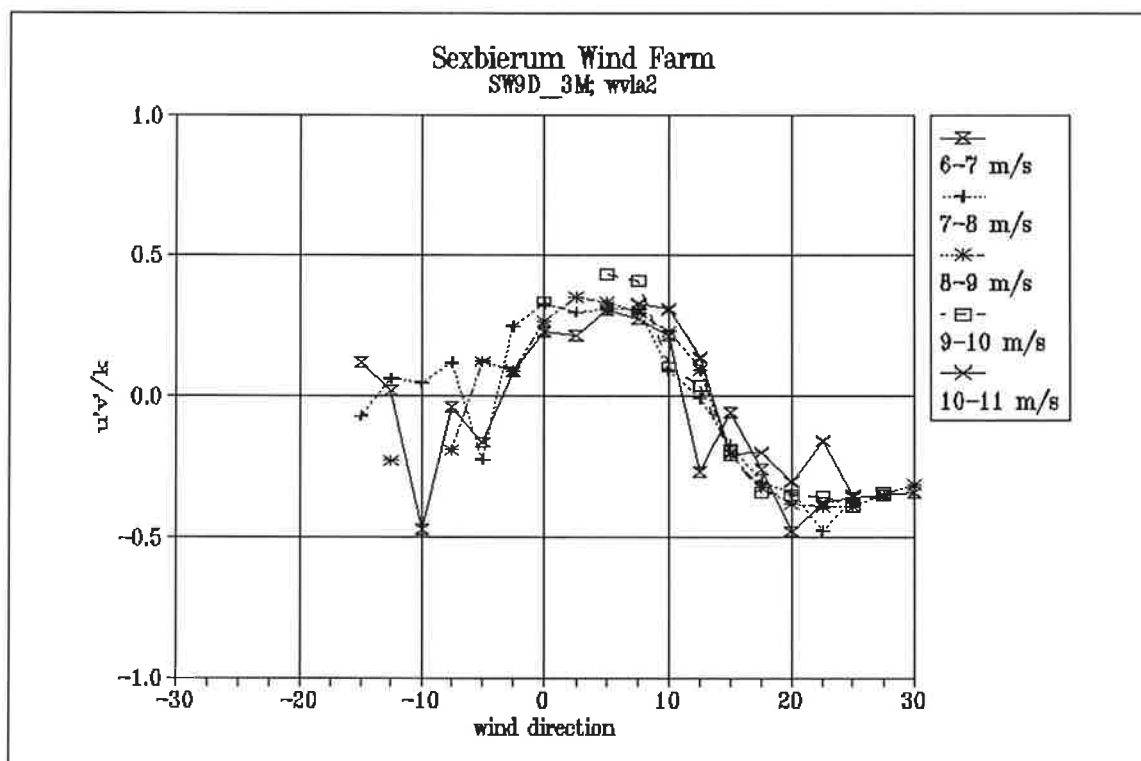


Figure 21 Non-dimensionalized shear stress $u'v'/k$ as a function of wind direction and wind speed bin

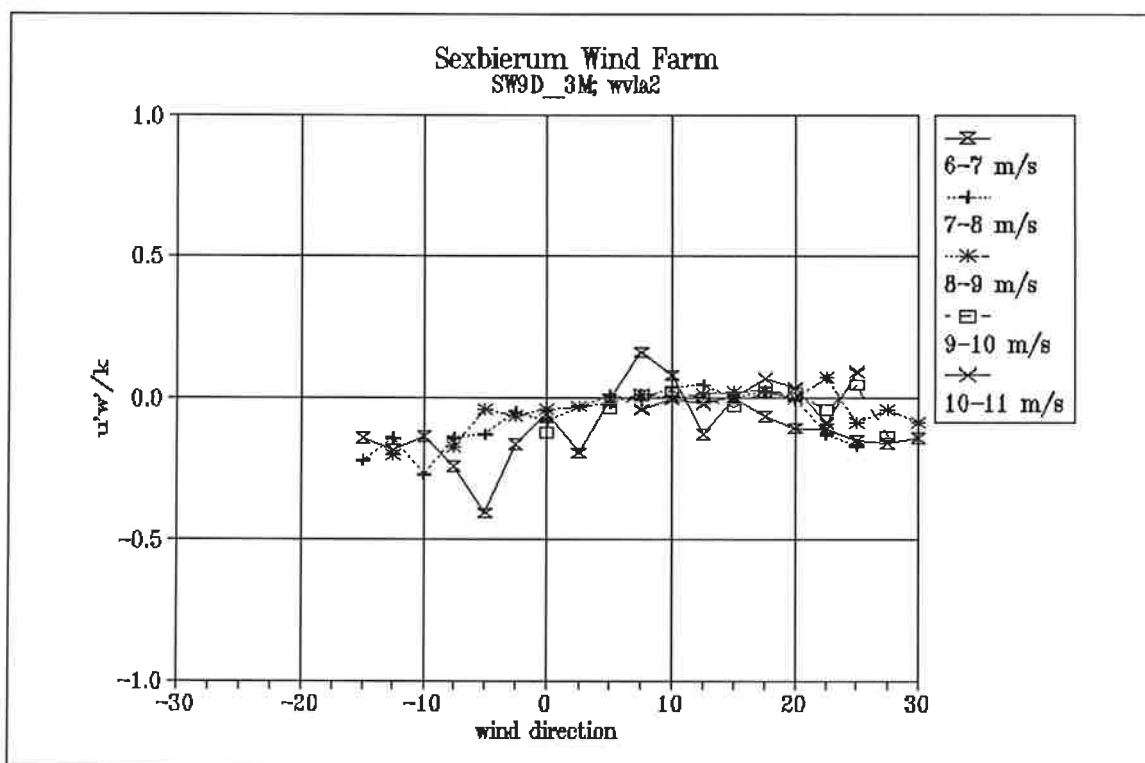


Figure 22 Non-dimensionalized shear stress $u'w'/k$ as a function of wind direction and wind speed bin

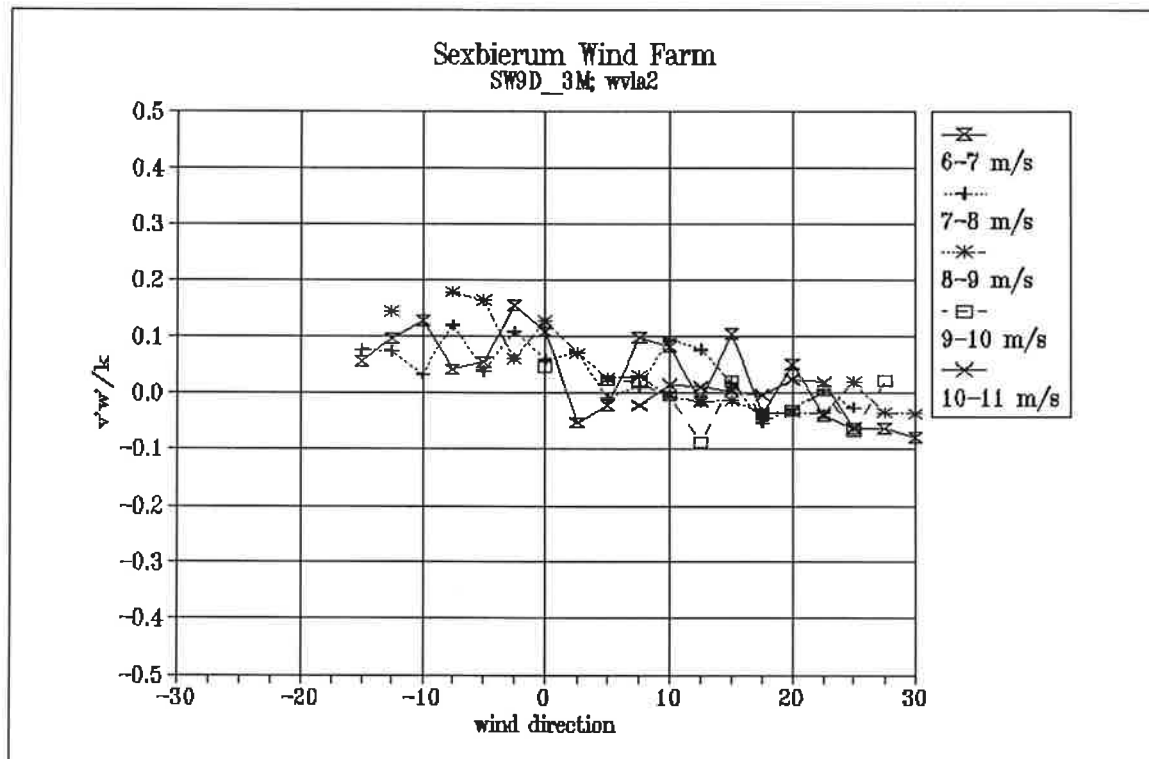


Figure 23 Non-dimensionalized shear stress $v'w'/k$ as a function of wind direction and wind speed bin

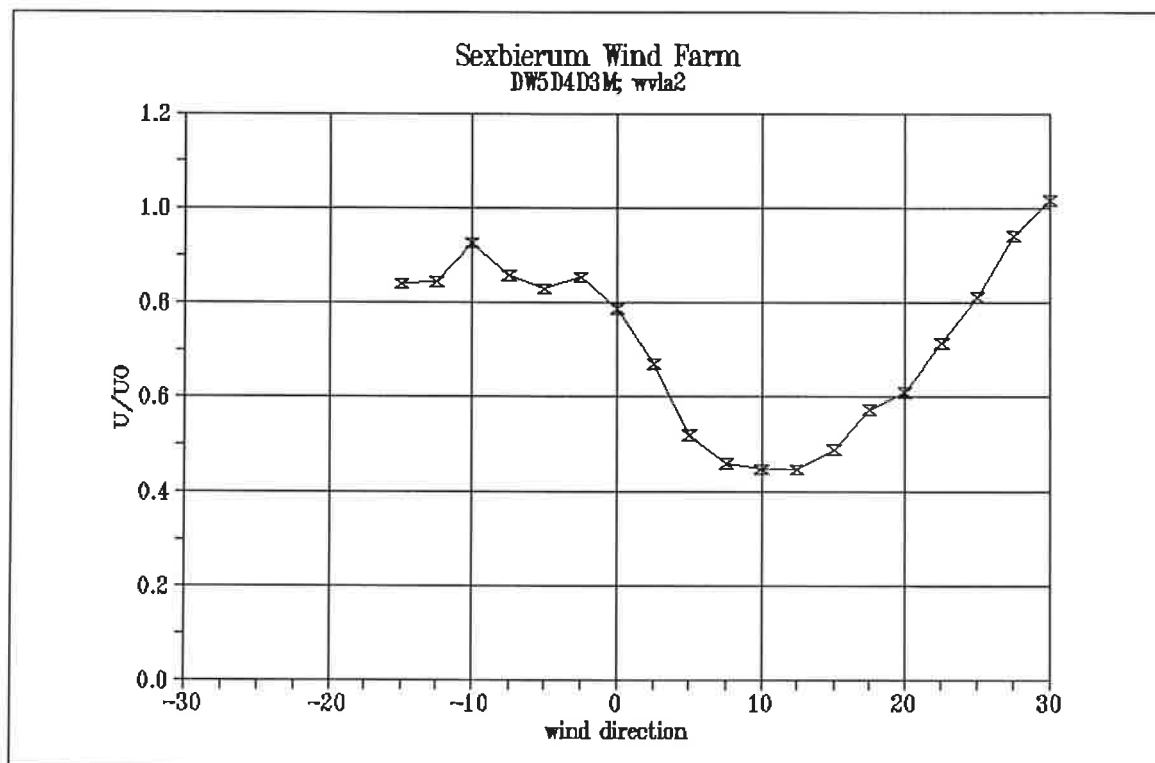


Figure 24 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

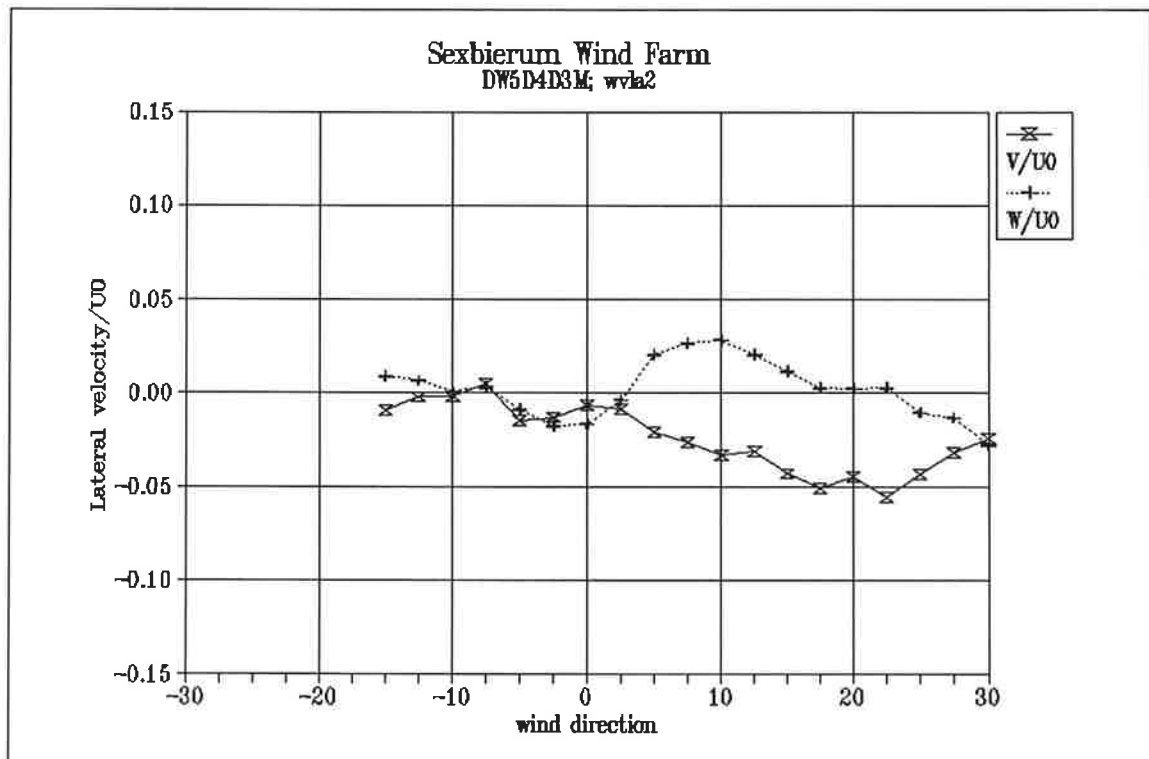


Figure 25 Lateral and vertical wind speed V/U_0 and W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

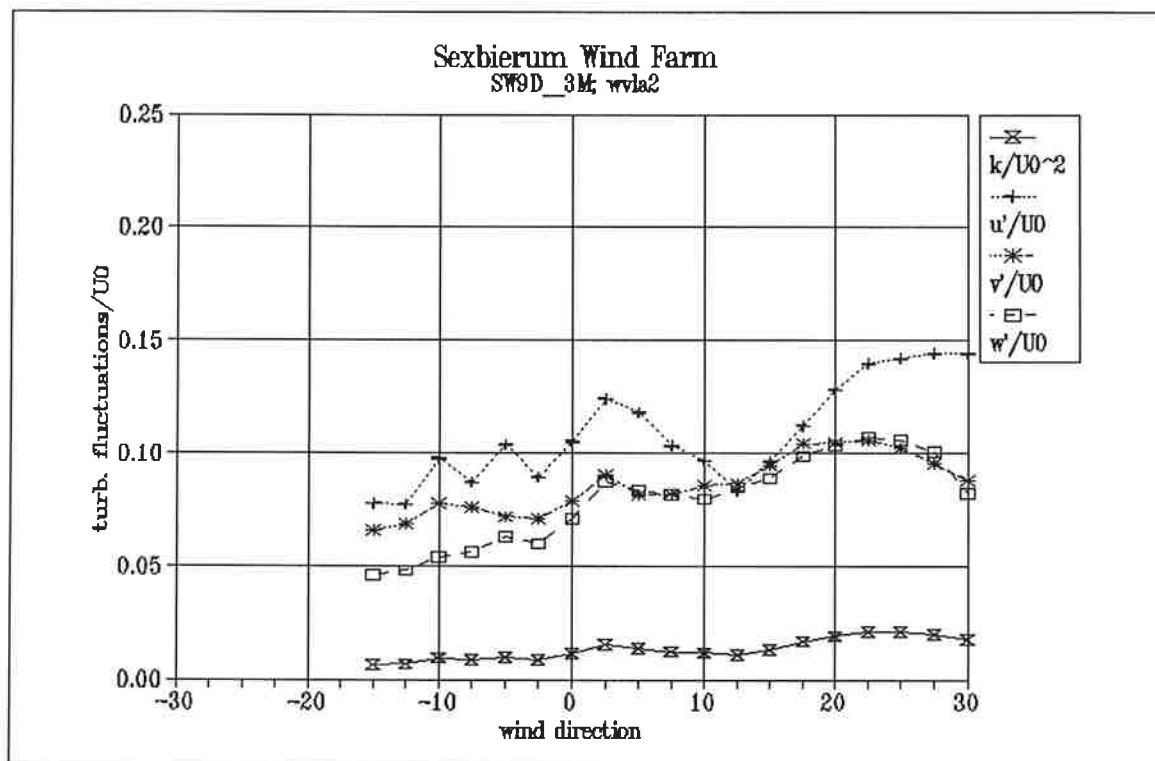


Figure 26 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U_0

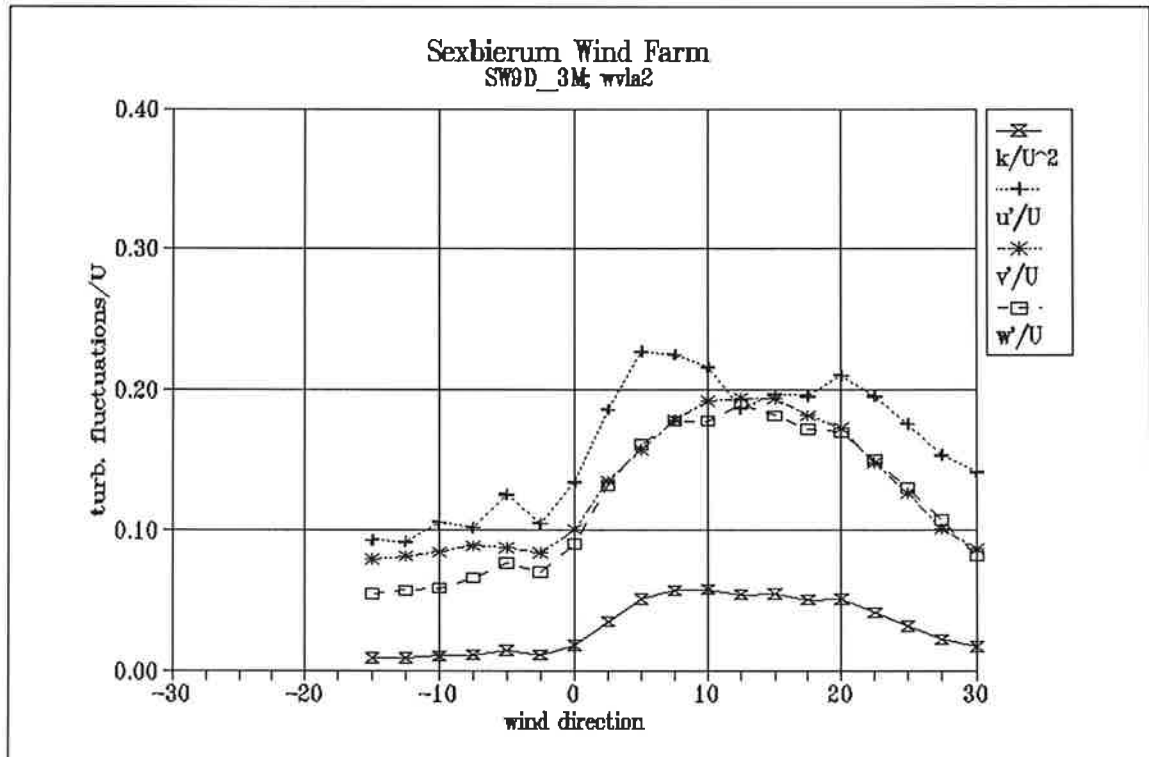


Figure 27 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U

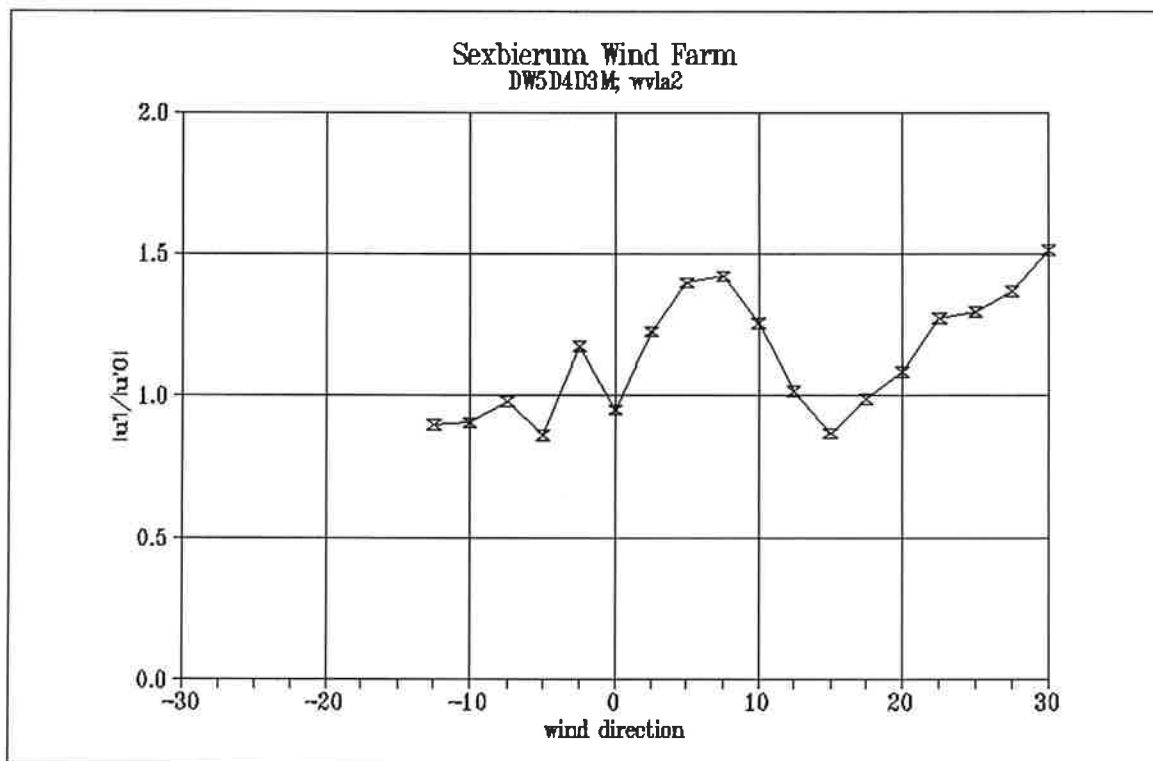


Figure 28 Longitudinal turbulence enhancement u'/u_0 as a function of wind direction in the wind speed bin 5-10 m/s

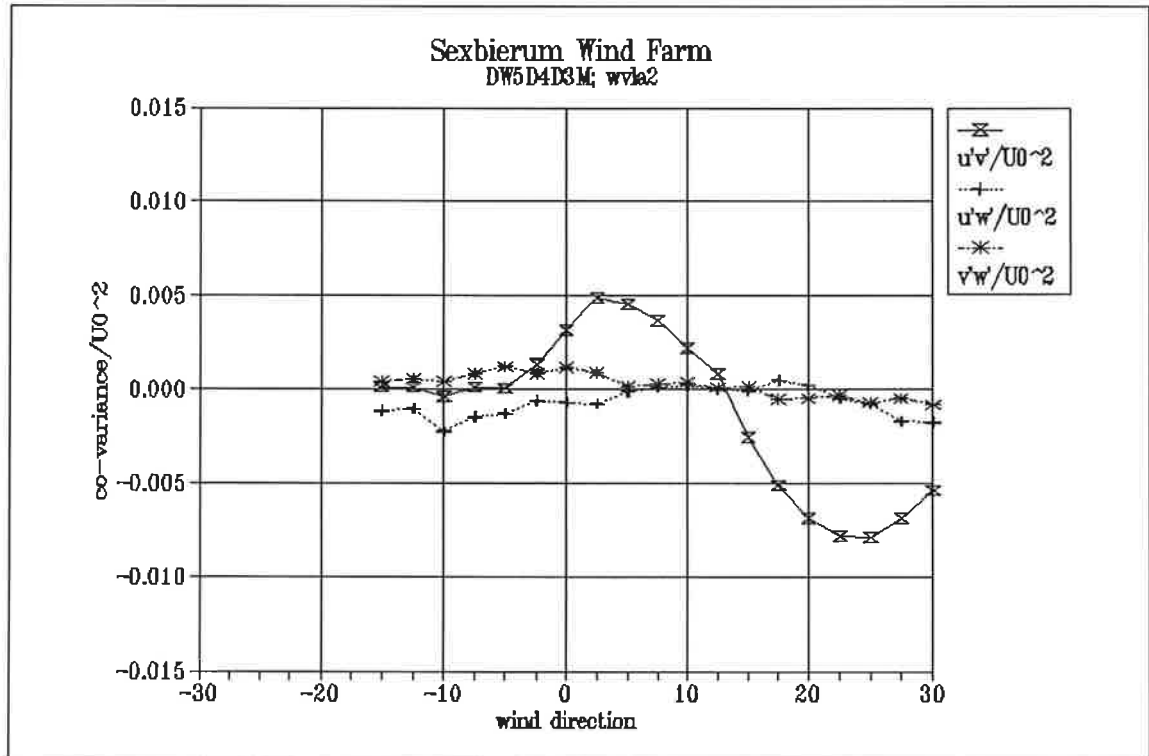


Figure 29 Non-dimensionalized shear stresses $u'v'/U_0^2$; $u'w'/U_0^2$; $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

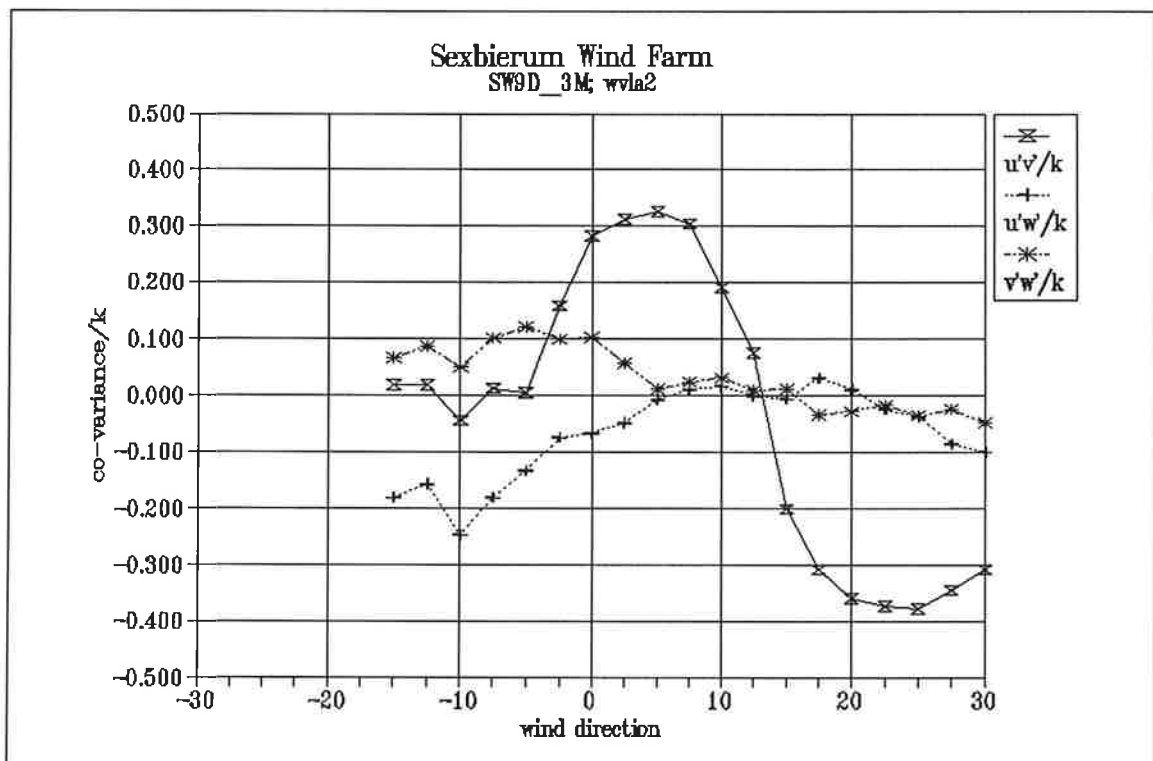


Figure 30 Non-dimensionalized shear stresses $u'v'/k$; $u'w'/k$; $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.2 Sensor b1

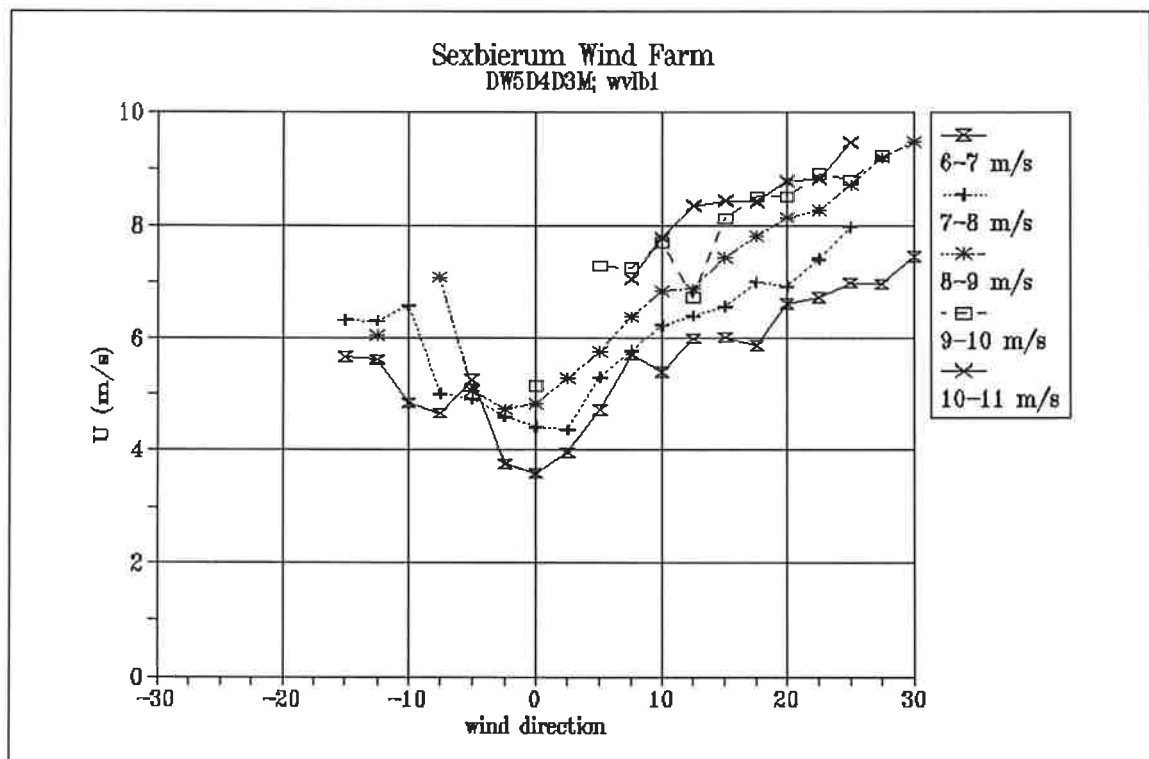


Figure 1 Horizontal wind speed U as a function of wind direction and wind speed bin

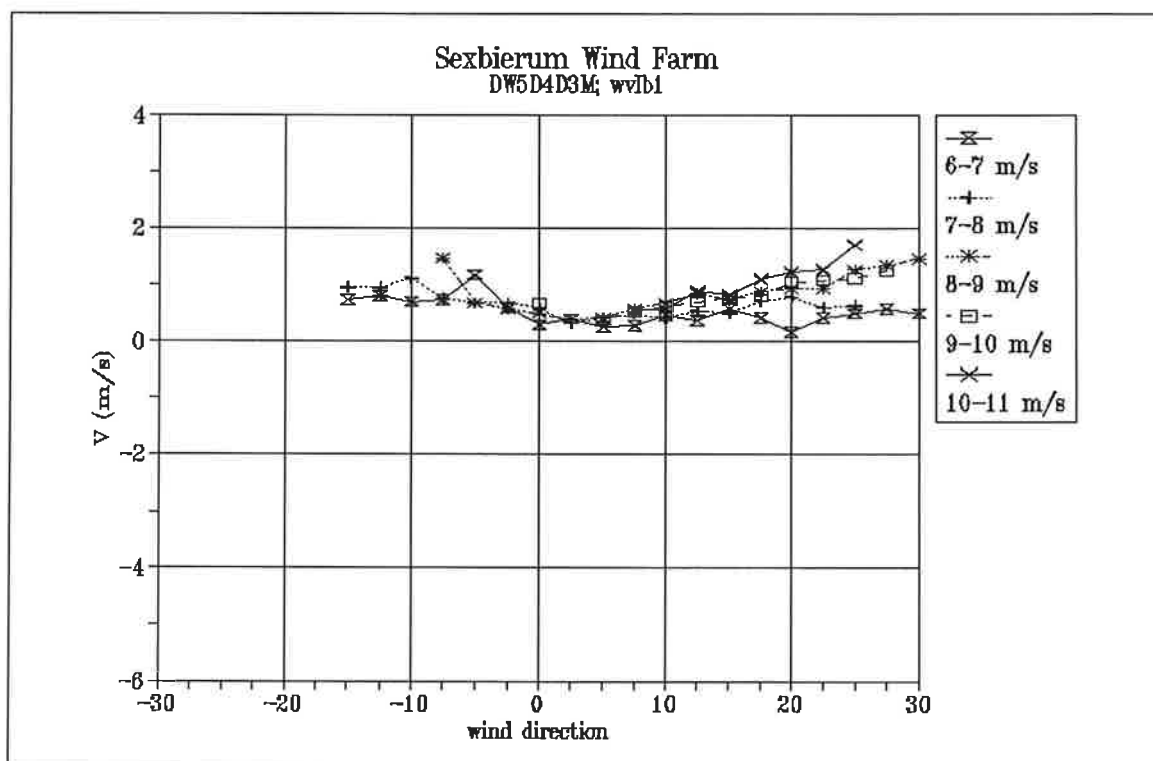


Figure 2 Lateral wind speed V as a function of wind direction and wind speed bin

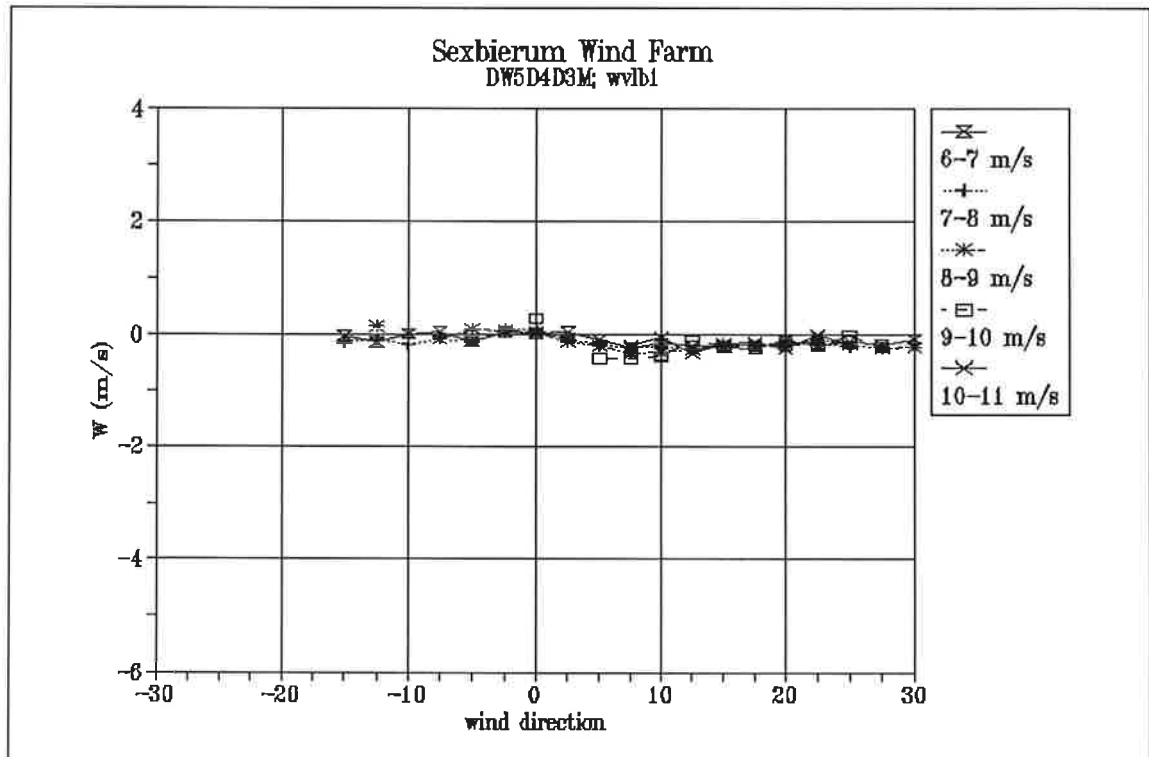


Figure 3 Vertical wind speed W as a function of wind direction and wind speed bin

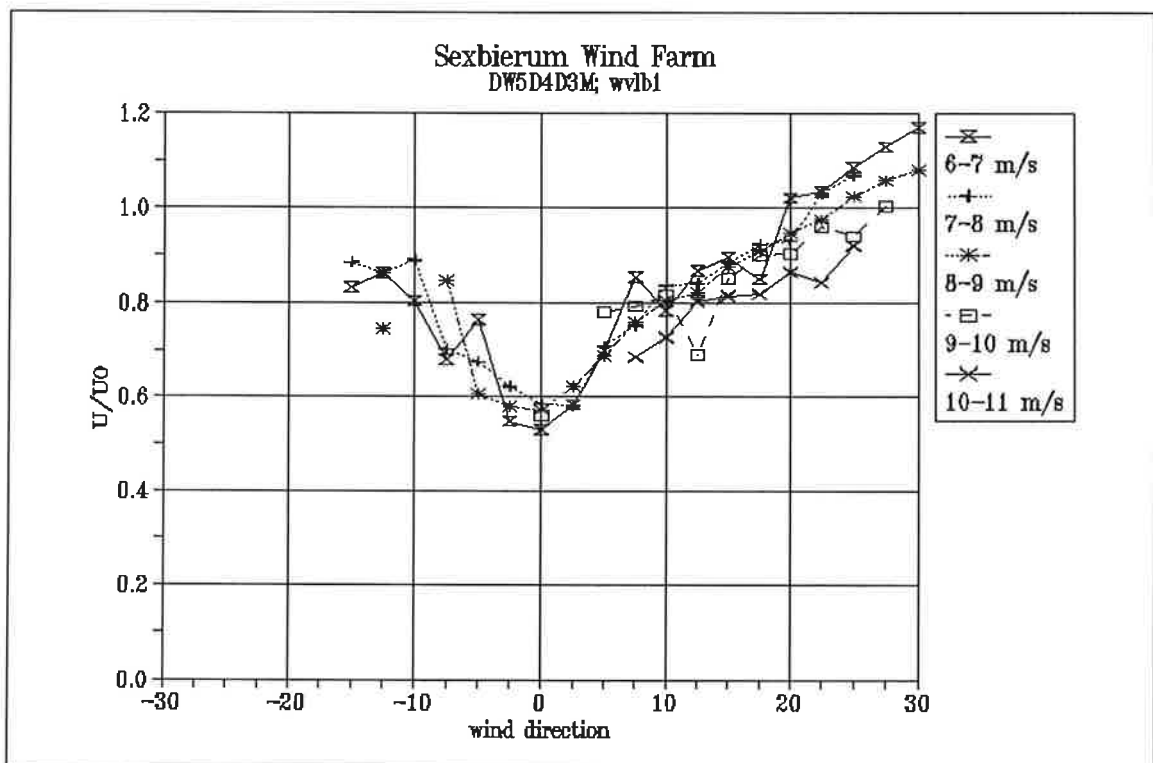


Figure 4 Wake deficit U/U_0 as a function of wind direction and wind speed bin

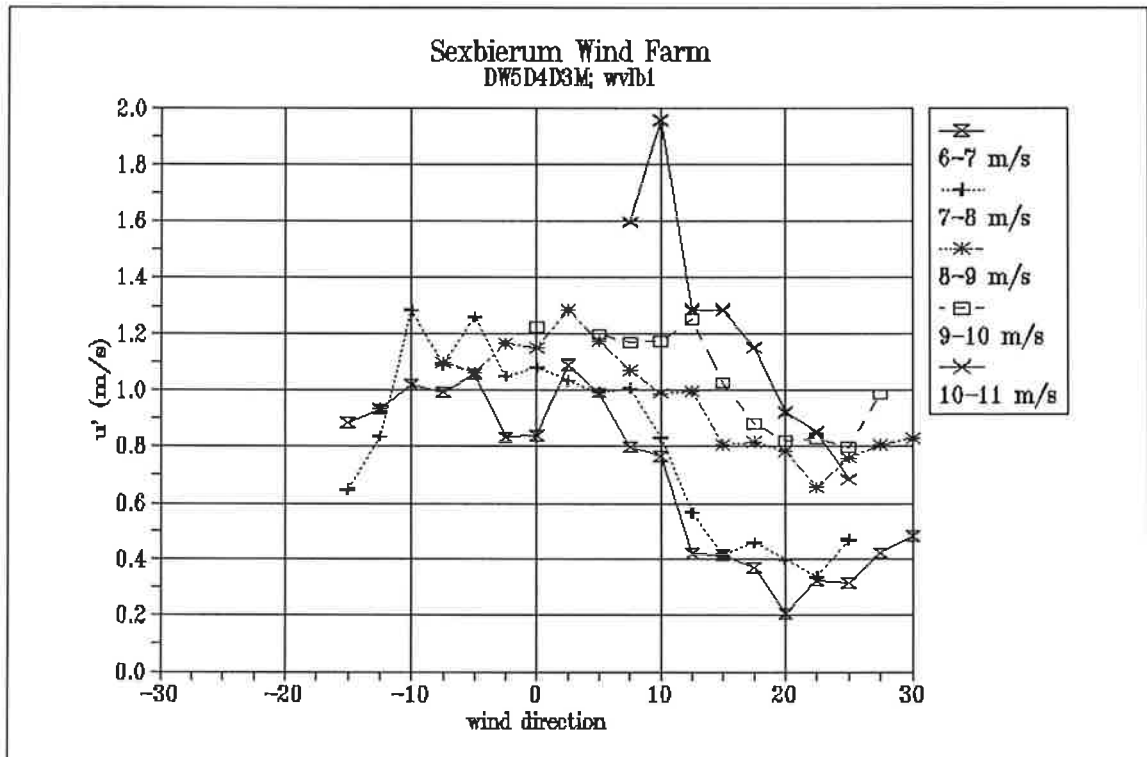


Figure 5 Longitudinal turbulent fluctuations u' as a function of wind direction and wind speed bin

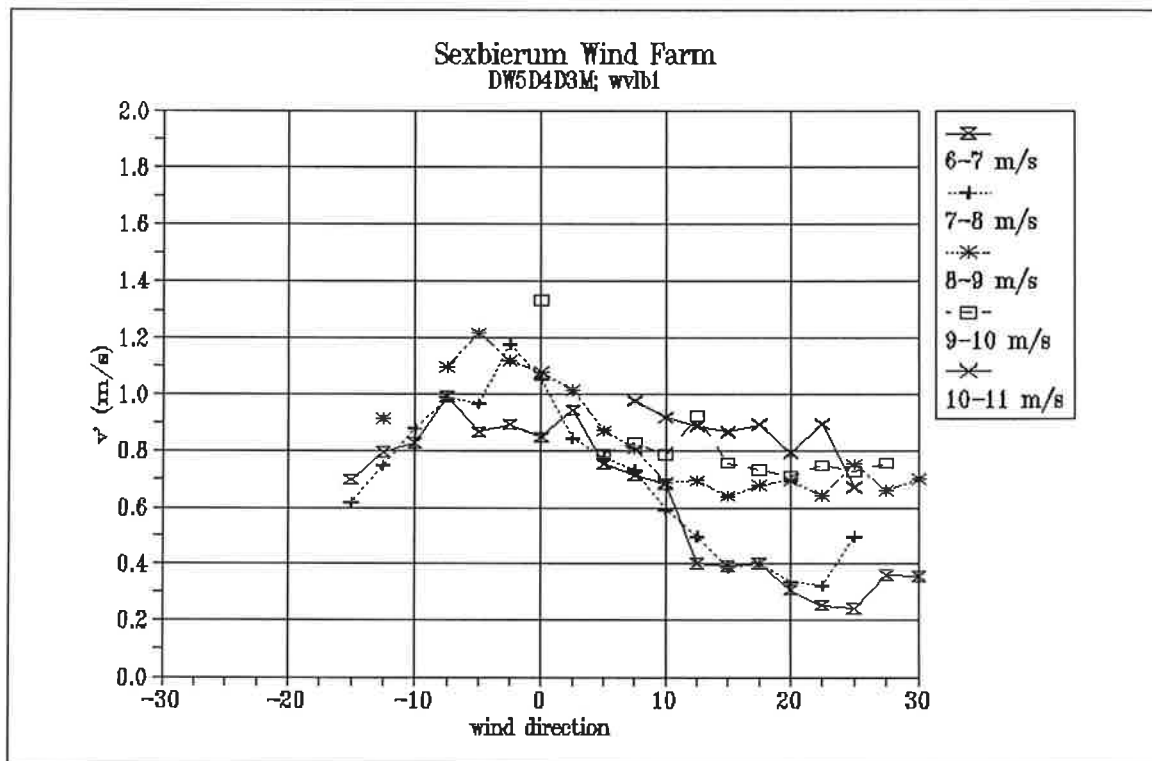


Figure 6 Lateral turbulent fluctuations v' as a function of wind direction and wind speed bin

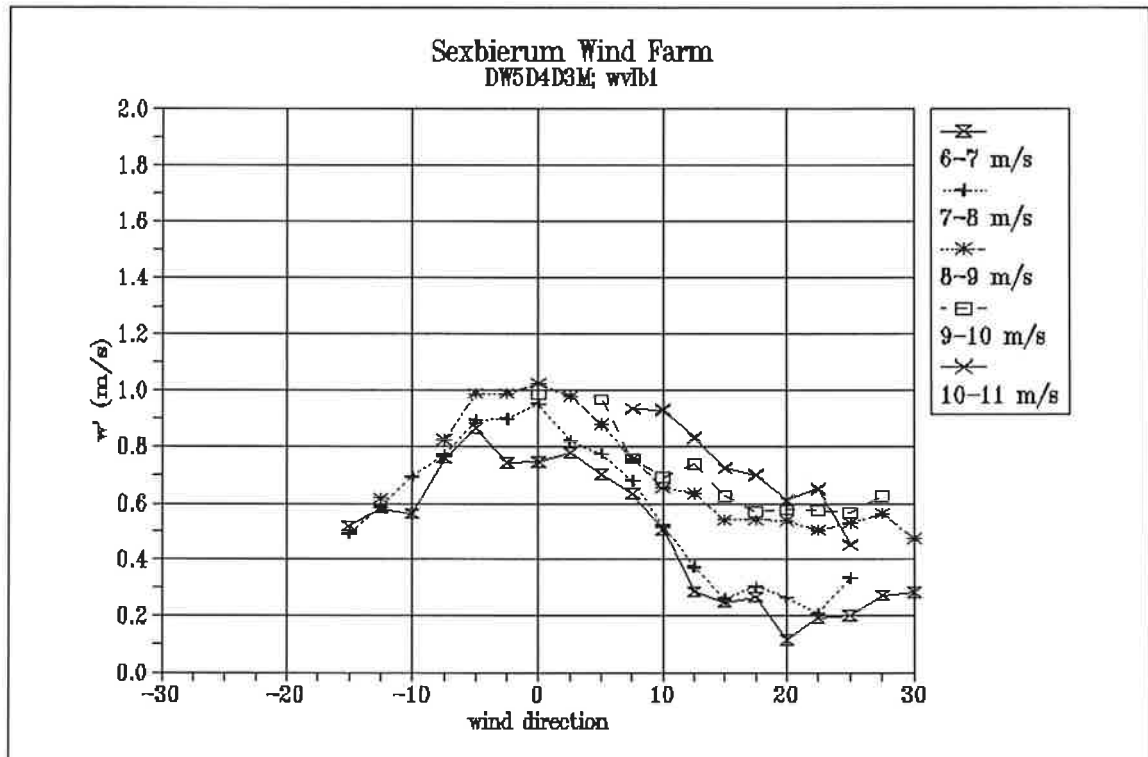


Figure 7 Vertical turbulent fluctuations w' as a function of wind direction and wind speed bin

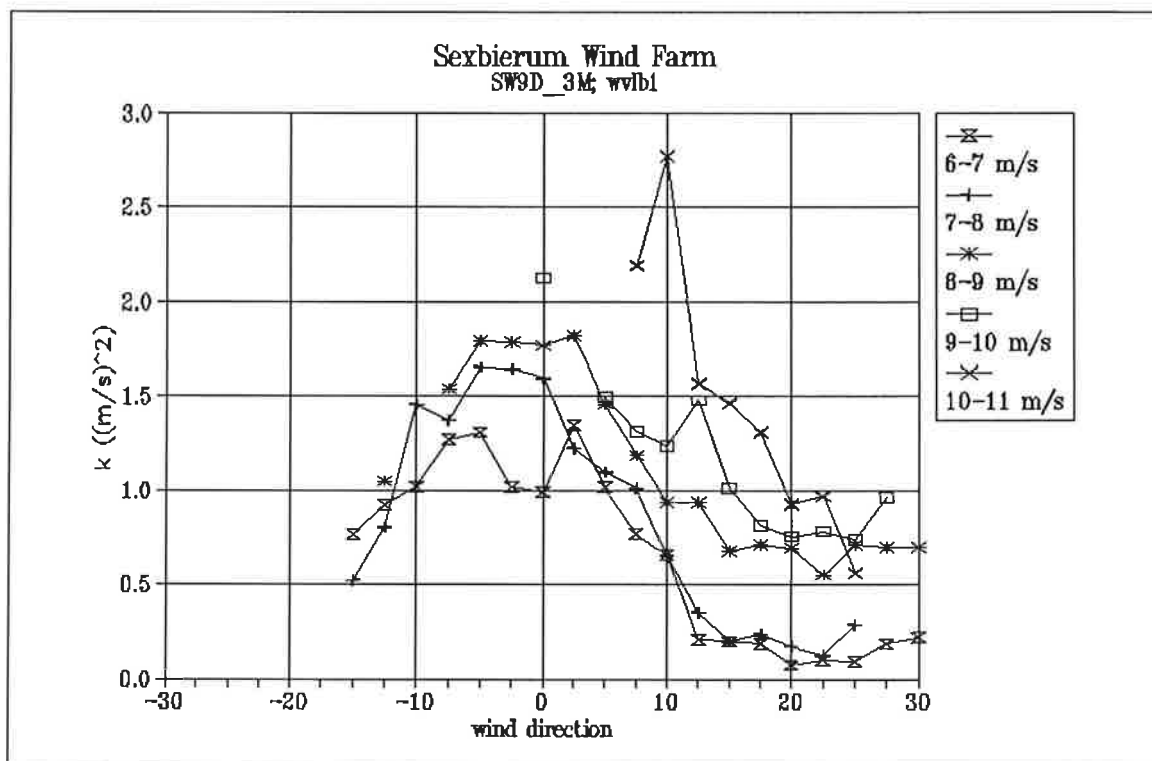


Figure 8 Turbulent kinetic energy per unit mass as a function of wind direction and wind speed bin

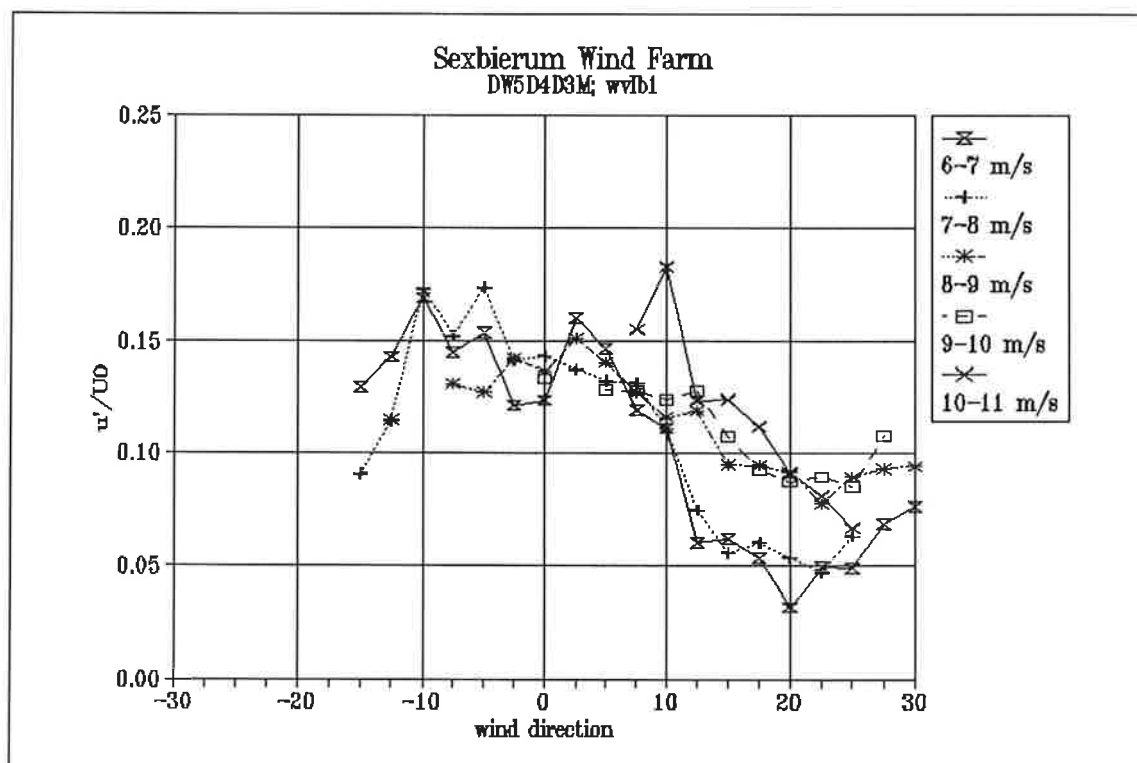


Figure 9 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

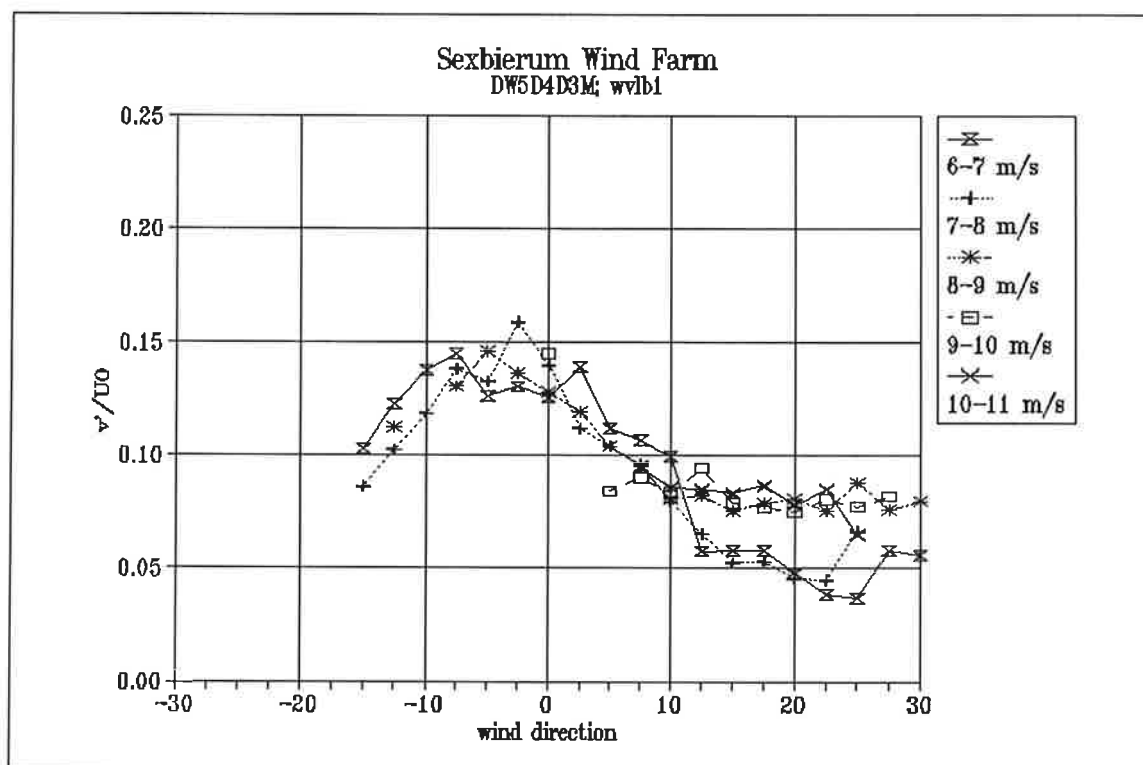


Figure 10 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction and wind speed bin

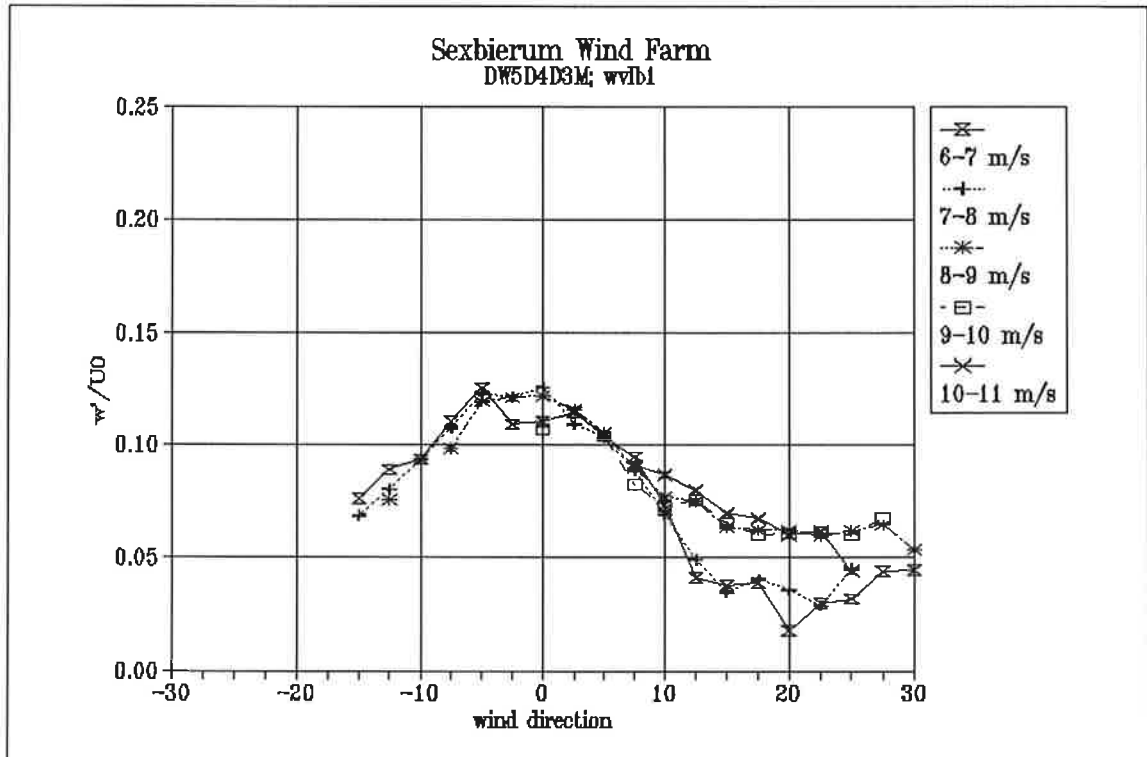


Figure 11 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction and wind speed bin

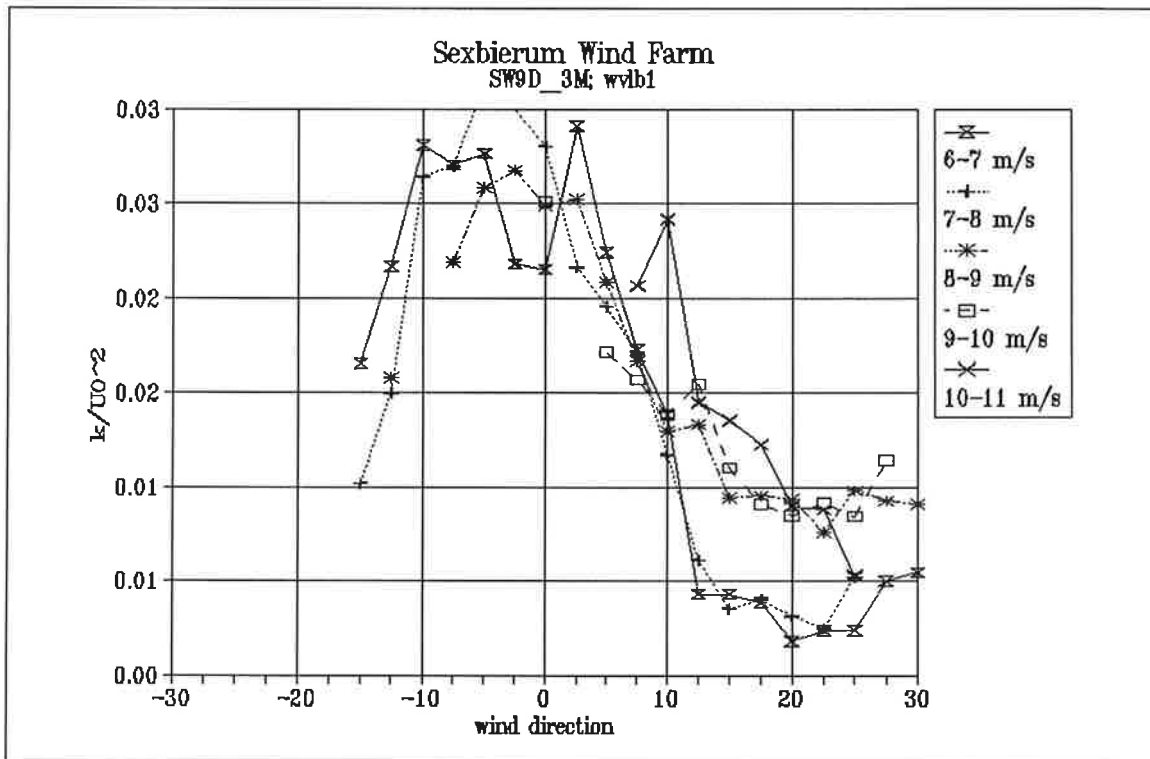


Figure 12 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction and wind speed bin

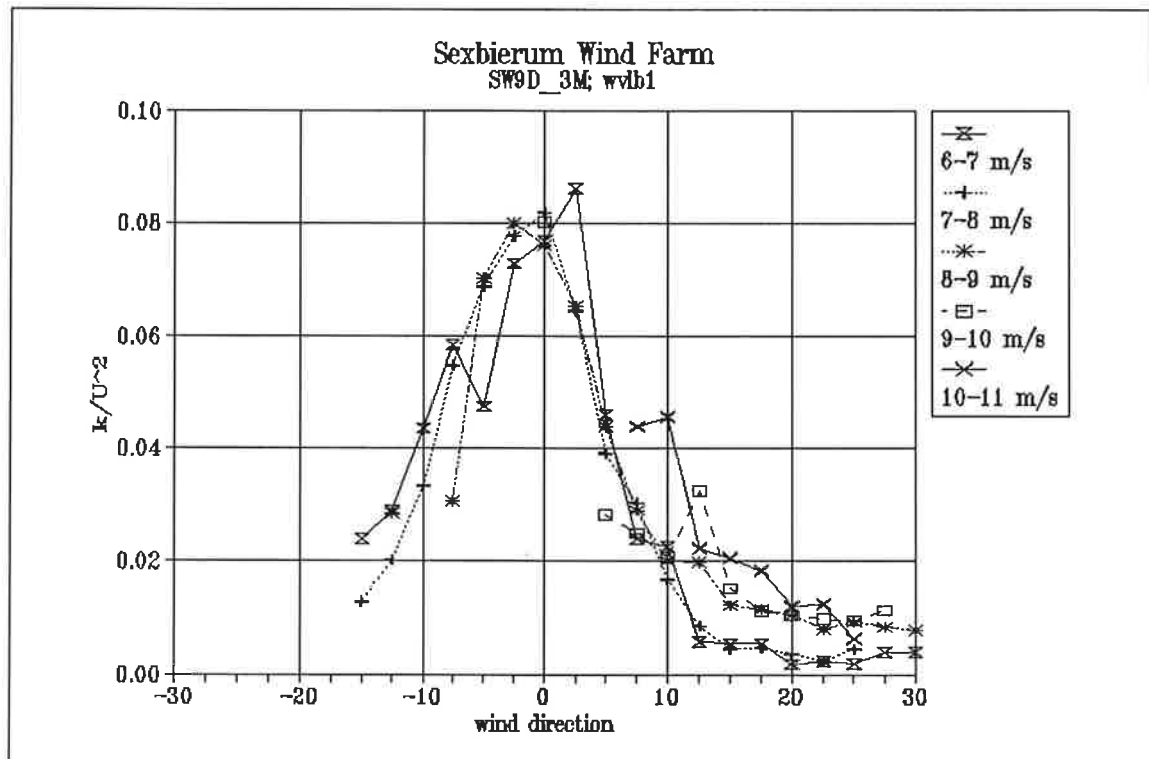


Figure 13 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction and wind speed bin

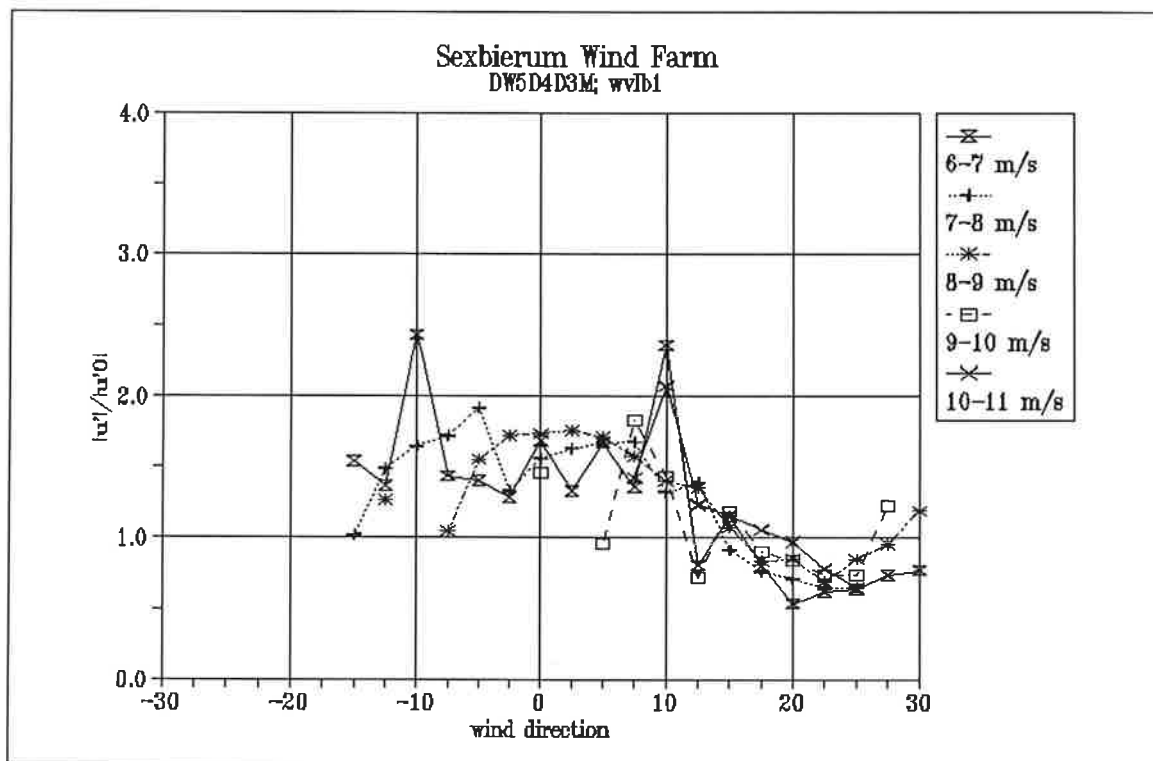


Figure 14 Longitudinal turbulence enhancement u'/u_0 as a function of wind direction and wind speed bin

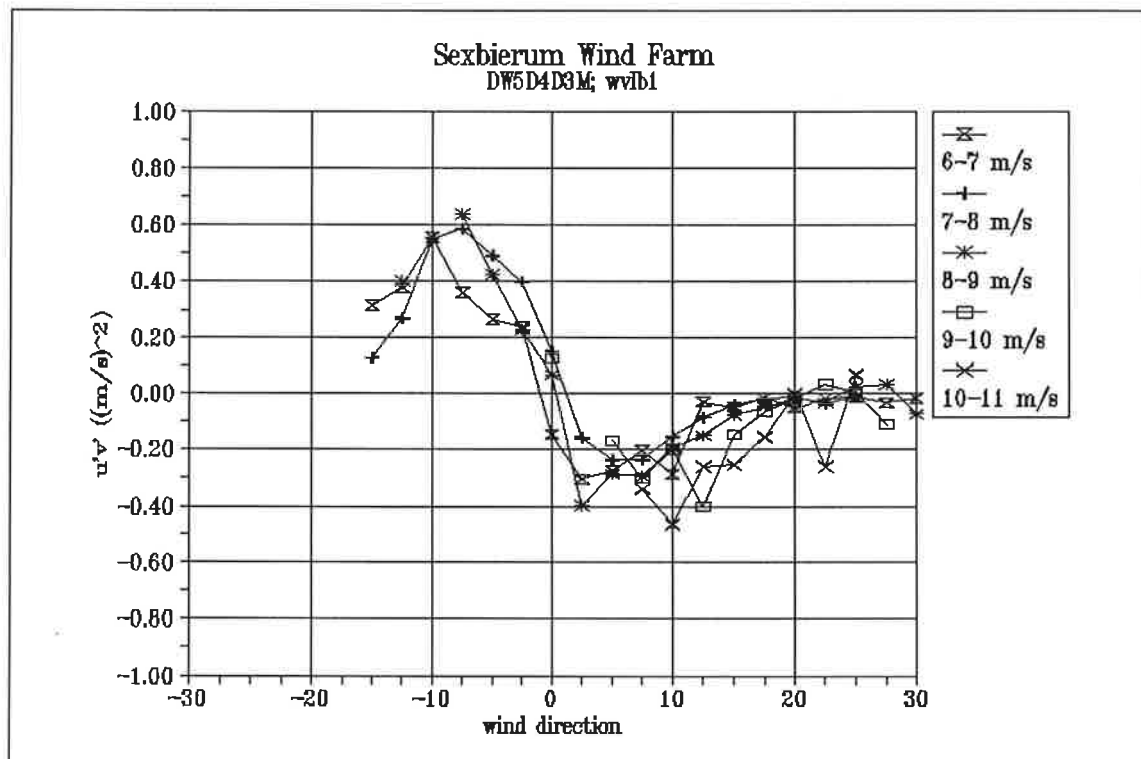


Figure 15 Shear stress $u'v'$ as a function of wind direction and wind speed bin

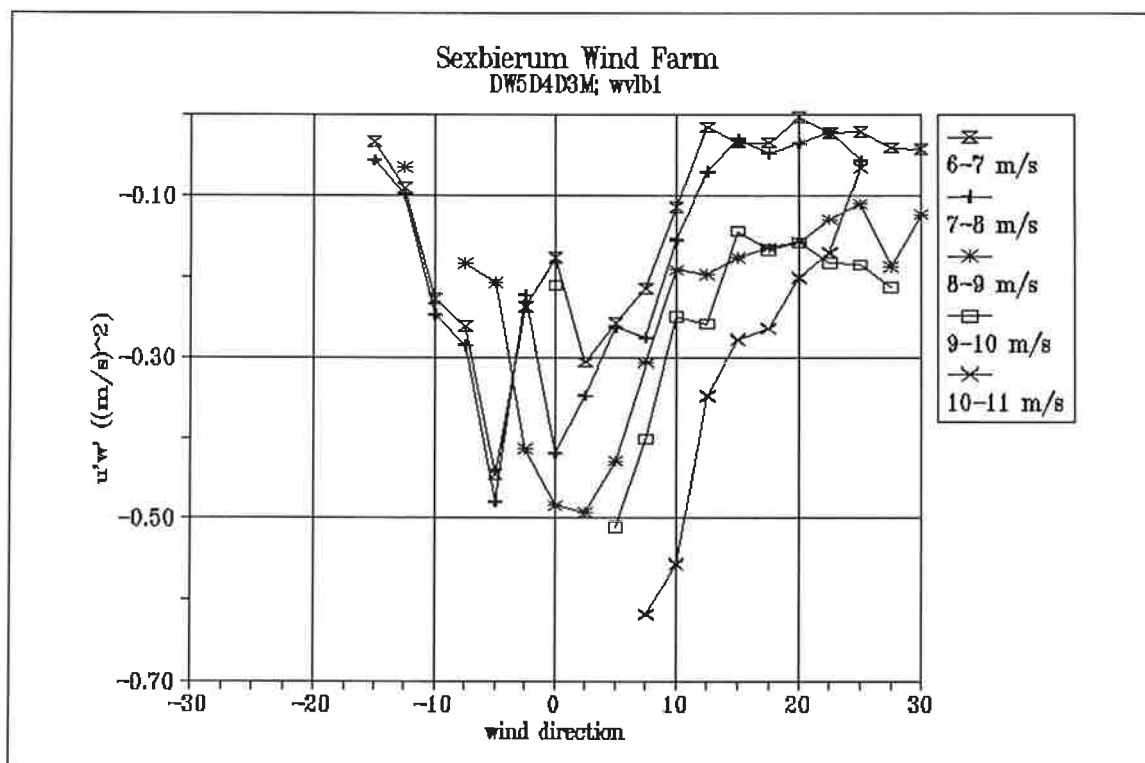


Figure 16 Shear stress $u'w'$ as a function of wind direction and wind speed bin

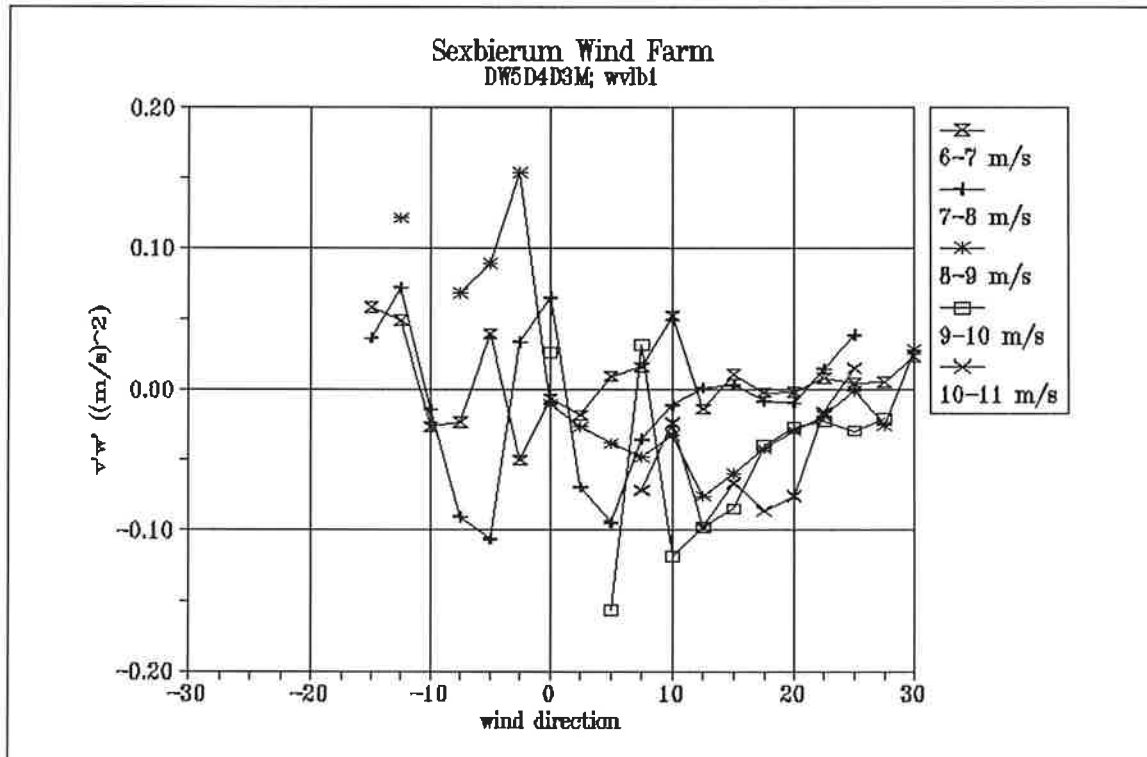


Figure 17 Shear stress $v'w'$ as a function of wind direction and wind speed bin

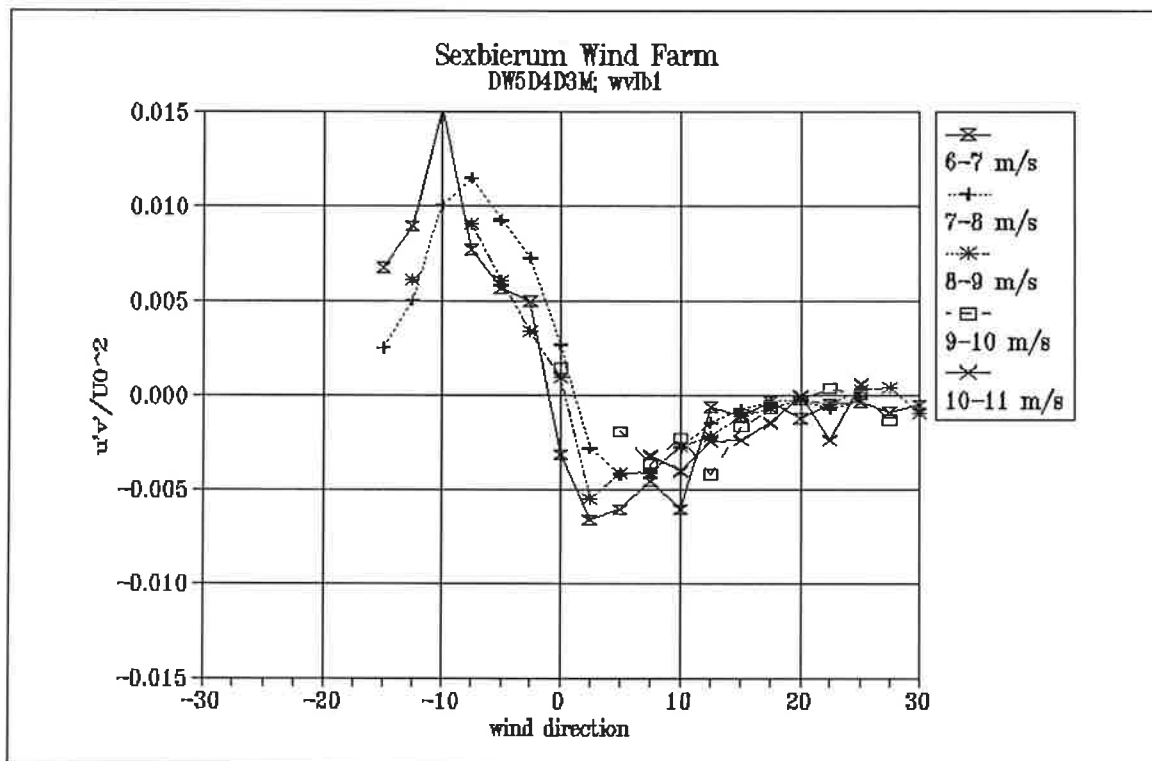


Figure 18 Non-dimensionalized shear stress $u'v'/U_0^2$ as a function of wind direction and wind speed bin

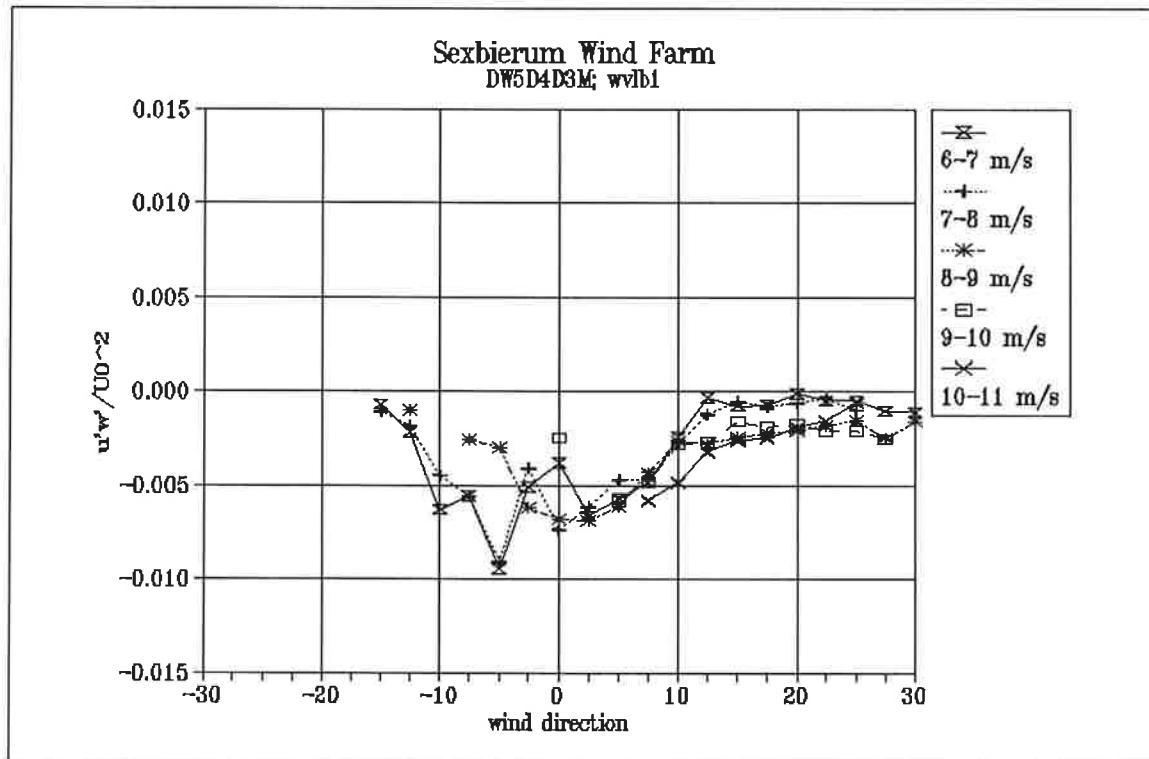


Figure 19 Non-dimensionalized shear stress $u'w'/U_0^2$ as a function of wind direction and wind speed bin

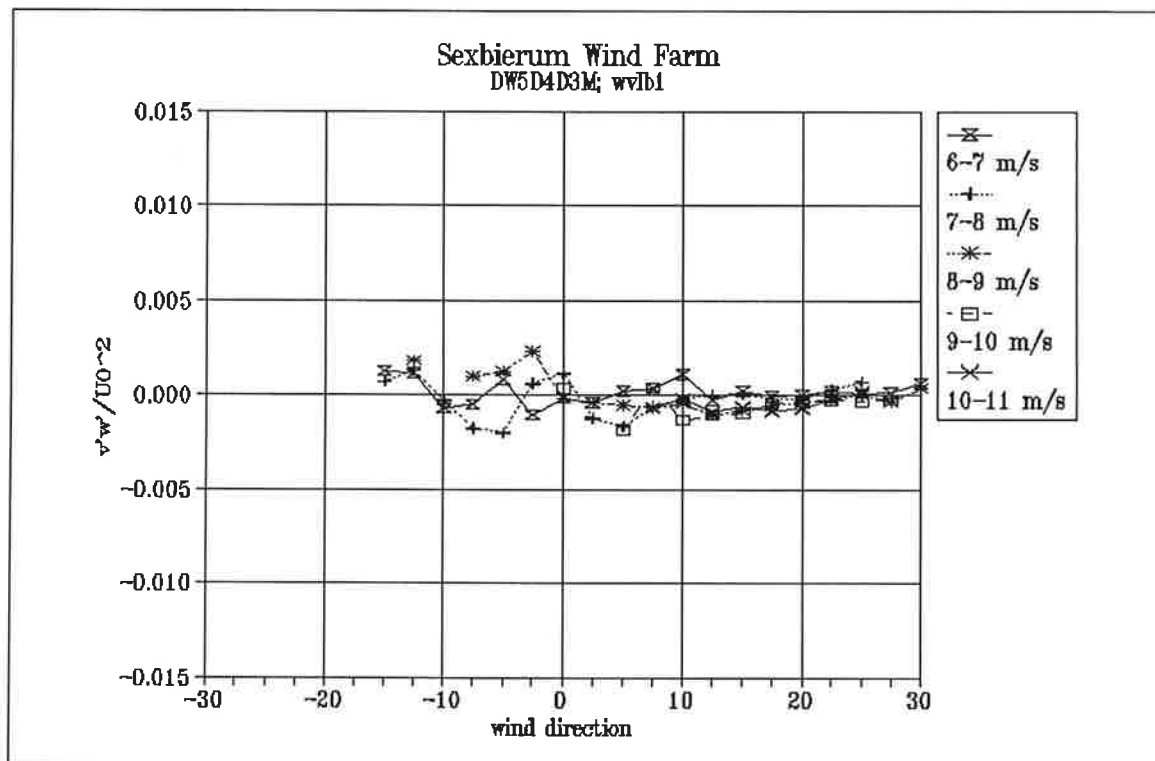


Figure 20 Non-dimensionalized shear stress $v'w'/U_0^2$ as a function of wind direction and wind speed bin

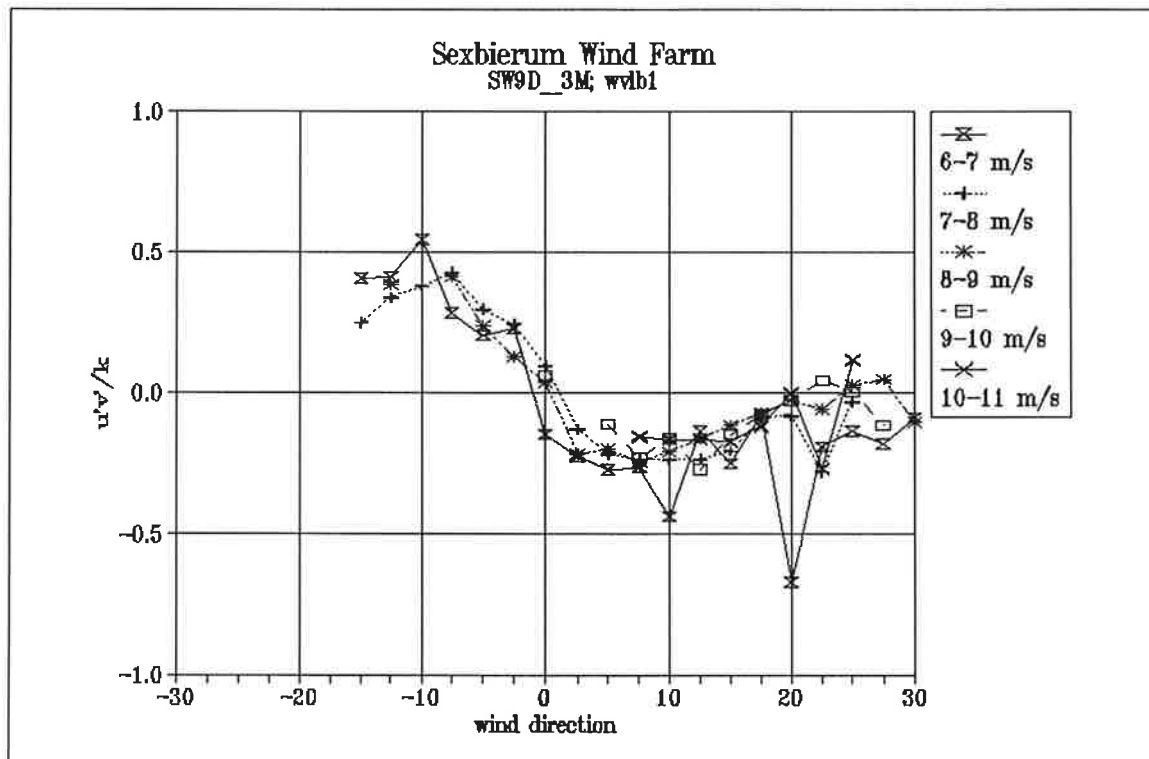


Figure 21 Non-dimensionalized shear stress $u'v'/k$ as a function of wind direction and wind speed bin

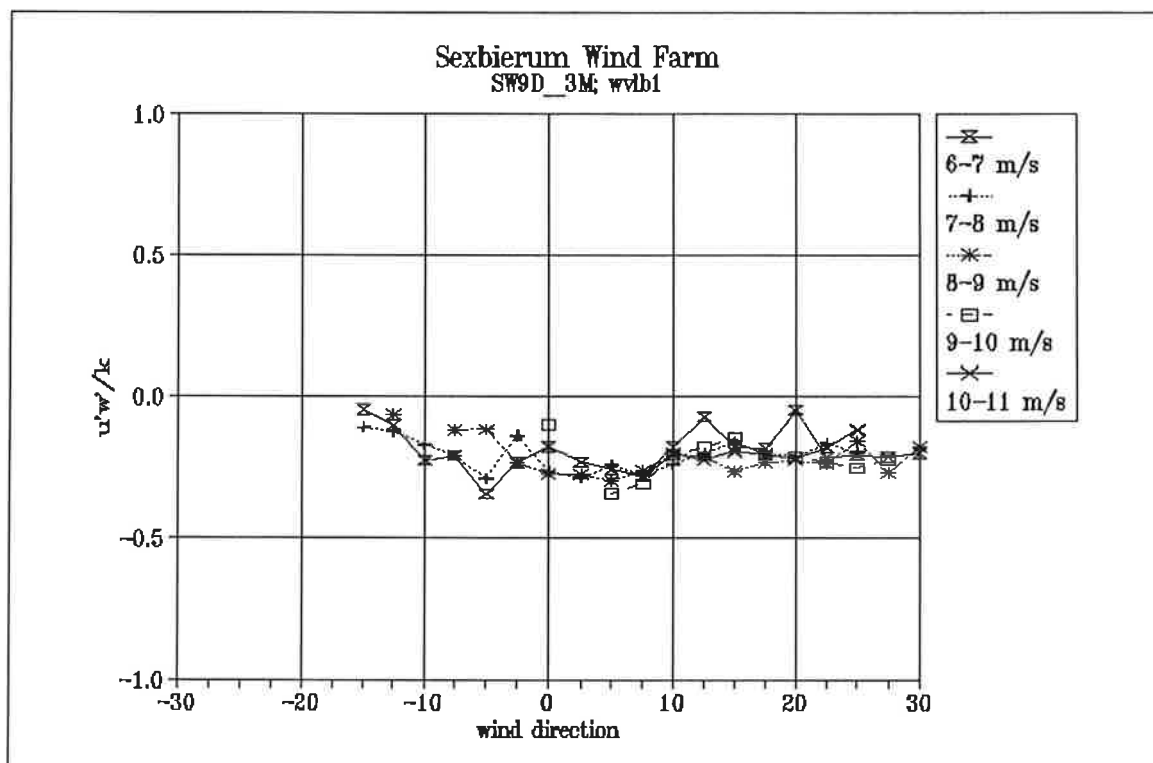


Figure 22 Non-dimensionalized shear stress $u'w'/k$ as a function of wind direction and wind speed bin

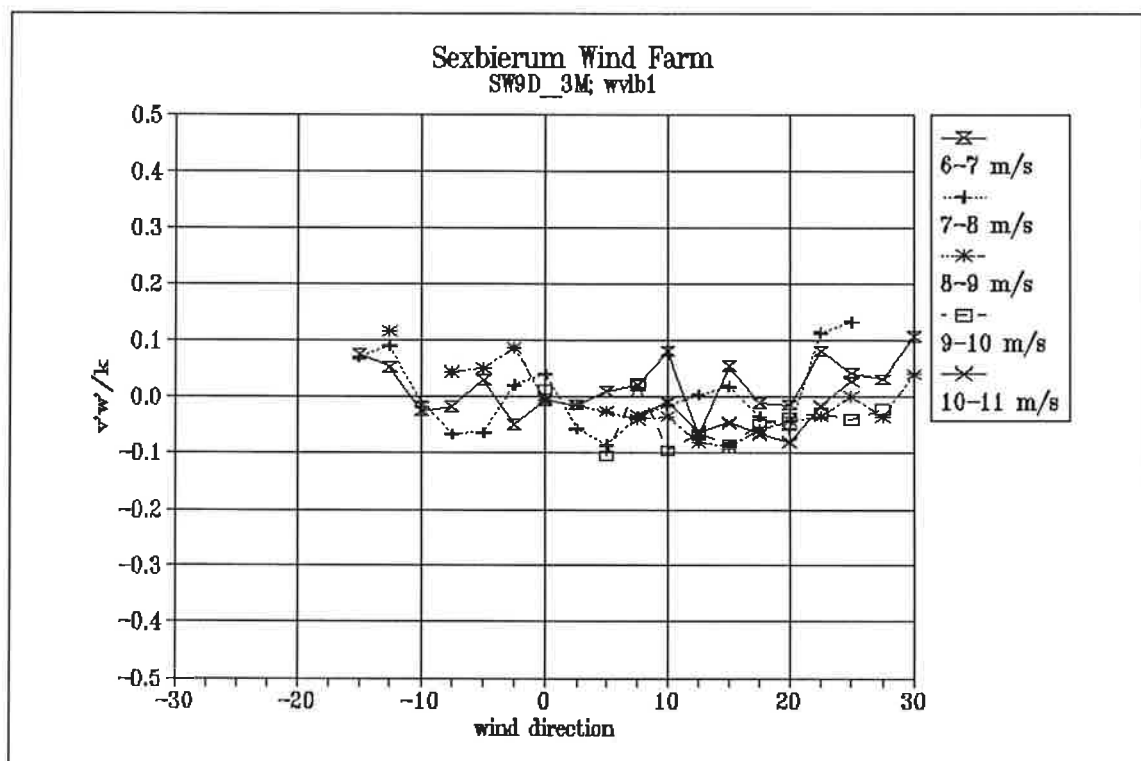


Figure 23 Non-dimensionalized shear stress $v'w'/k$ as a function of wind direction and wind speed bin

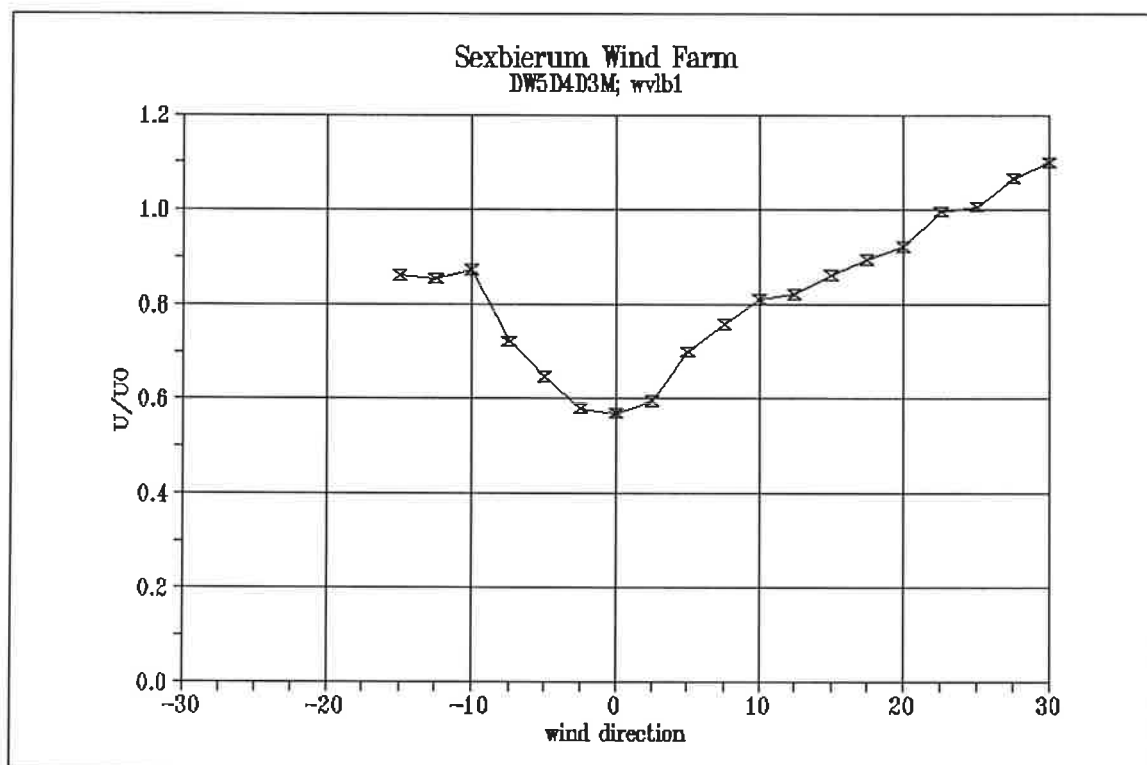


Figure 24 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

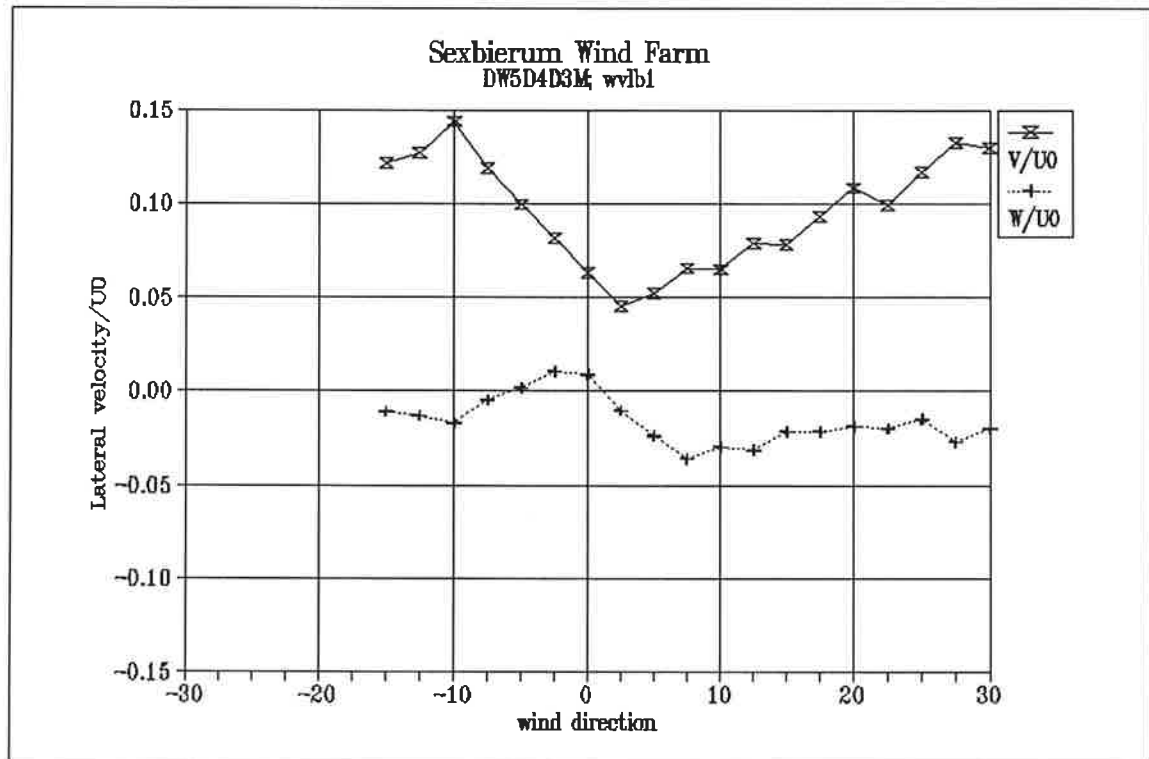


Figure 25 Lateral and vertical wind speed V/U_0 and W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

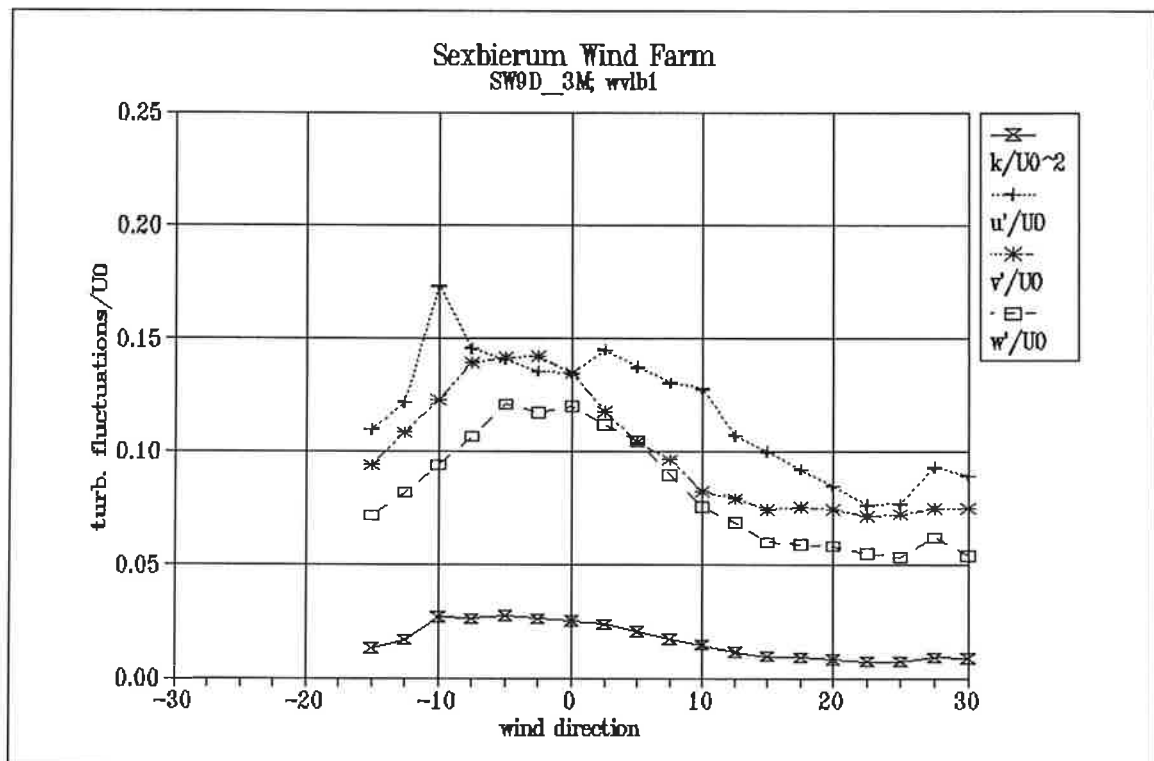


Figure 26 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U_0

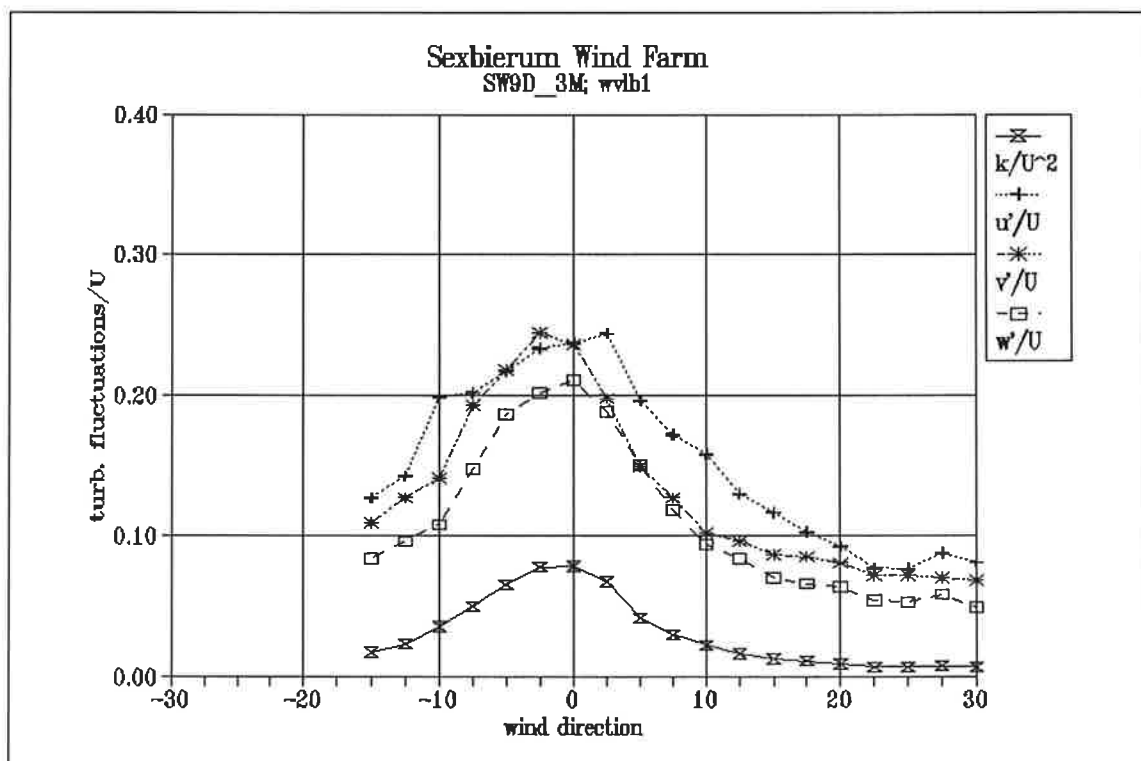


Figure 27 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U

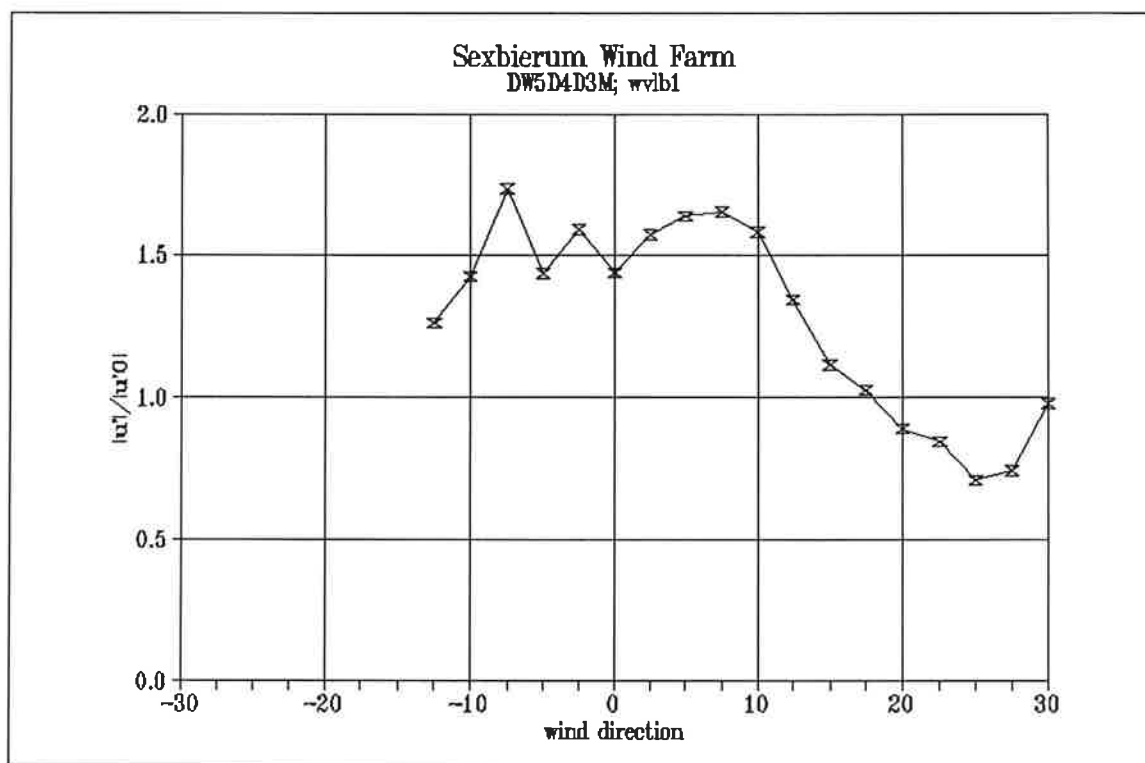


Figure 28 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

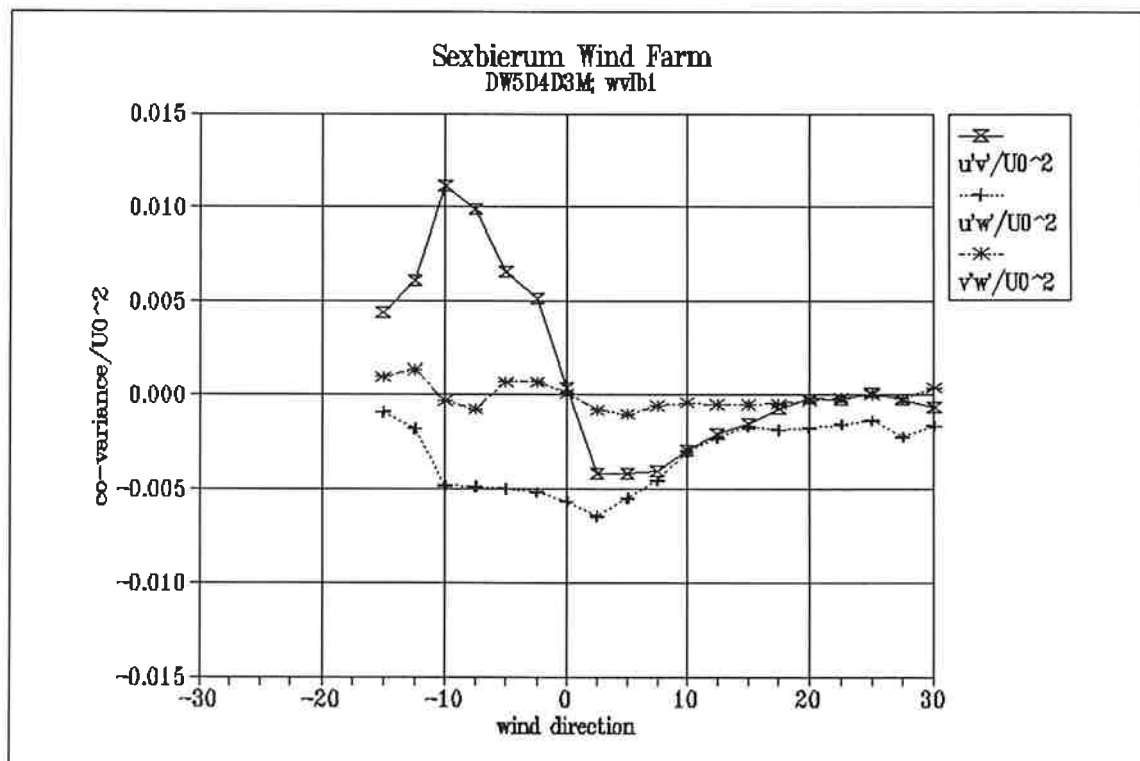


Figure 29 Non-dimensionalized shear stresses $u'v'/U_0^2$; $u'w'/U_0^2$; $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

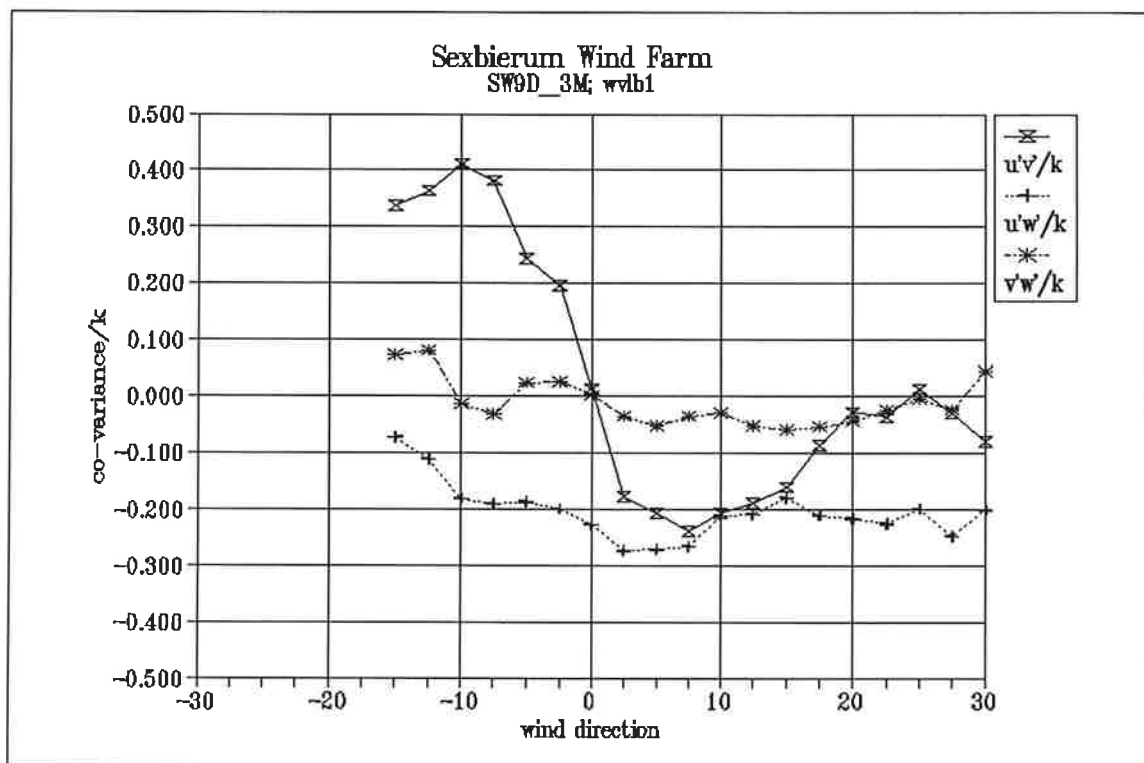


Figure 30 Non-dimensionalized shear stresses $u'v'/k$; $u'w'/k$; $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.3 Sensor b2h

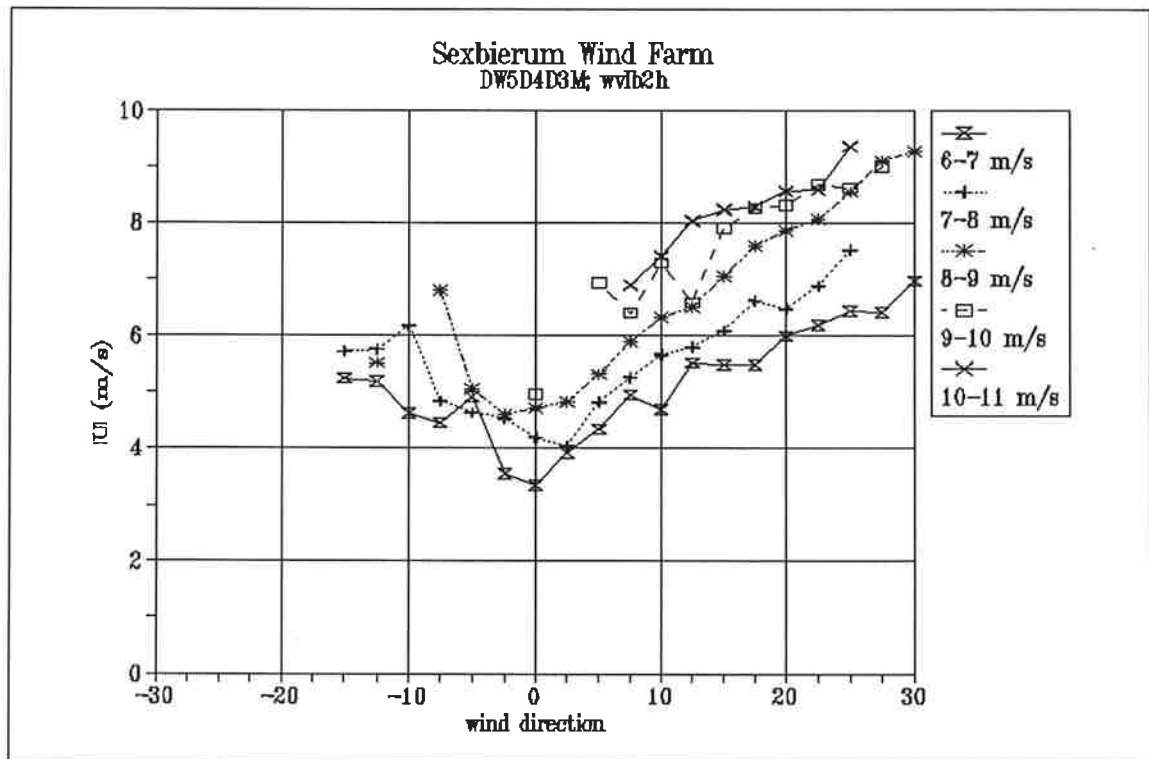


Figure 1 Wind speed U as a function of wind direction and wind speed bin

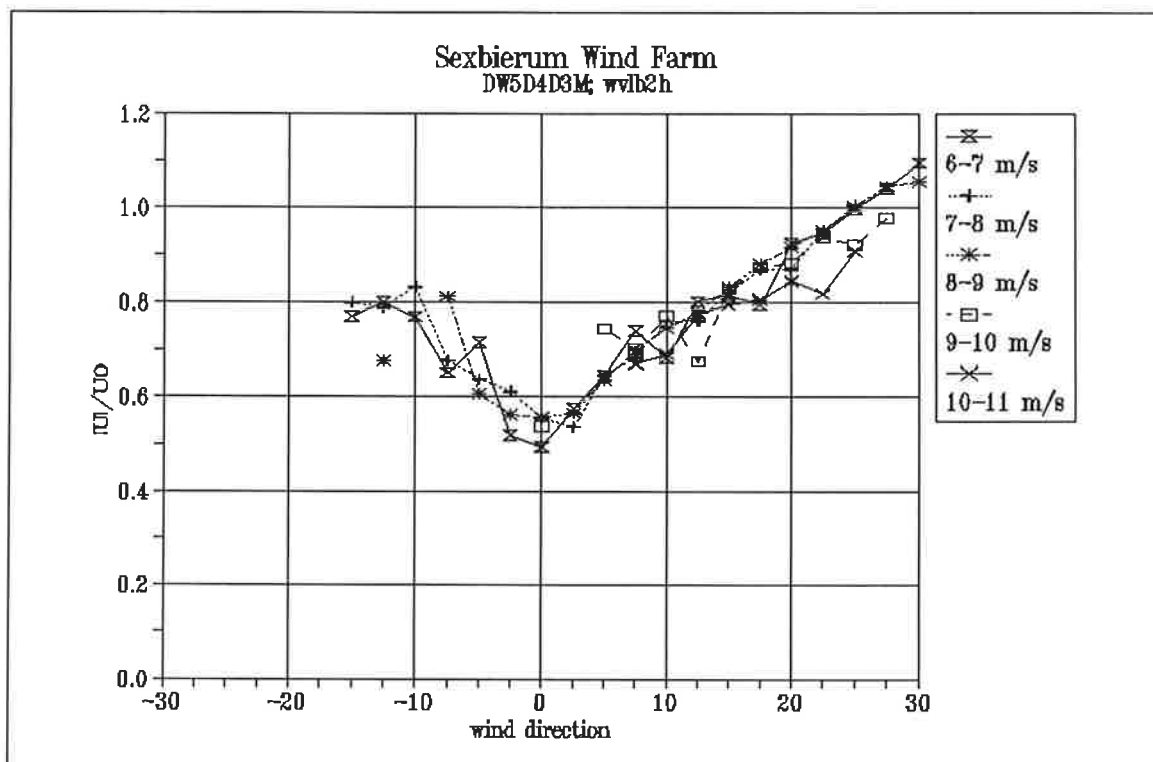


Figure 2 Wake deficit U/U_0 as a function of wind direction and wind speed bin

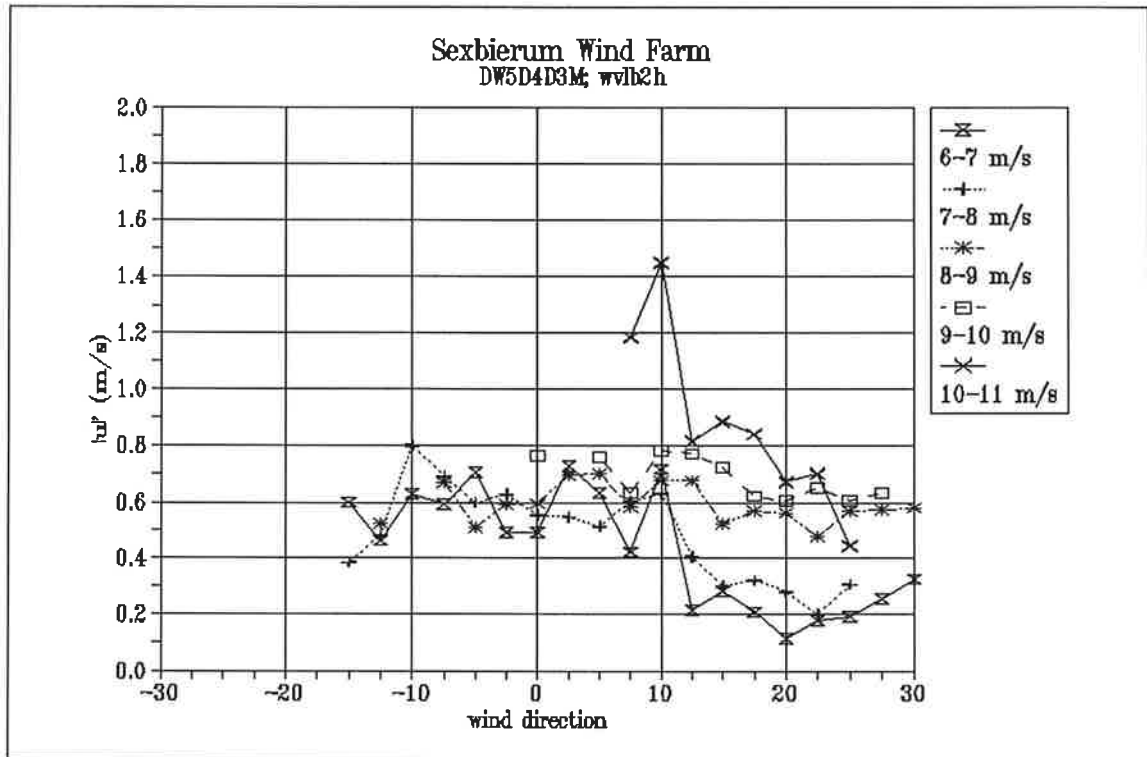


Figure 3 Turbulent fluctuations u' as a function of wind direction and wind speed bin

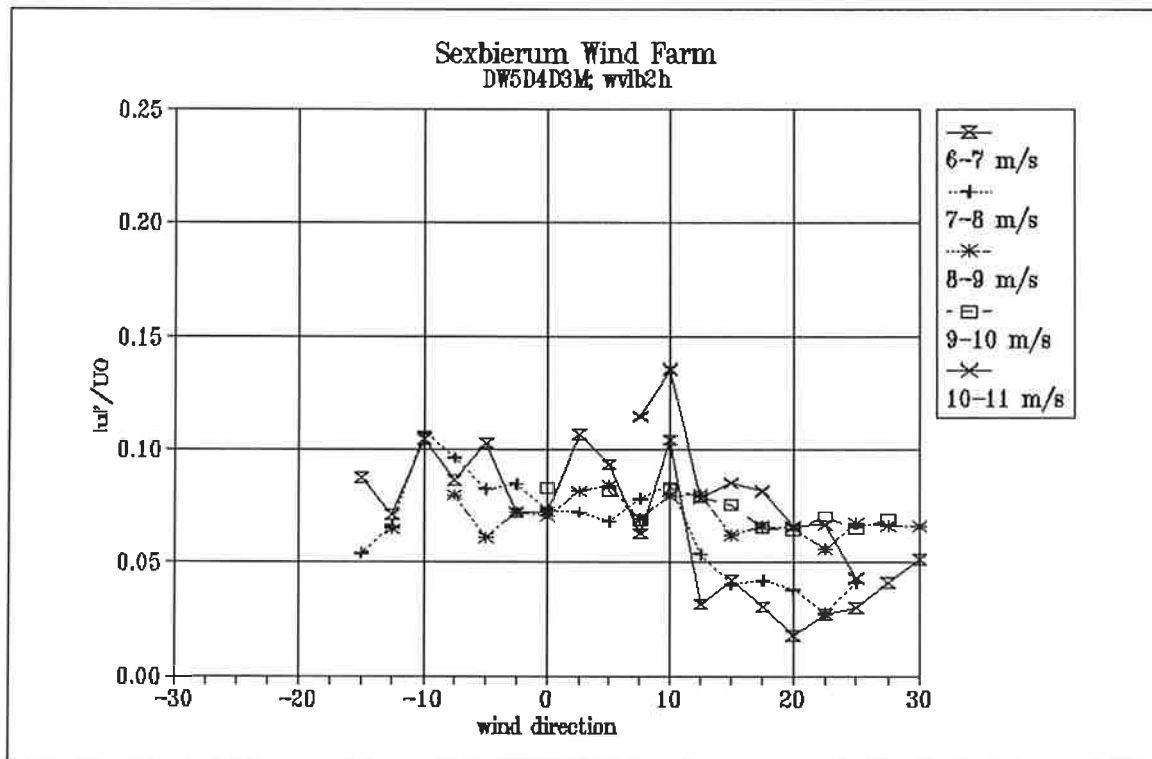


Figure 4 Non-dimensionalized turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

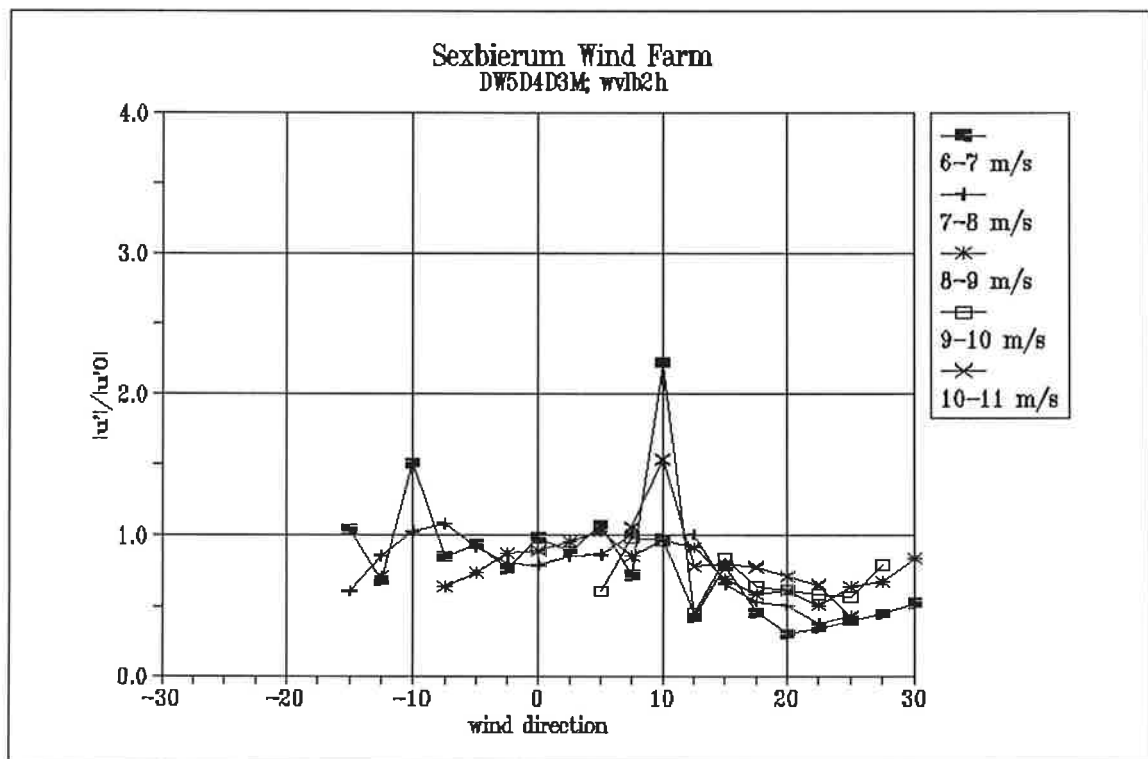


Figure 5 Turbulence enhancement u'/u'_0 as a function of wind direction and wind speed bin

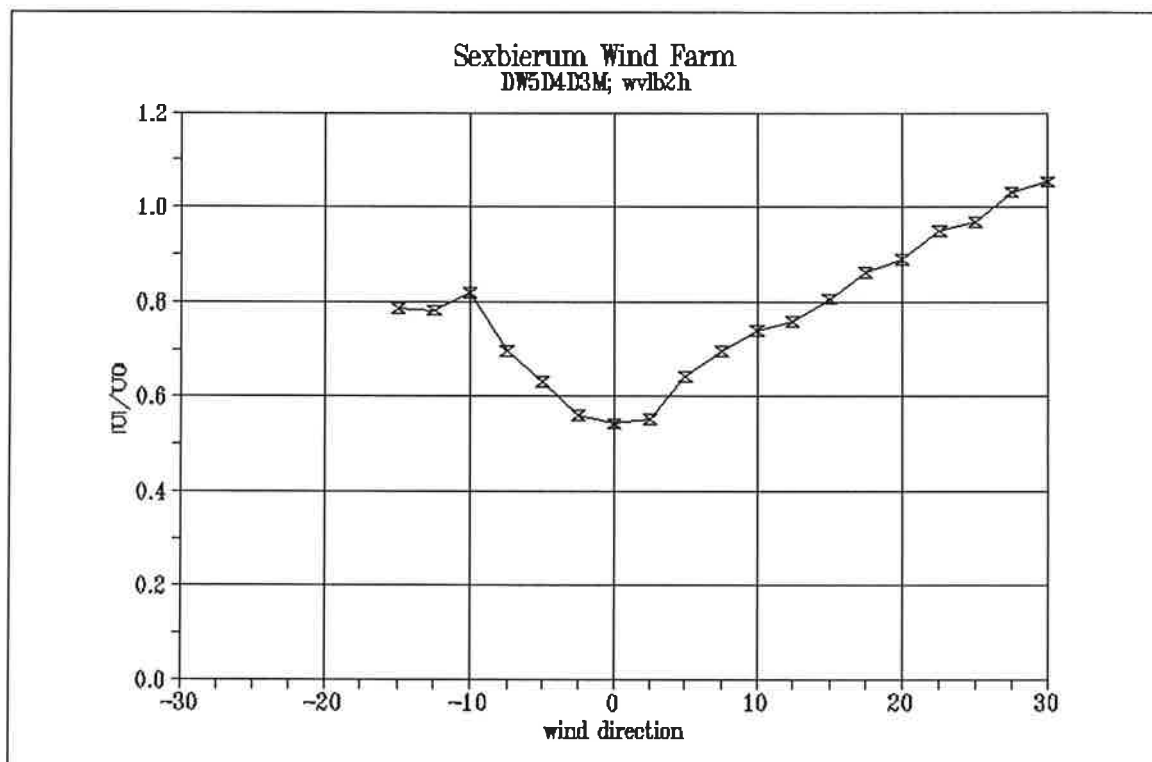


Figure 6 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

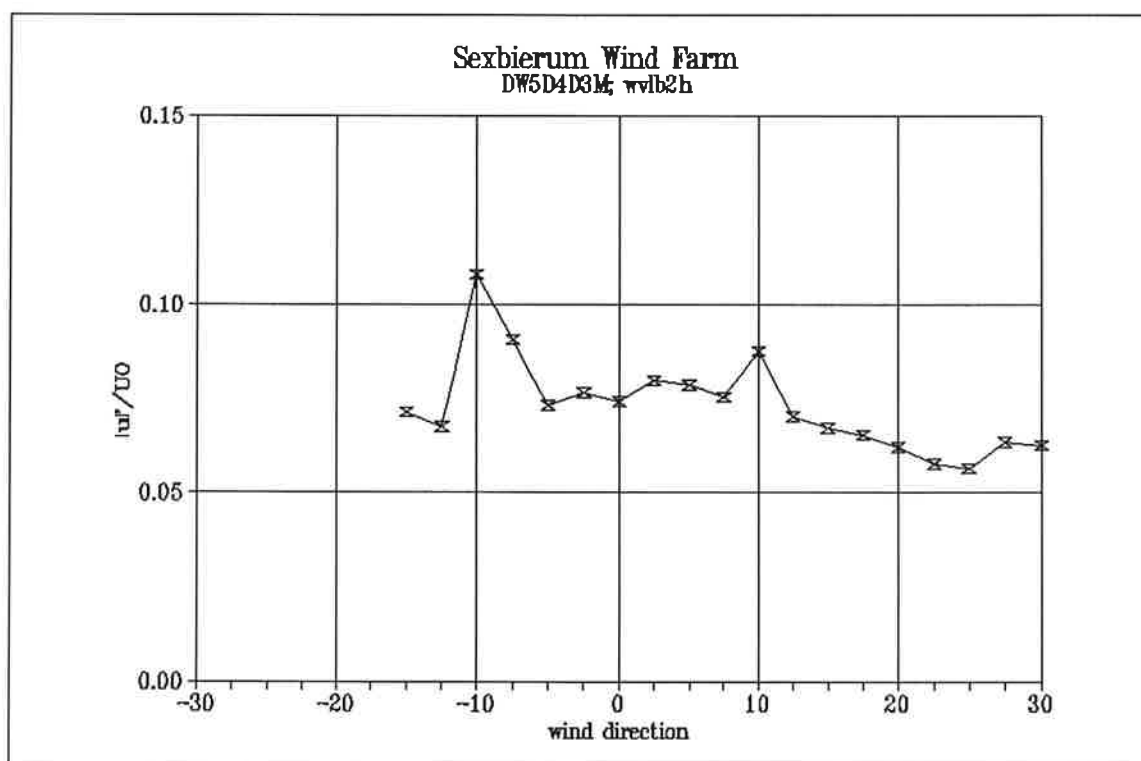


Figure 7 Non-dimensionalized turbulent fluctuations u'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

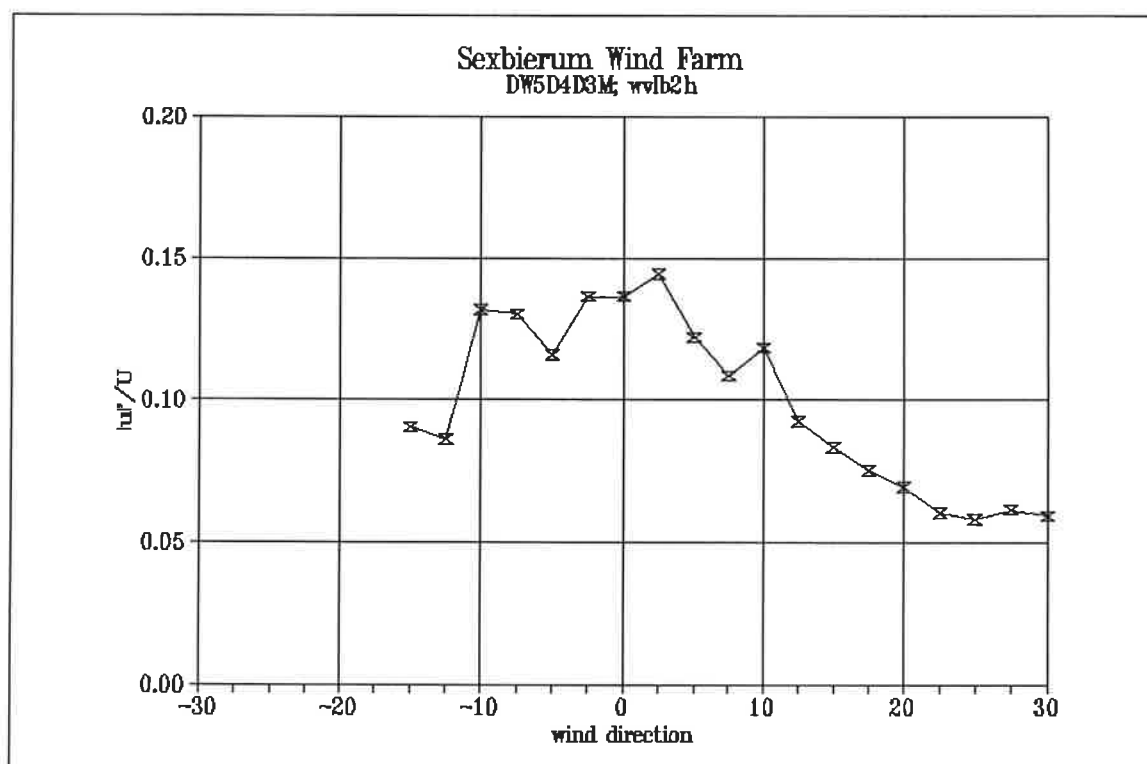


Figure 8 Non-dimensionalized turbulent fluctuations u'/U as a function of wind direction in the wind speed bin 5-10 m/s

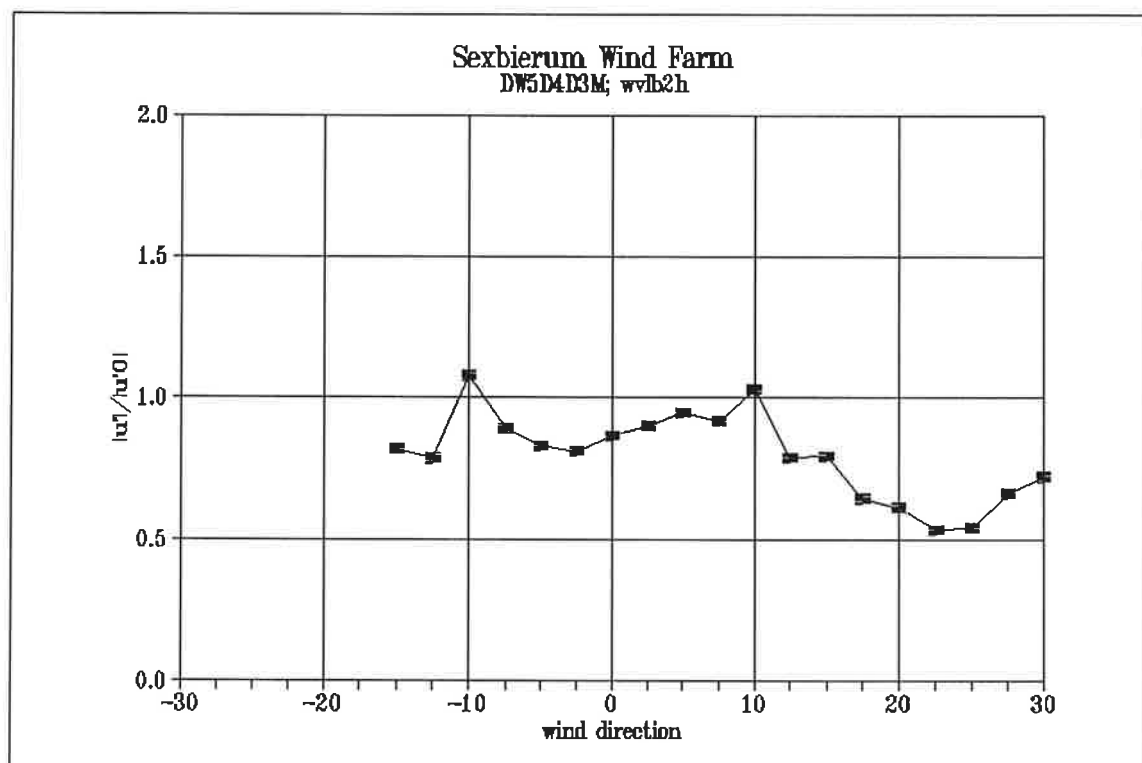


Figure 9 Turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.4 Sensor b2

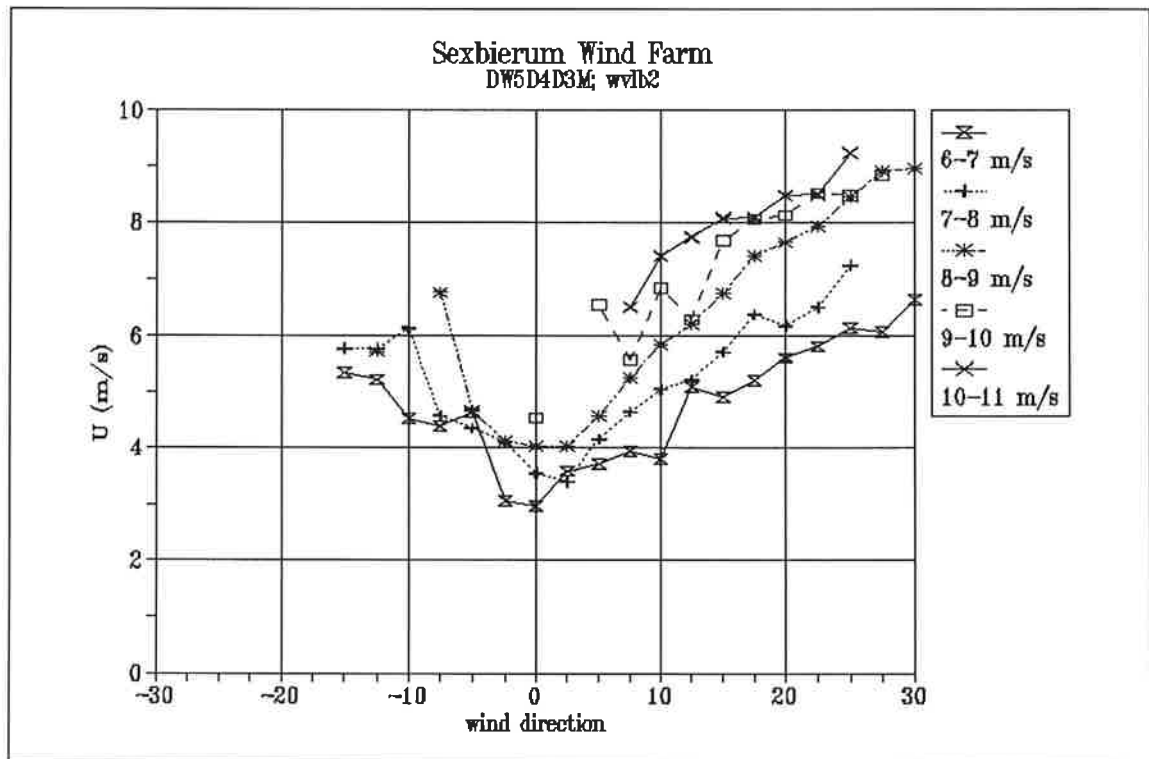


Figure 1 Horizontal wind speed U as a function of wind direction and wind speed bin

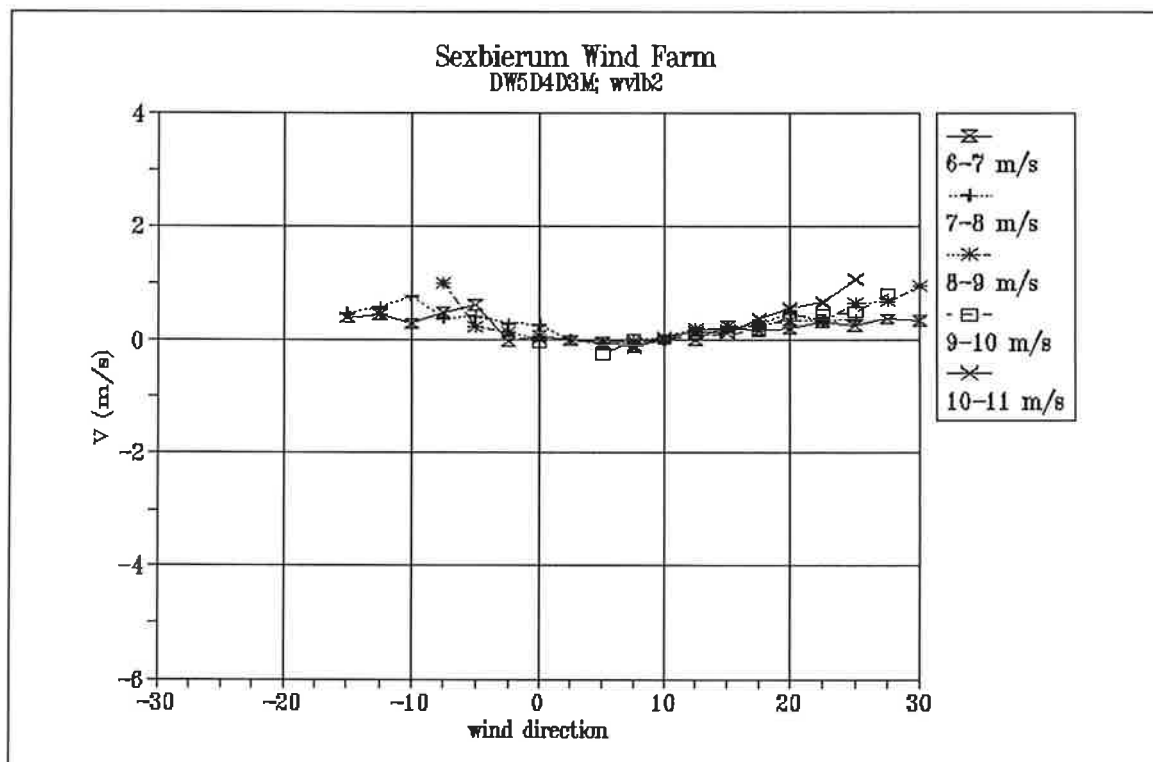


Figure 2 Lateral wind speed V as a function of wind direction and wind speed bin

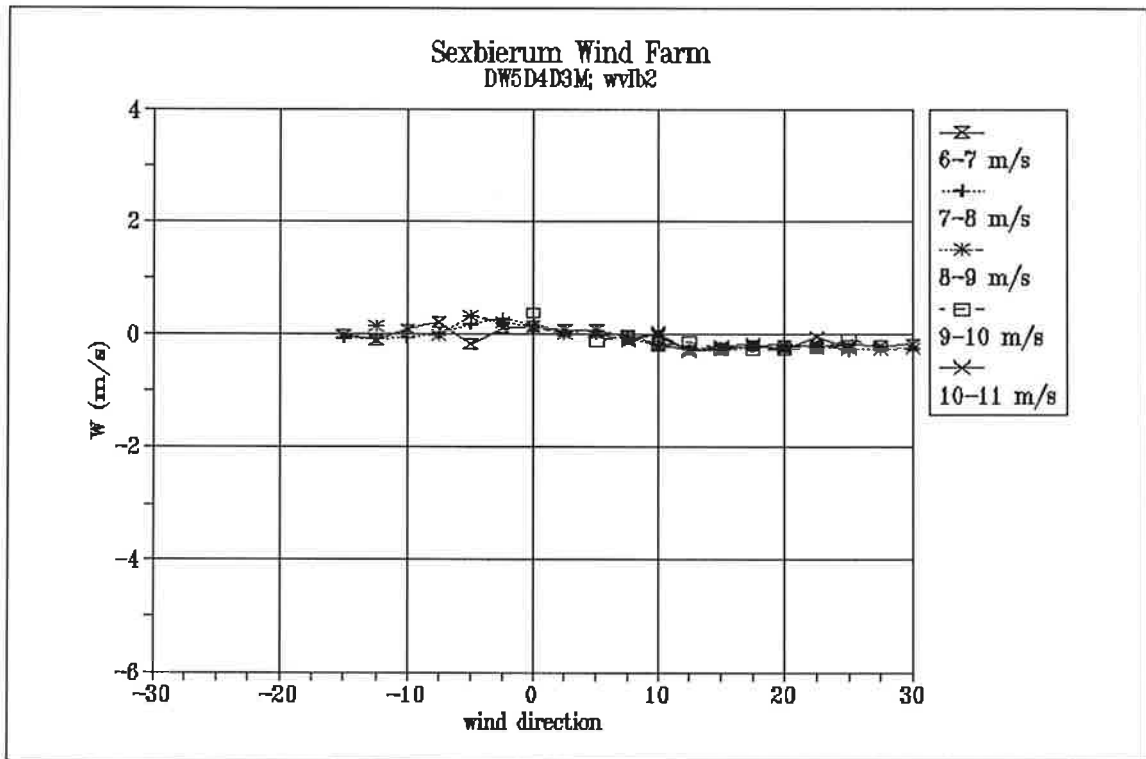


Figure 3 Vertical wind speed W as a function of wind direction and wind speed bin

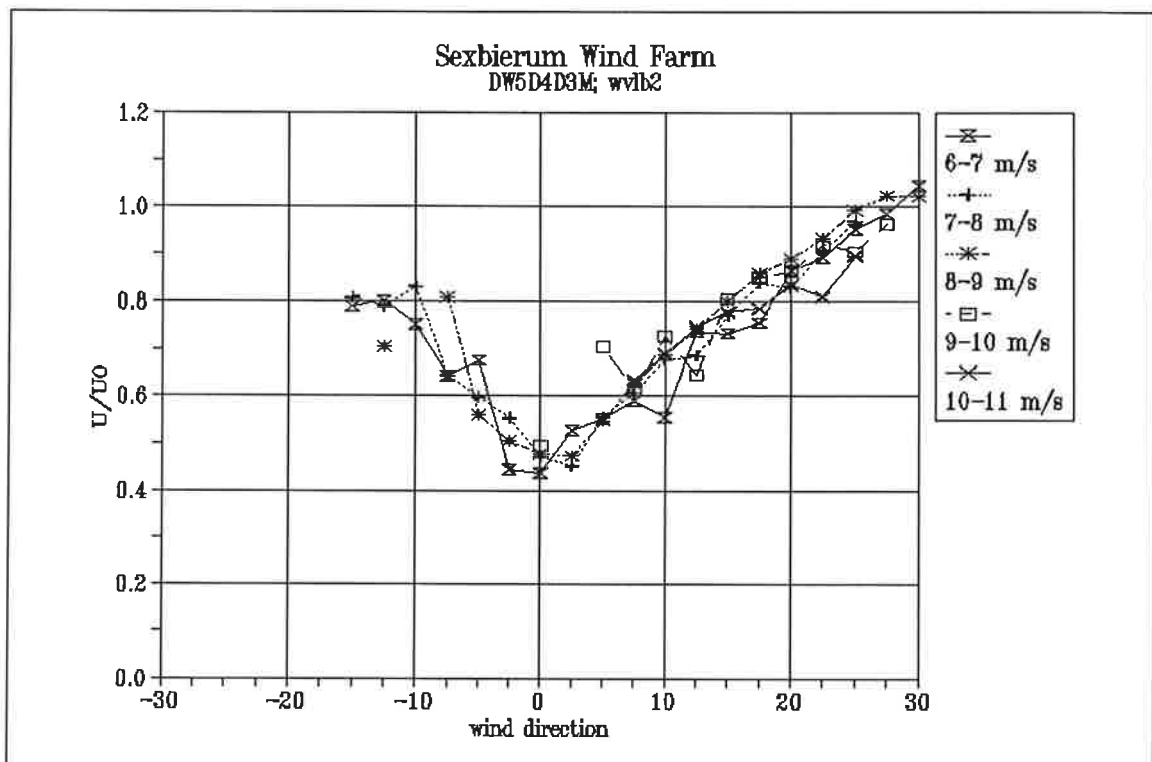


Figure 4 Wake deficit U/U_0 as a function of wind direction and wind speed bin

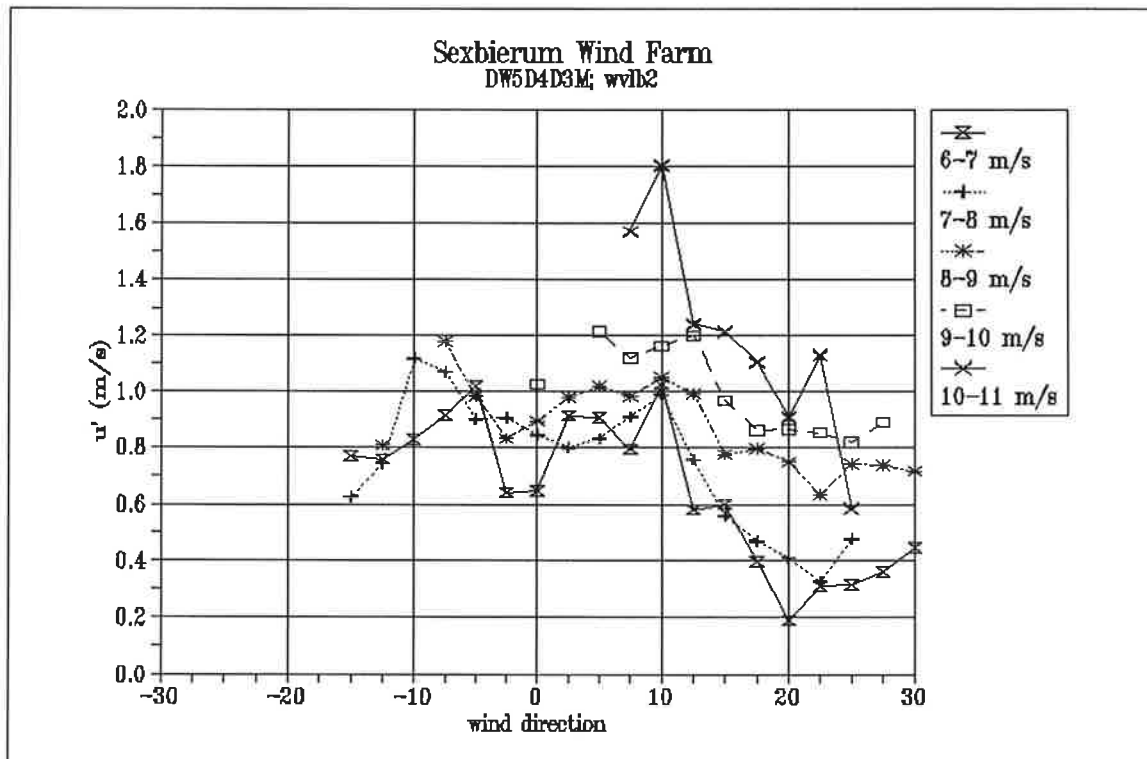


Figure 5 Longitudinal turbulent fluctuations u' as a function of wind direction and wind speed bin

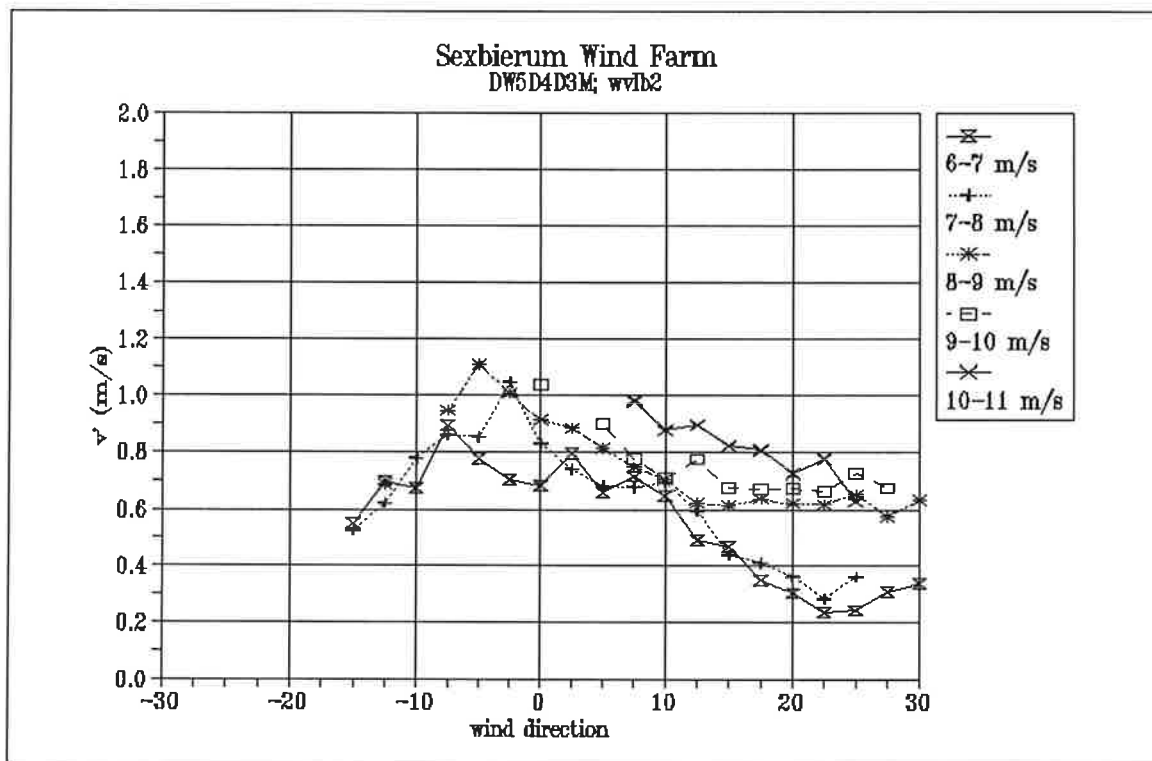


Figure 6 Lateral turbulent fluctuations v' as a function of wind direction and wind speed bin

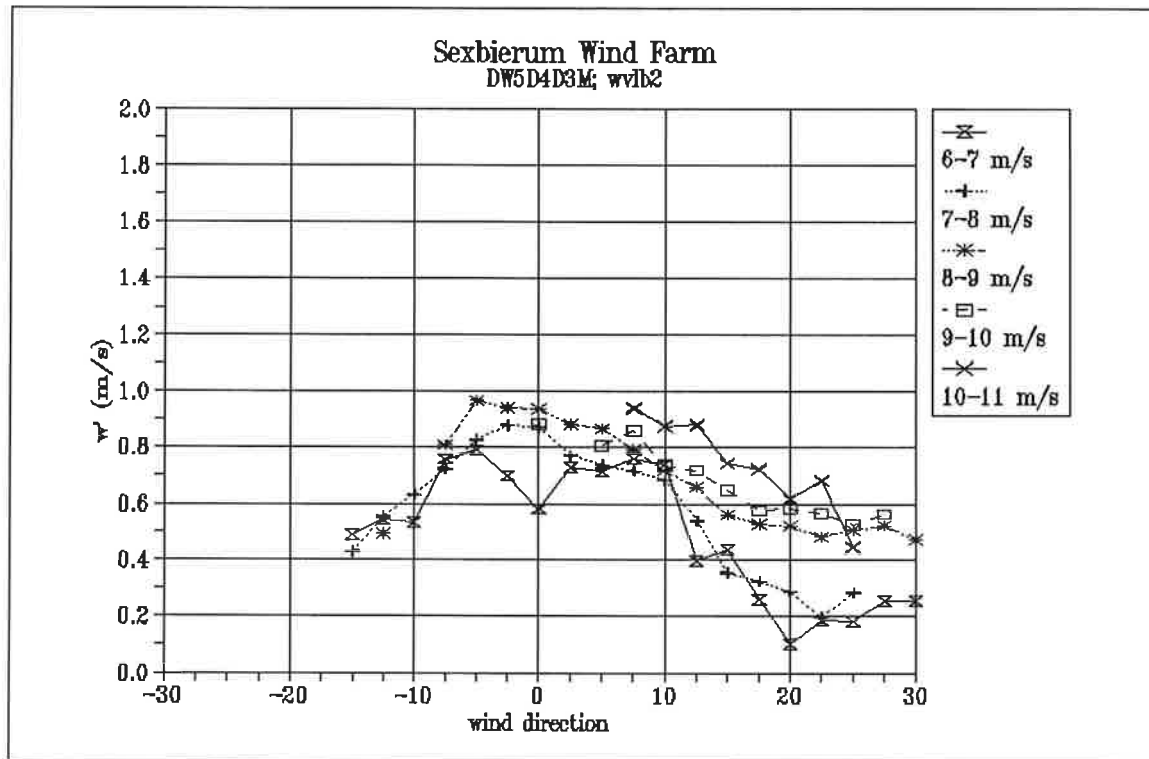


Figure 7 Vertical turbulent fluctuations w' as a function of wind direction and wind speed bin

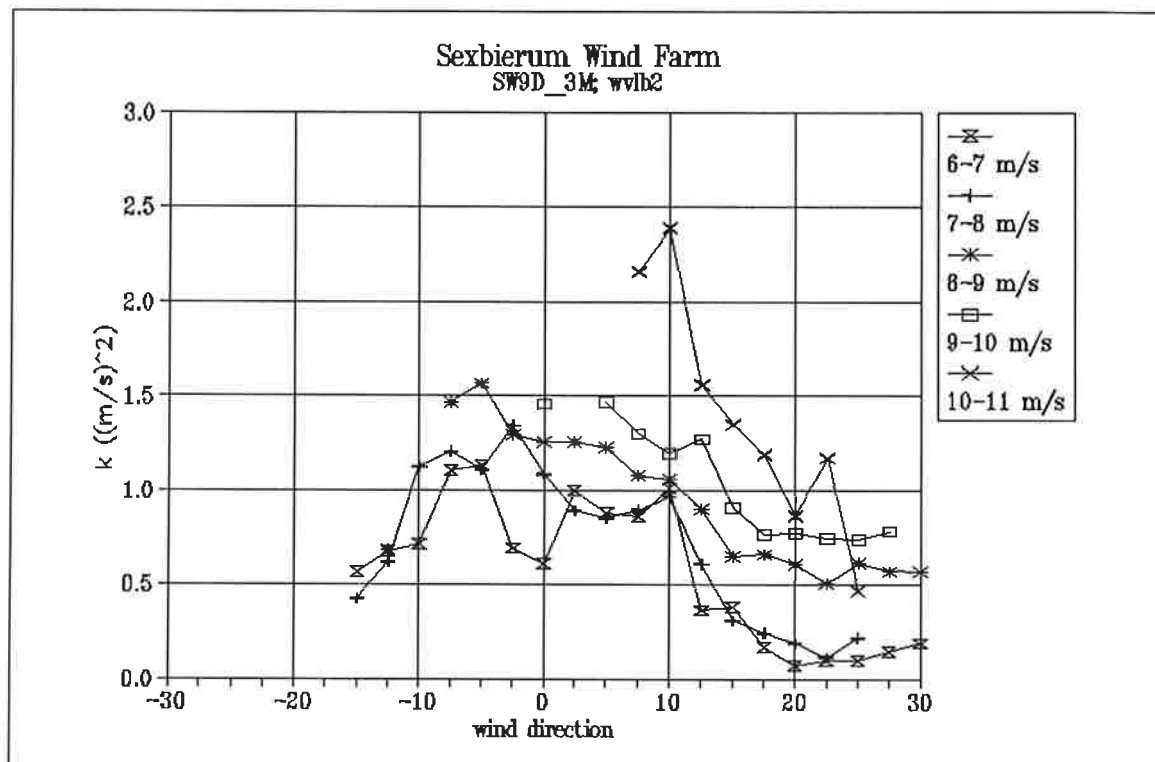


Figure 8 Turbulent kinetic energy per unit mass as a function of wind direction and wind speed bin

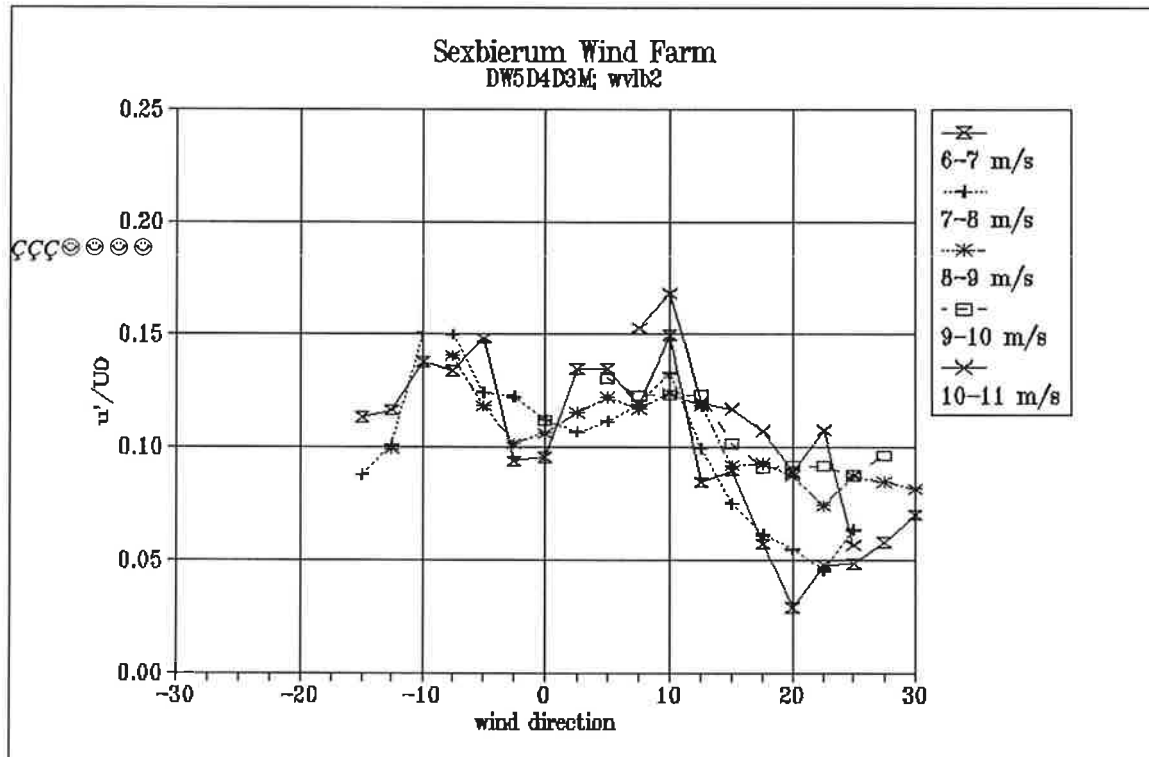


Figure 9 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

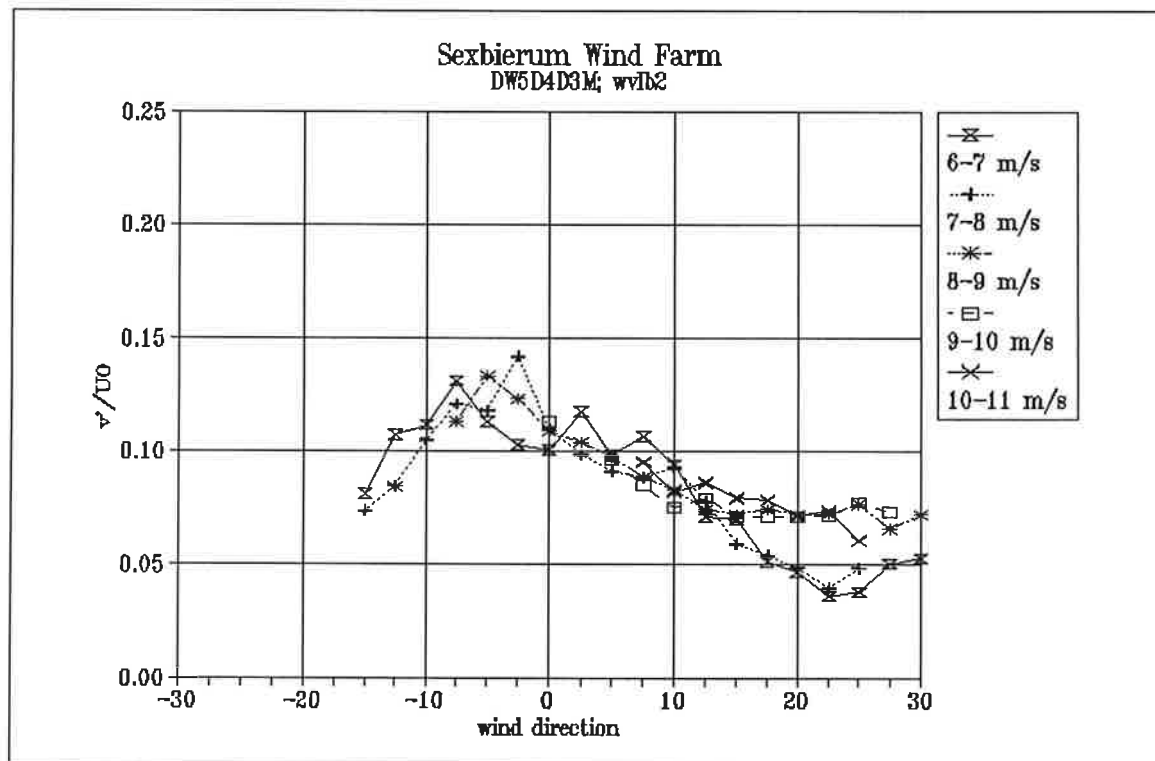


Figure 10 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction and wind speed bin

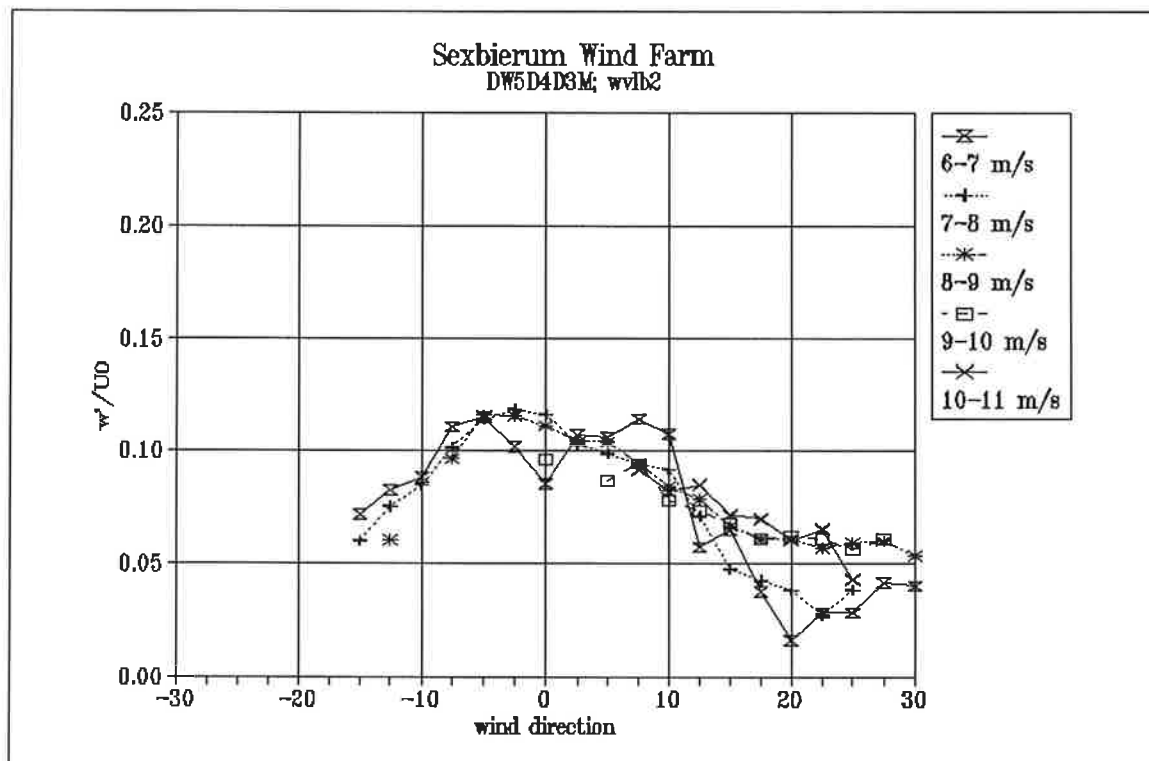


Figure 11 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction and wind speed bin

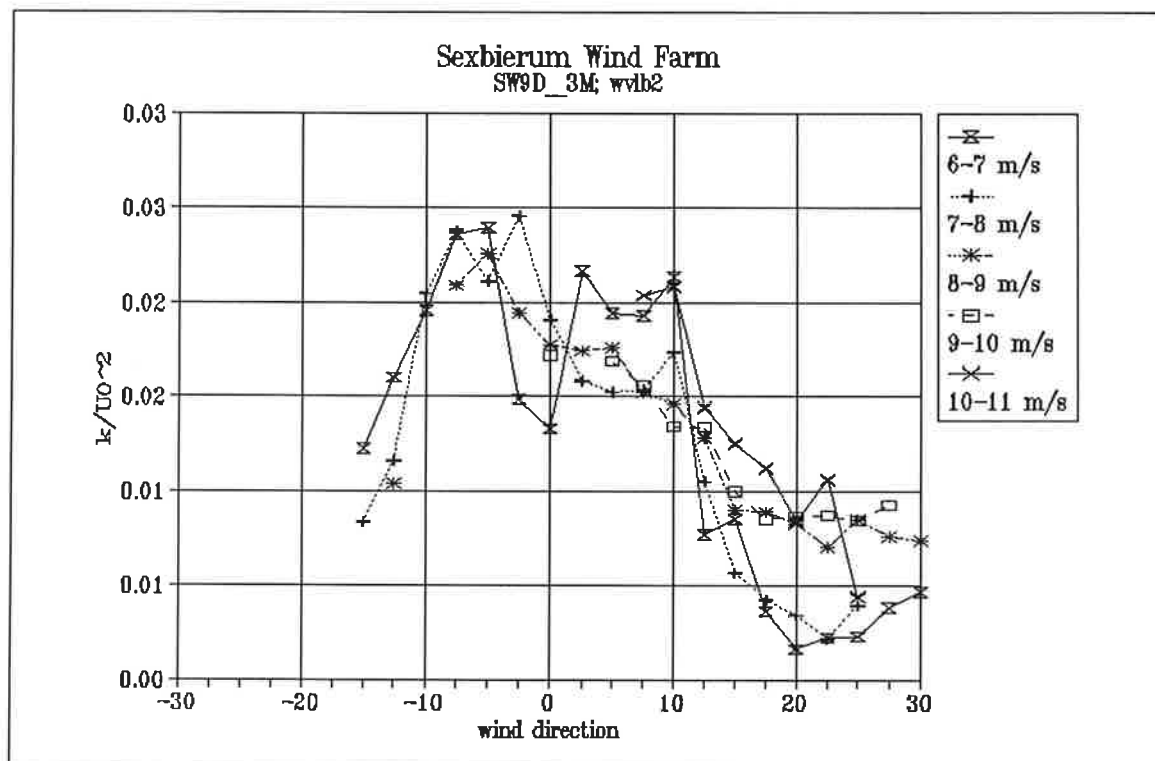


Figure 12 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction and wind speed bin

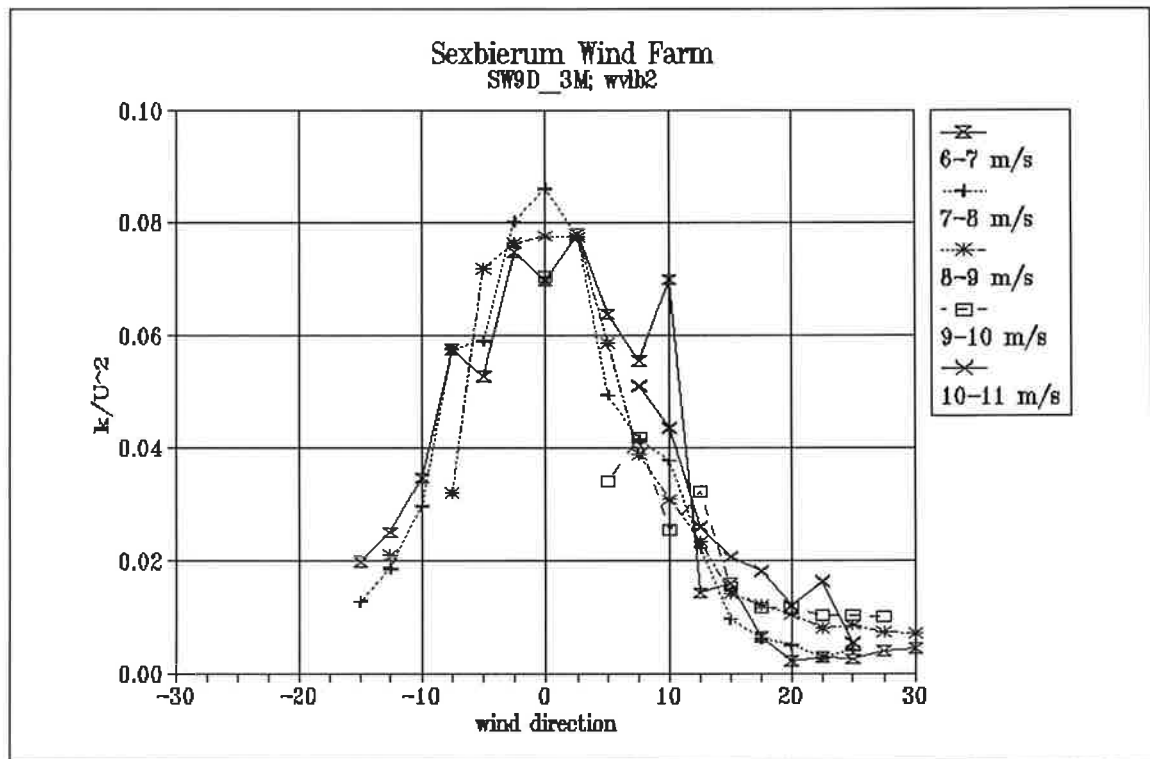


Figure 13 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction and wind speed bin

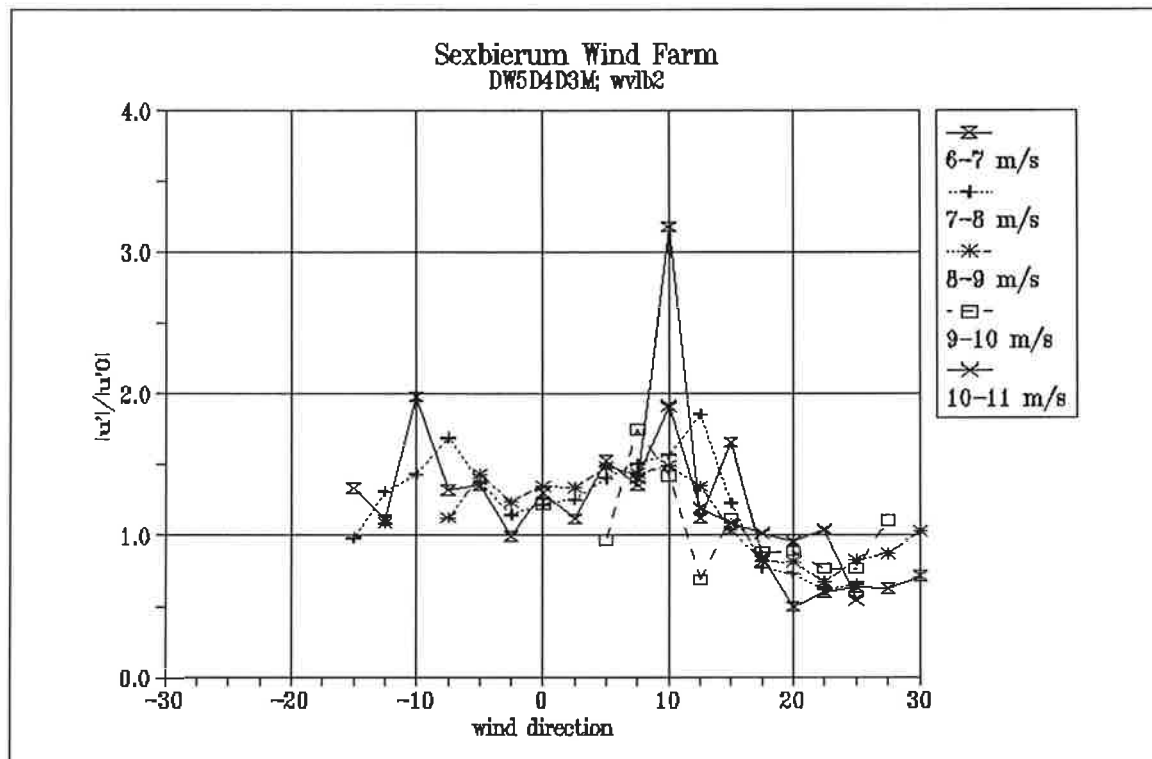


Figure 14 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction and wind speed bin

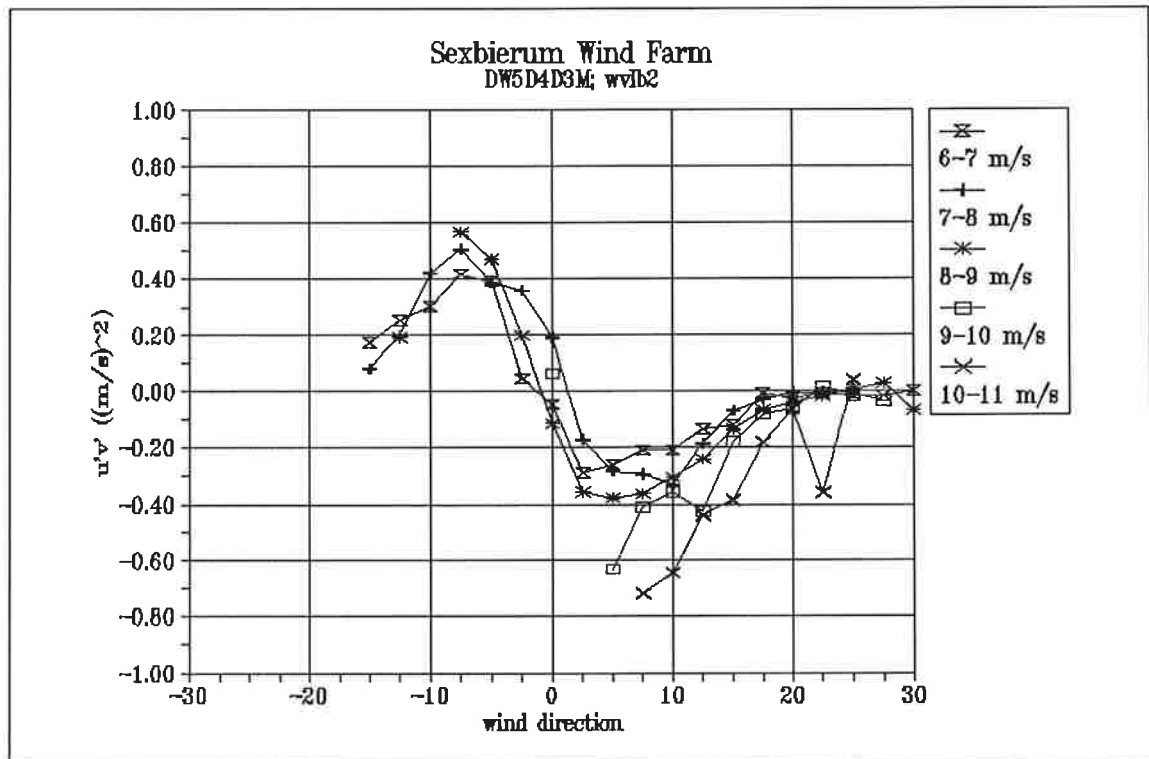


Figure 15 Shear stress $u'v'$ as a function of wind direction and wind speed bin

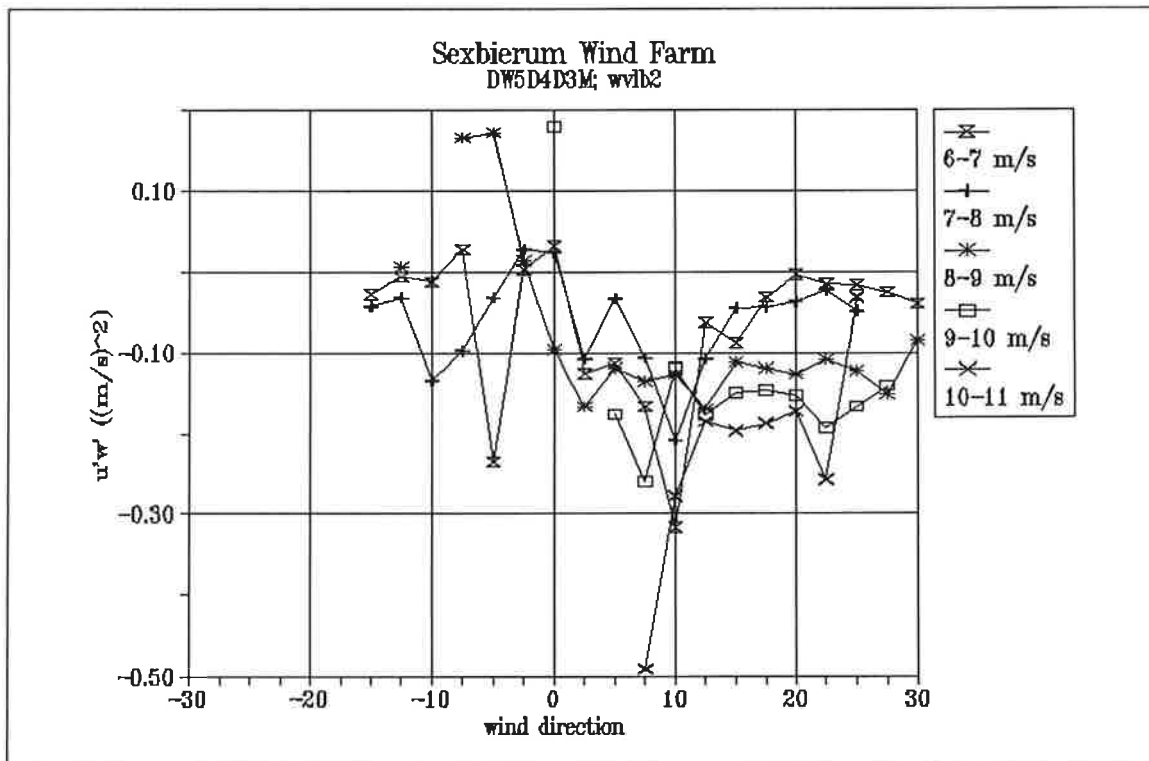


Figure 16 Shear stress $u'w'$ as a function of wind direction and wind speed bin

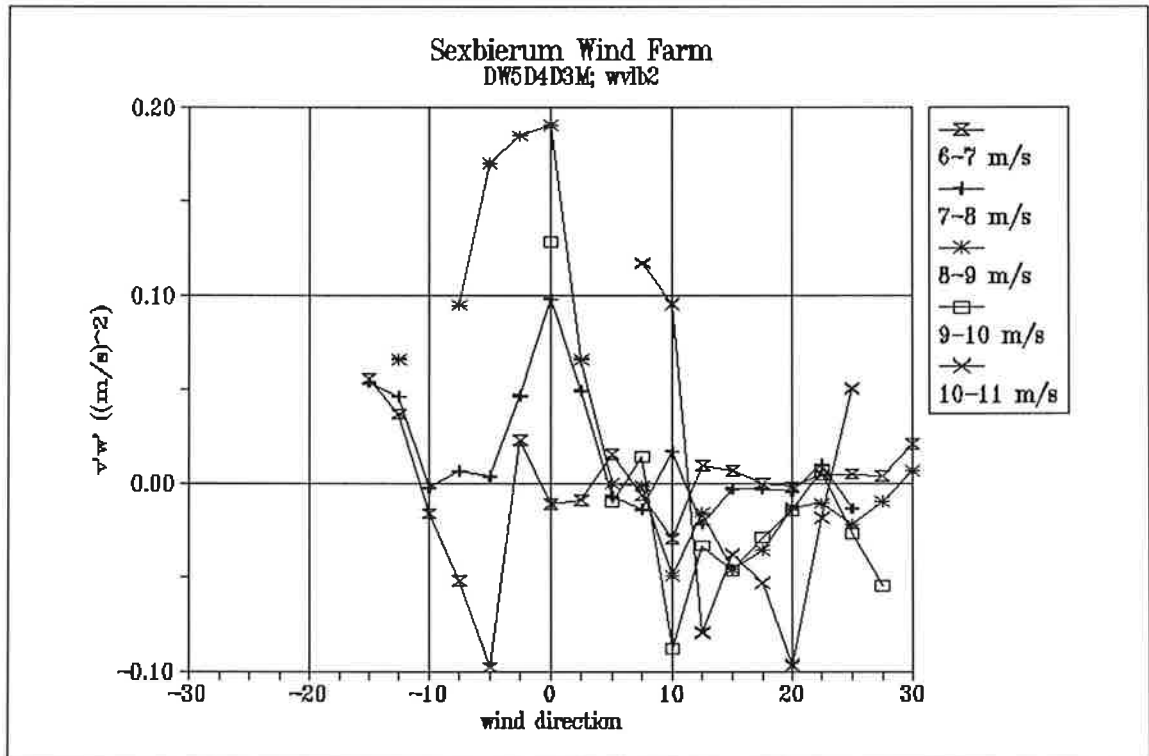


Figure 17 Shear stress $v'w'$ as a function of wind direction and wind speed bin

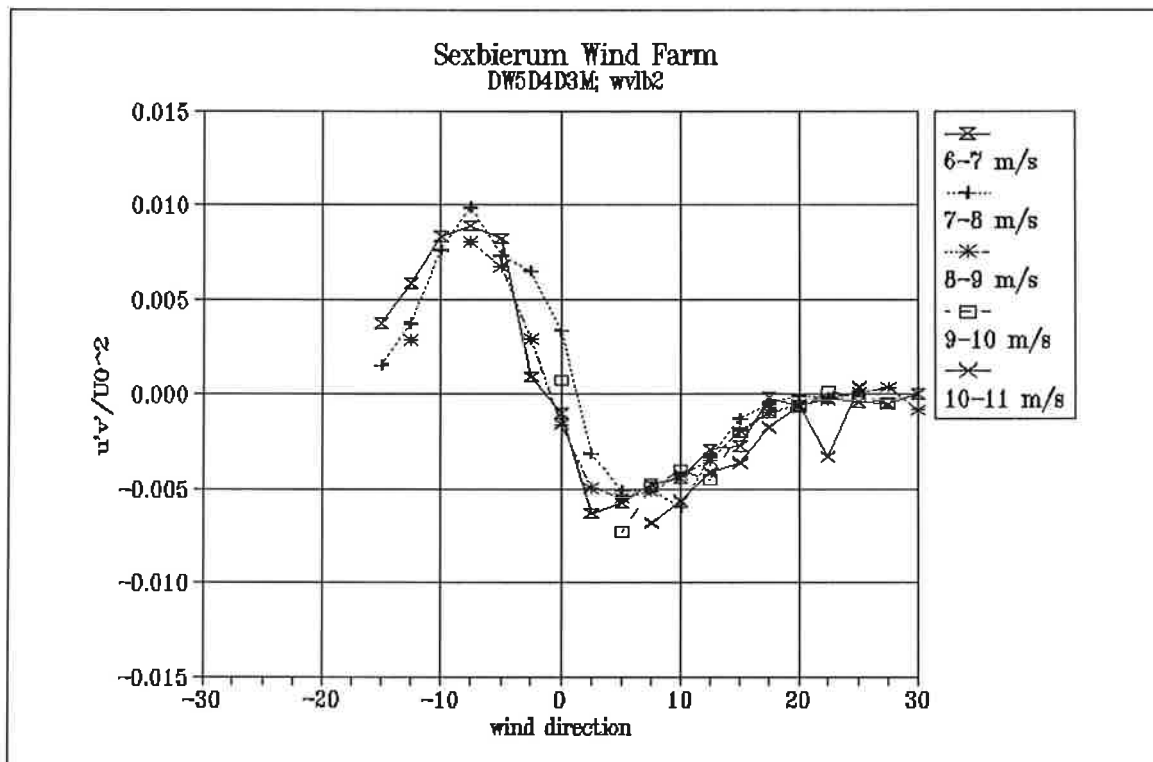


Figure 18 Non-dimensionalized shear stress $u'v'/U_0^2$ as a function of wind direction and wind speed bin

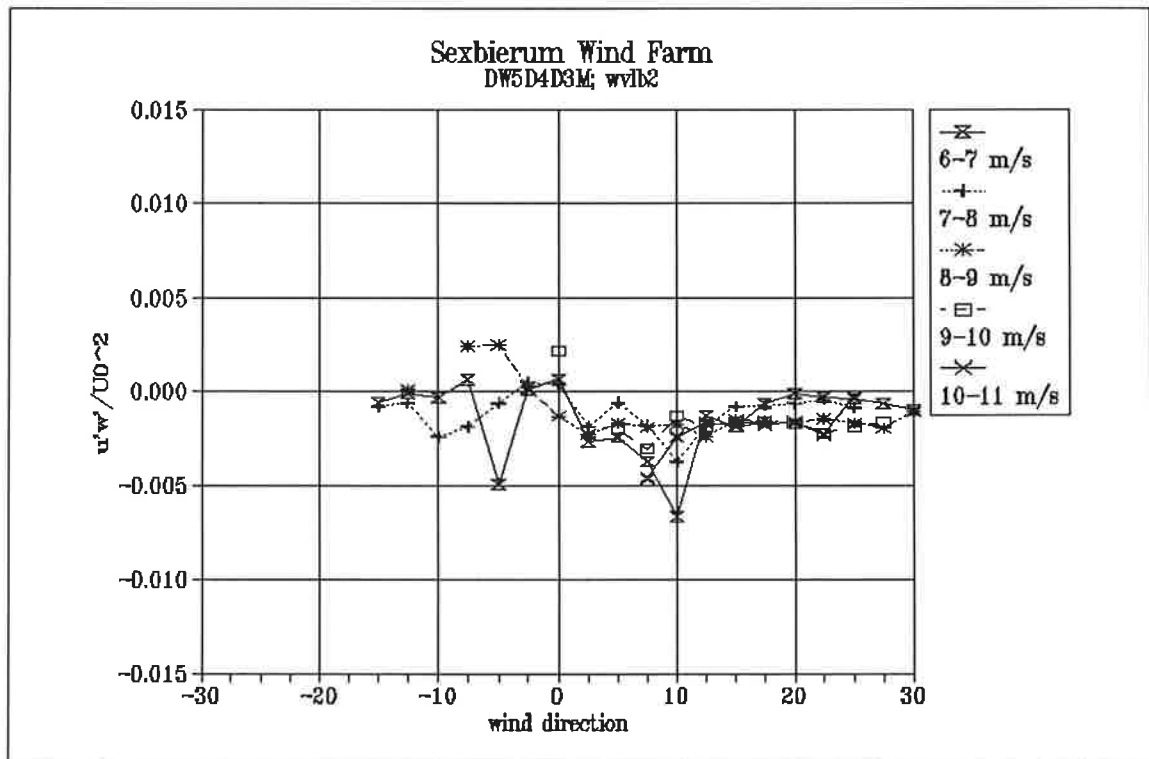


Figure 19 Non-dimensionalized shear stress $u'w'/U_0^2$ as a function of wind direction and wind speed bin

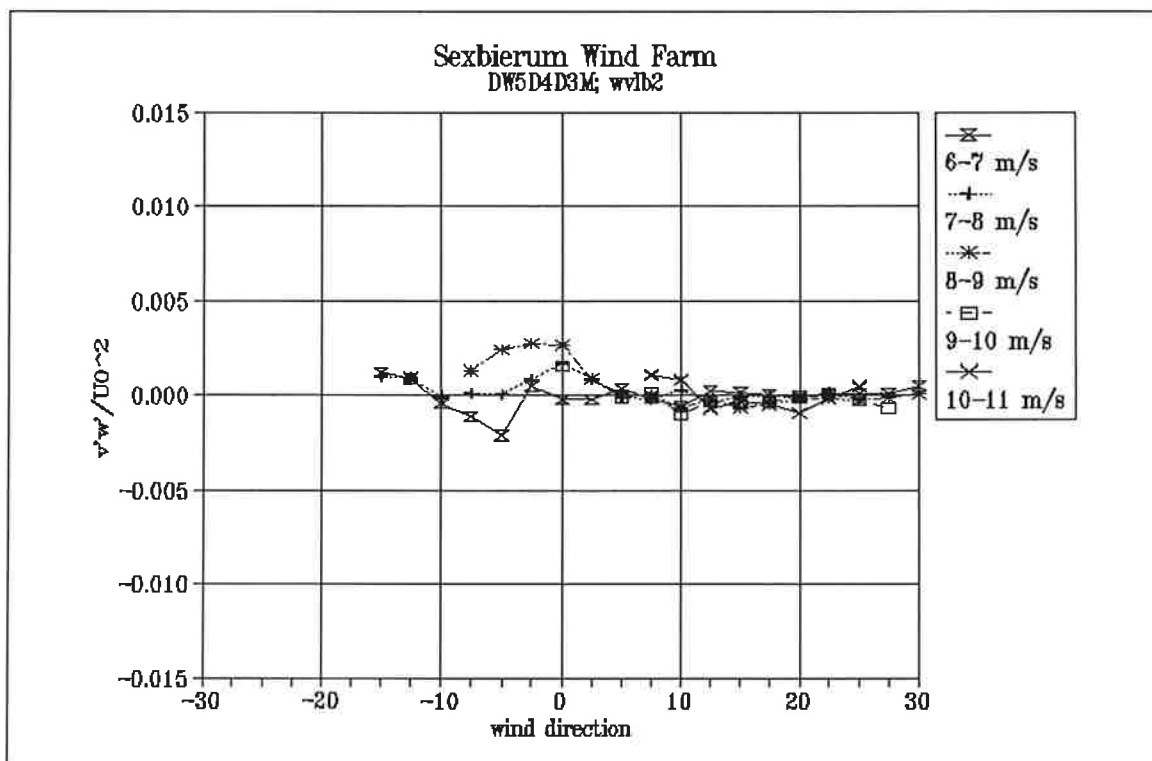


Figure 20 Non-dimensionalized shear stress $v'w'/U_0^2$ as a function of wind direction and wind speed bin

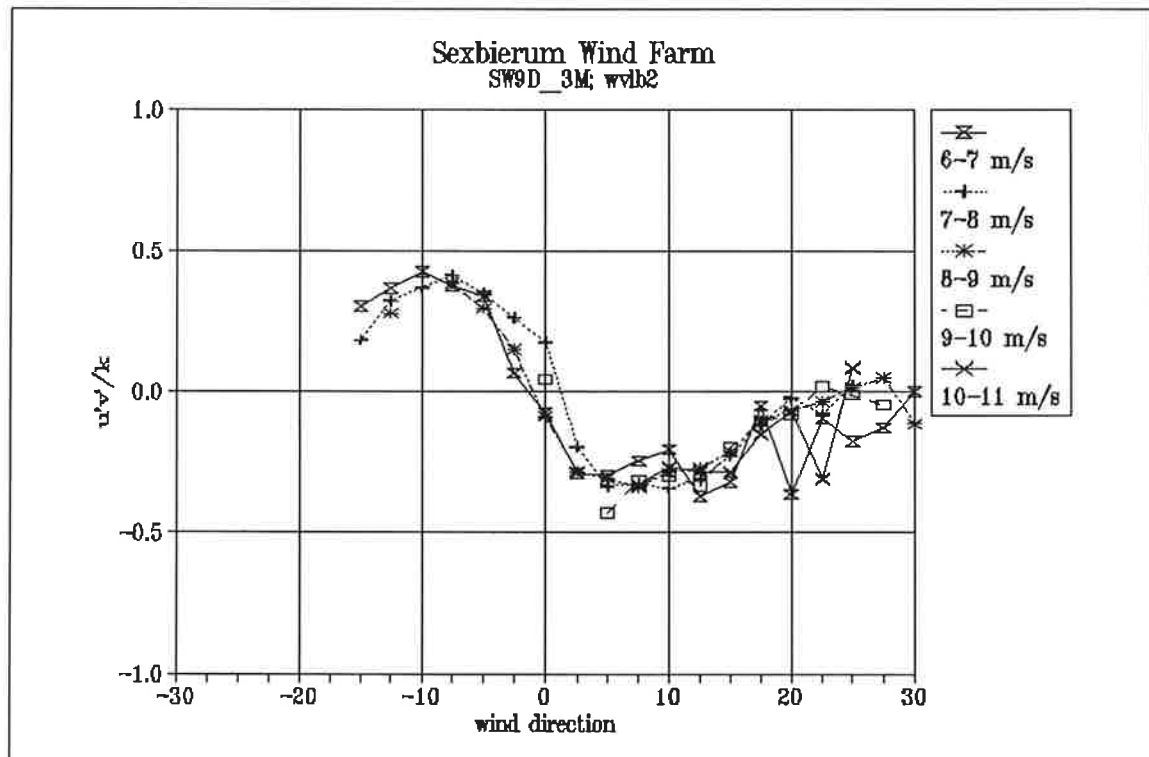


Figure 21 Non-dimensionalized shear stress $u'v'/k$ as a function of wind direction and wind speed bin

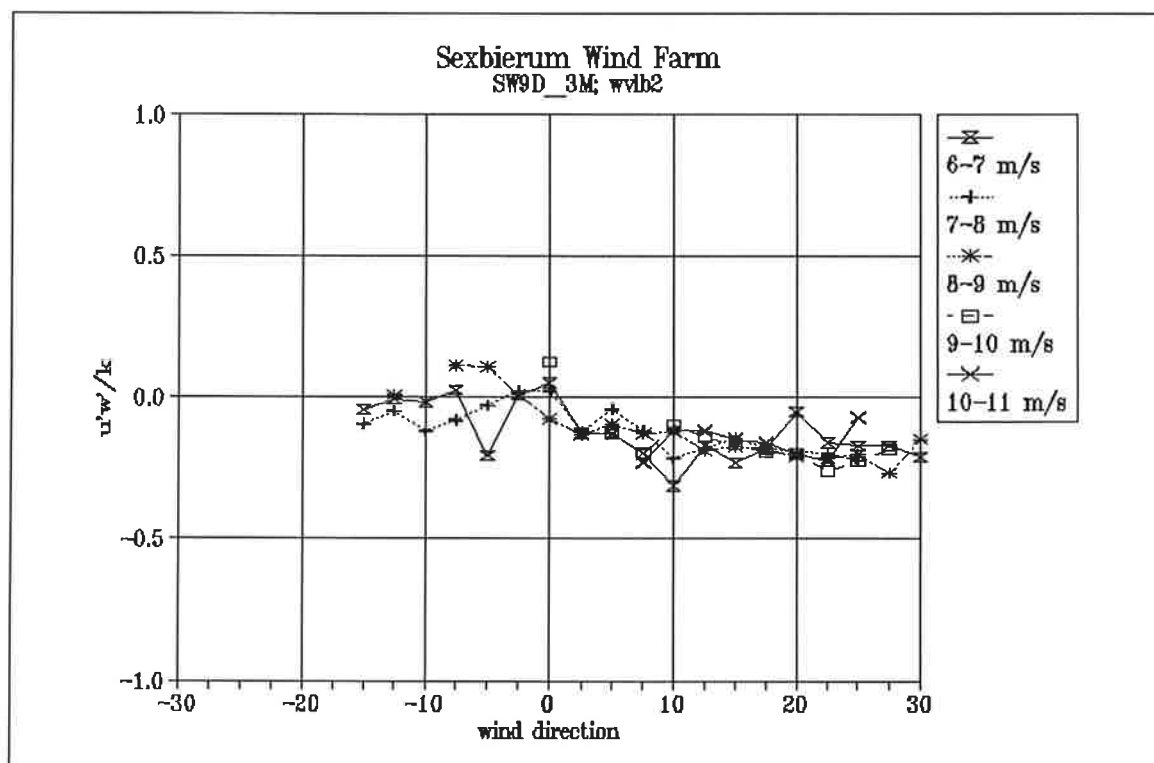


Figure 22 Non-dimensionalized shear stress $u'w'/k$ as a function of wind direction and wind speed bin

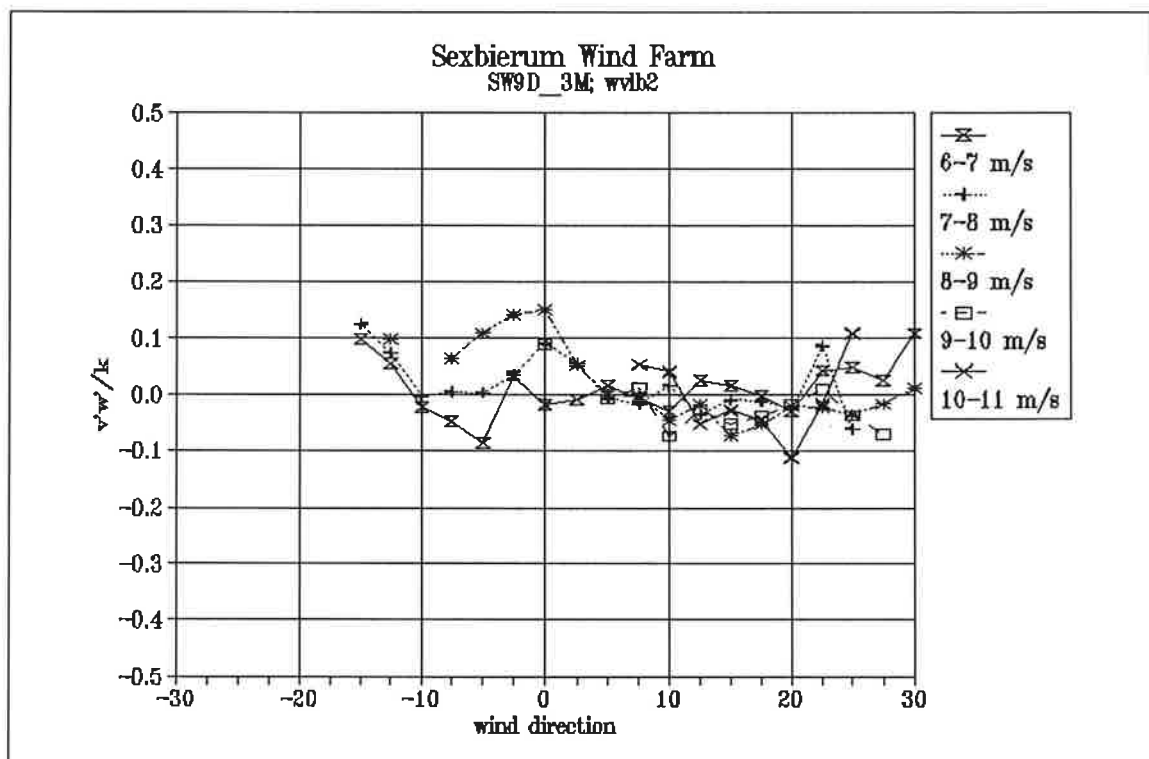


Figure 23 Non-dimensionalized shear stress $v'w'/k$ as a function of wind direction and wind speed bin

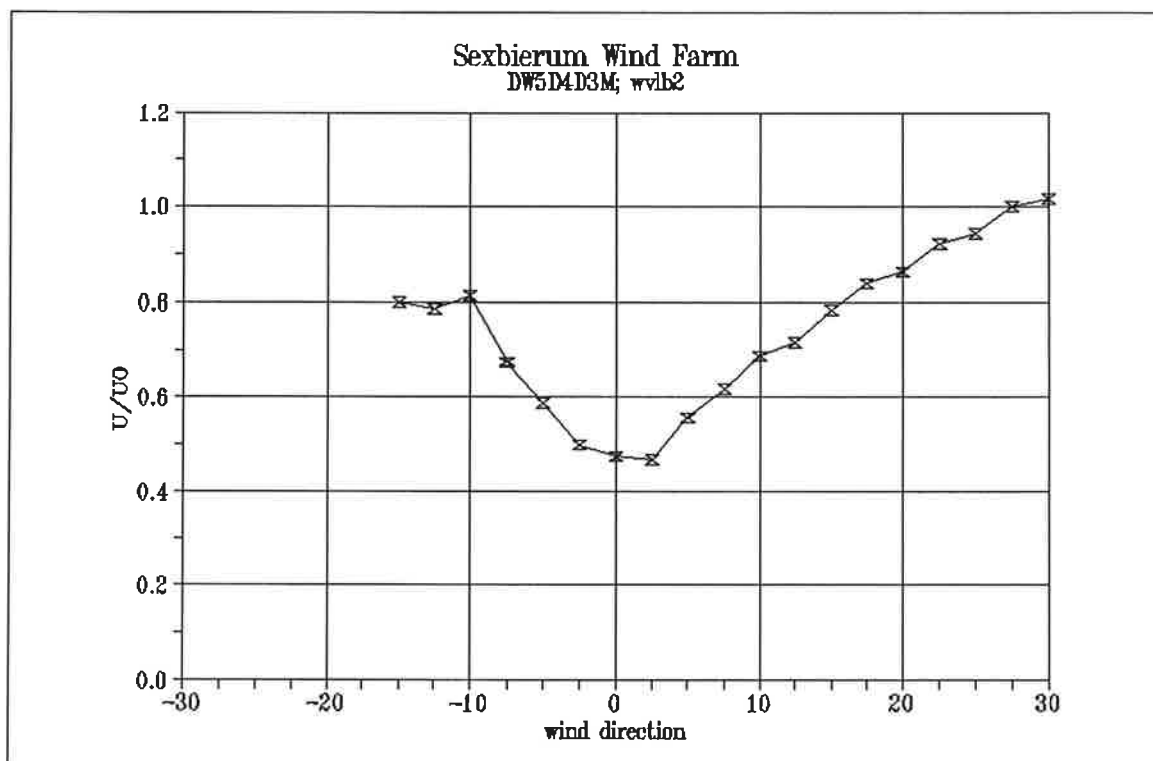


Figure 24 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

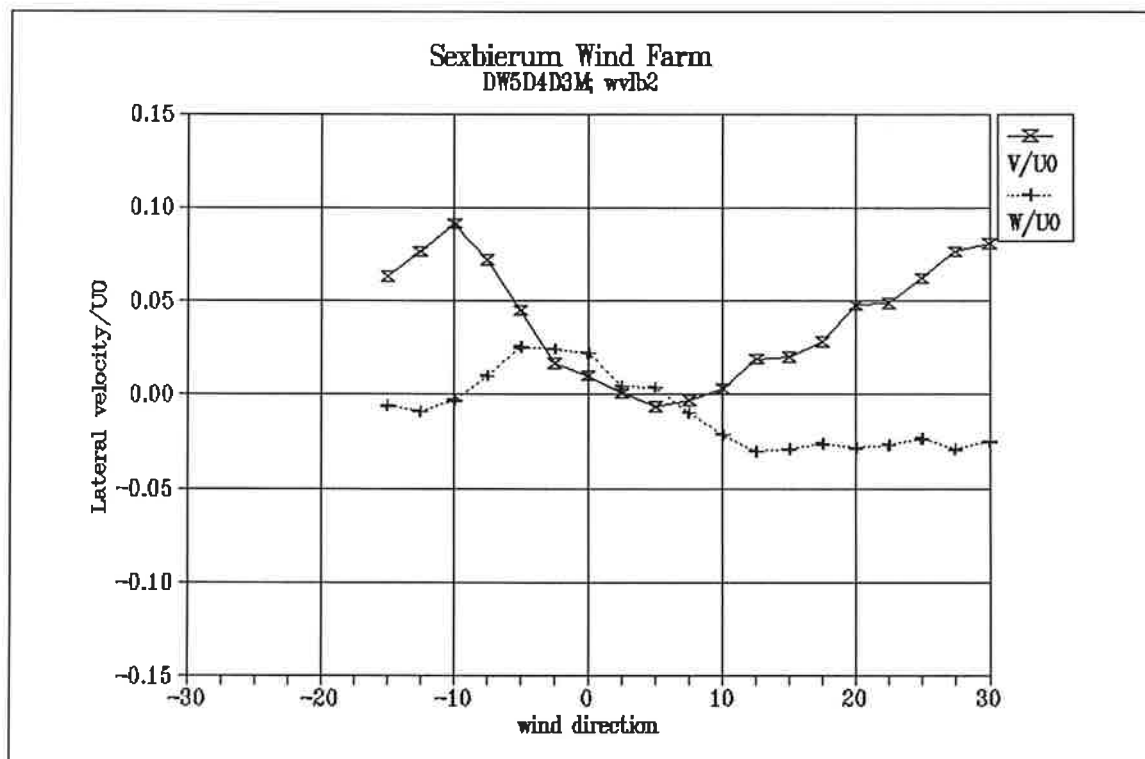


Figure 25 Lateral and vertical wind speed V/U_0 and W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

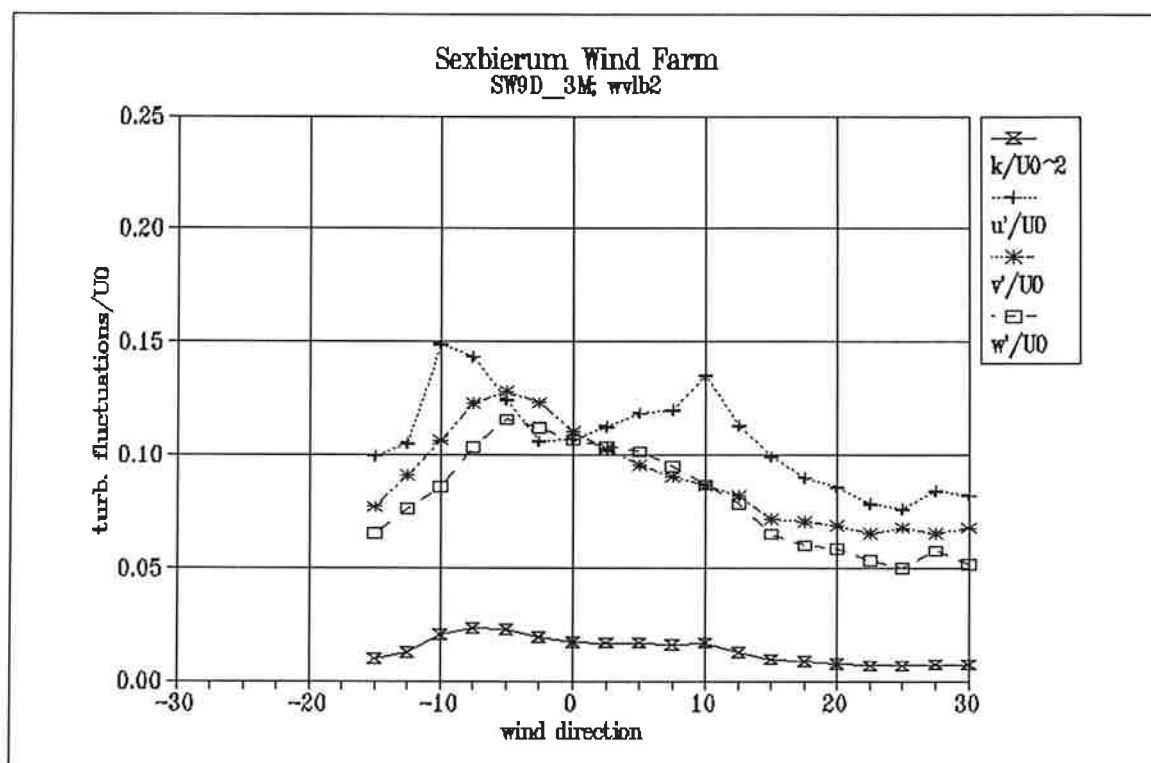


Figure 26 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U_0

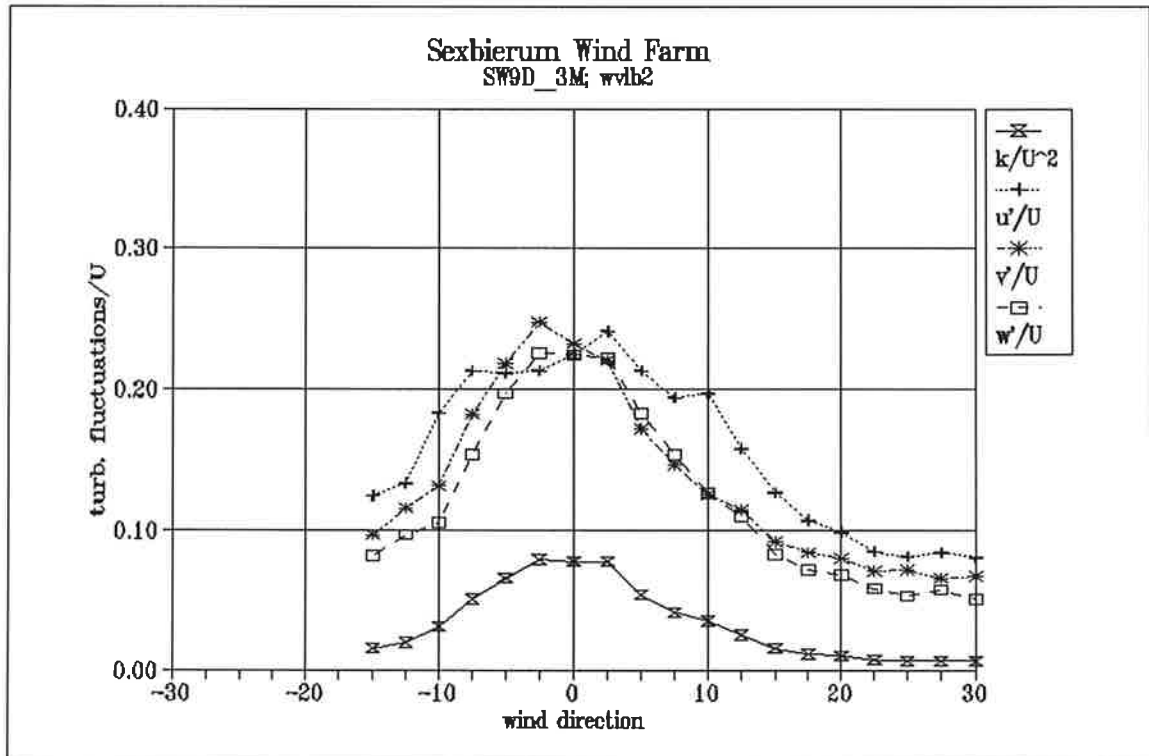


Figure 27 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U

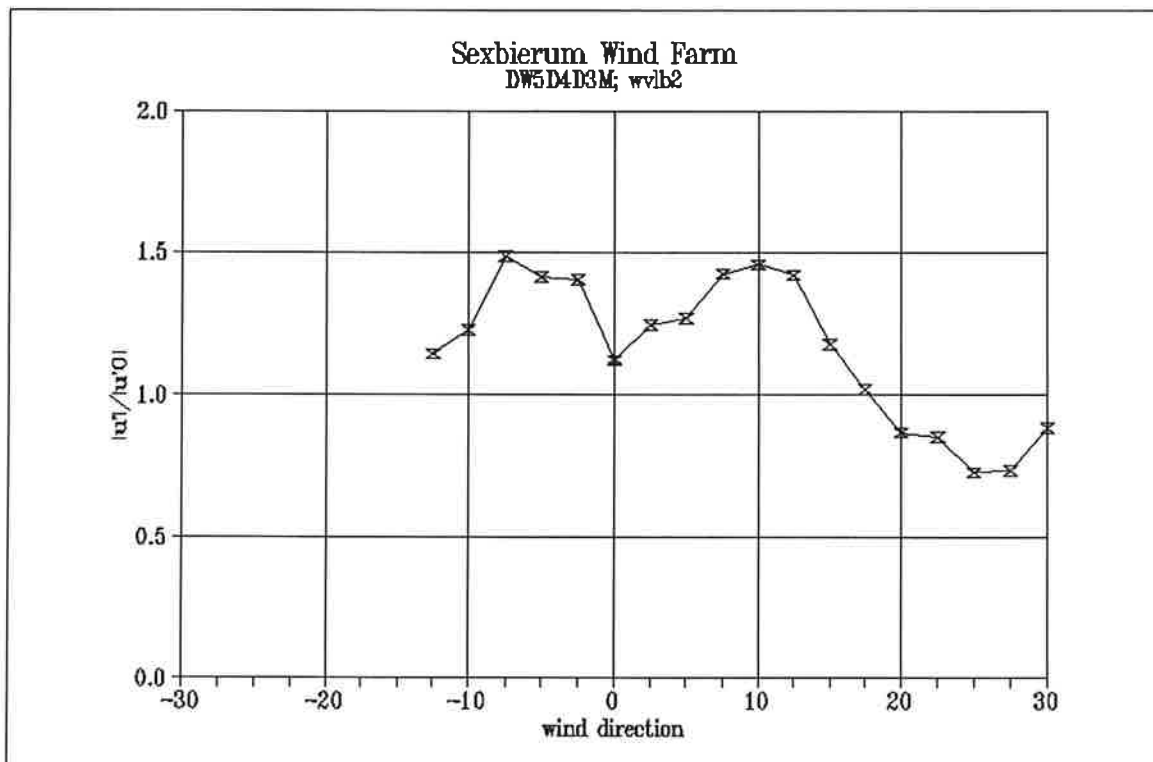


Figure 28 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

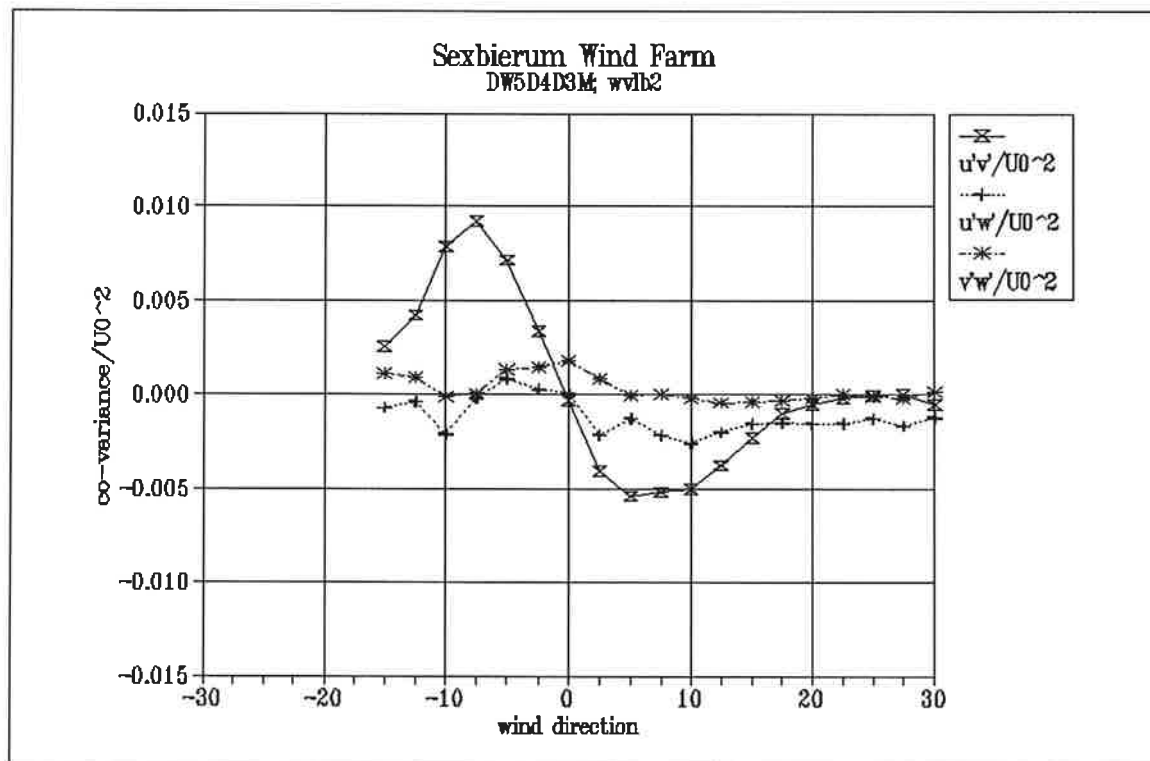


Figure 29 Non-dimensionalized shear stresses $u'v'/U_0^2$; $u'w'/U_0^2$; $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

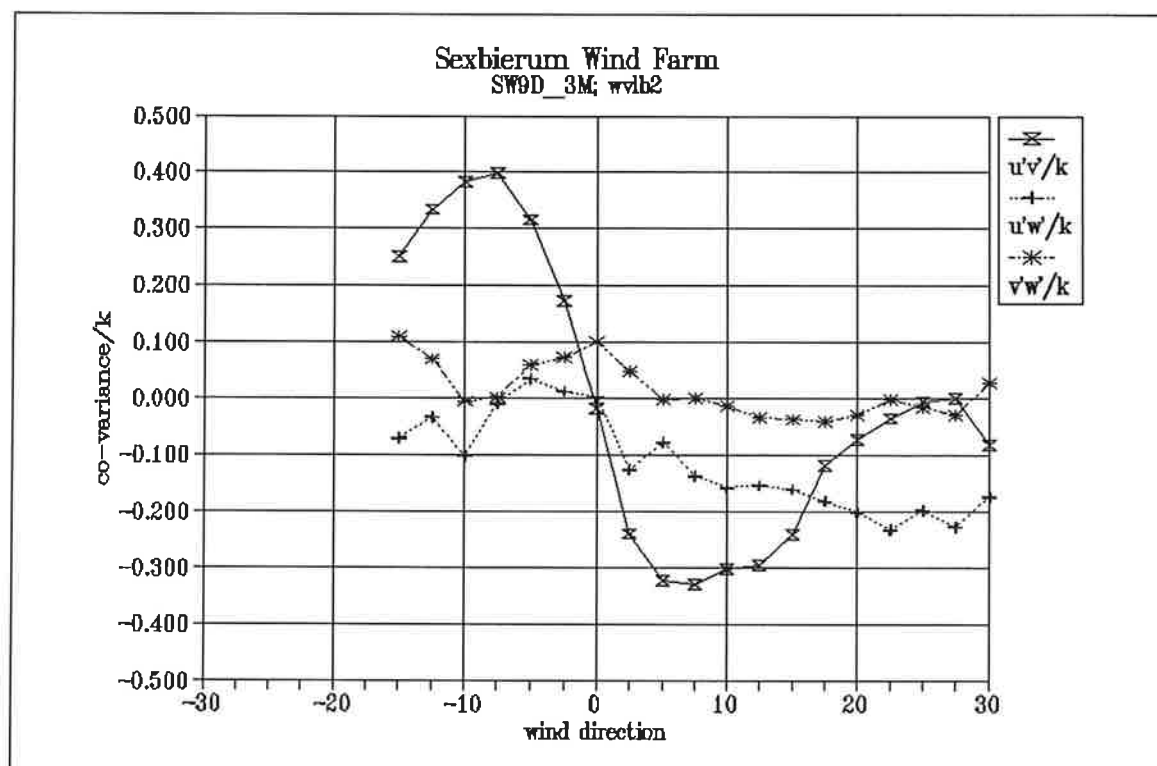


Figure 30 Non-dimensionalized shear stresses $u'v'/k$; $u'w'/k$; $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.5 Sensor b2l

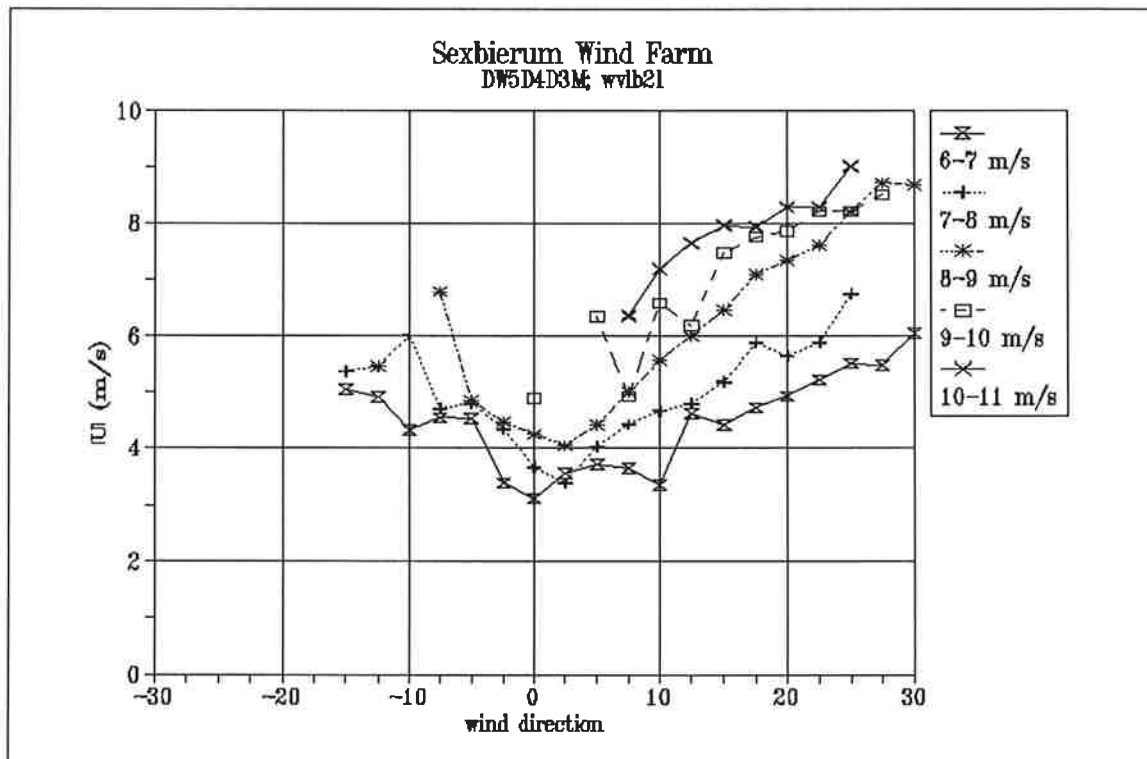


Figure 1 Wind speed U as a function of wind direction and wind speed bin

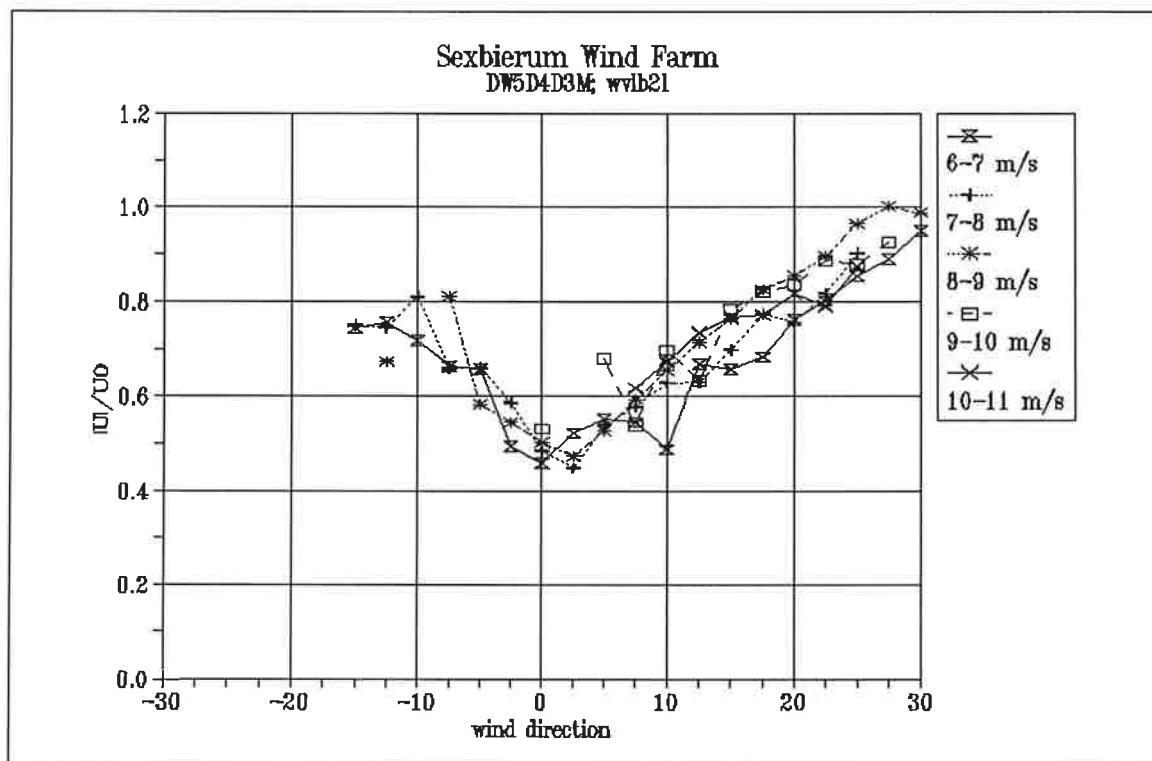


Figure 2 Wake deficit U/U_0 as a function of wind direction and wind speed bin

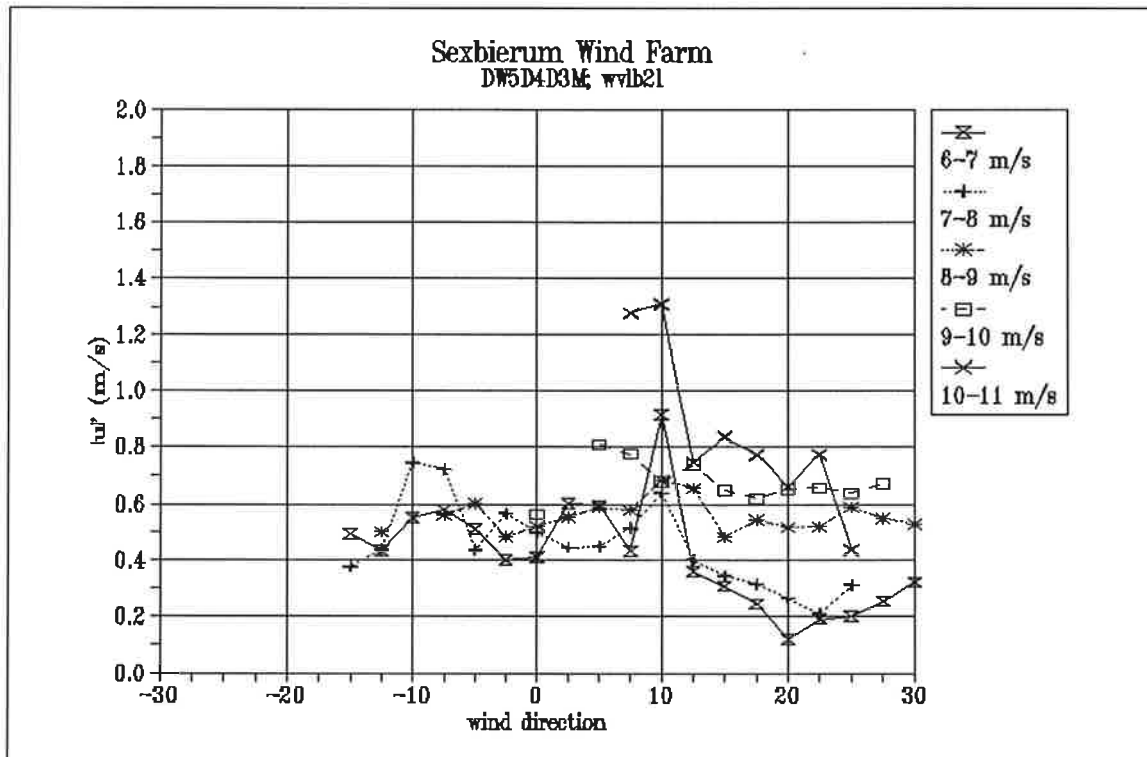


Figure 3 Turbulent fluctuations u' as a function of wind direction and wind speed bin

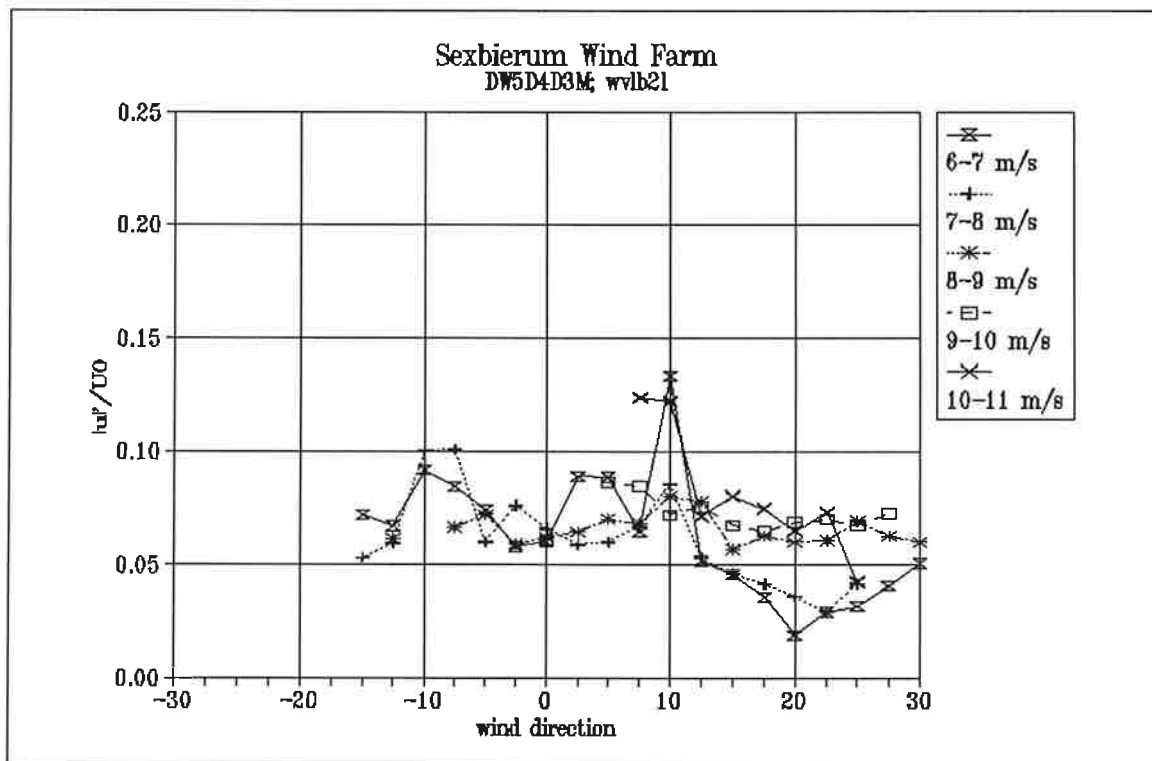


Figure 4 Non-dimensionalized turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

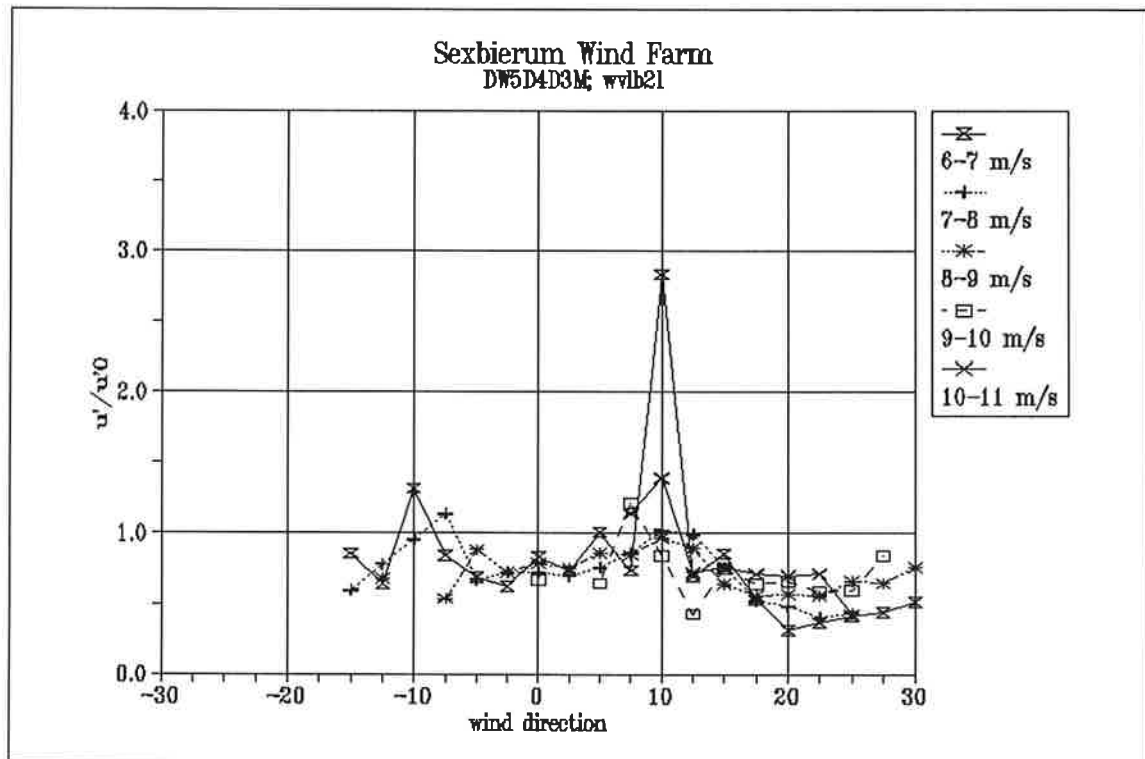


Figure 5 Turbulence enhancement u'/u'_0 as a function of wind direction and wind speed bin

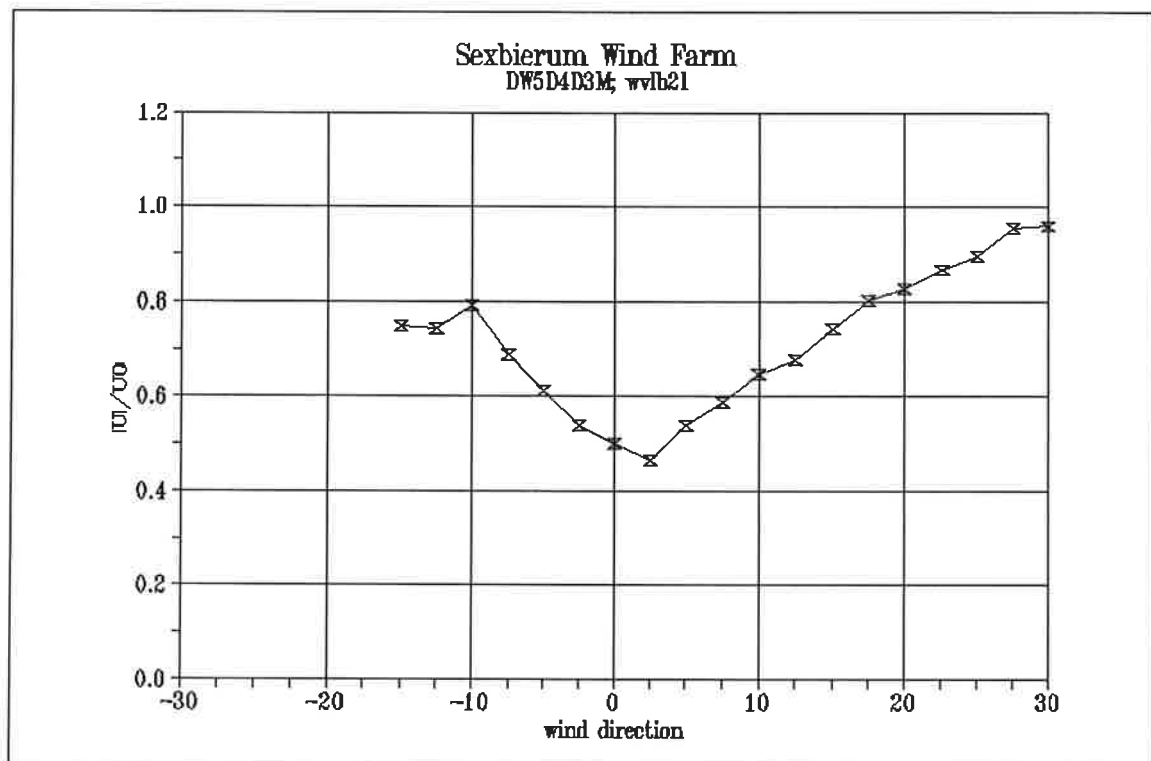


Figure 6 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

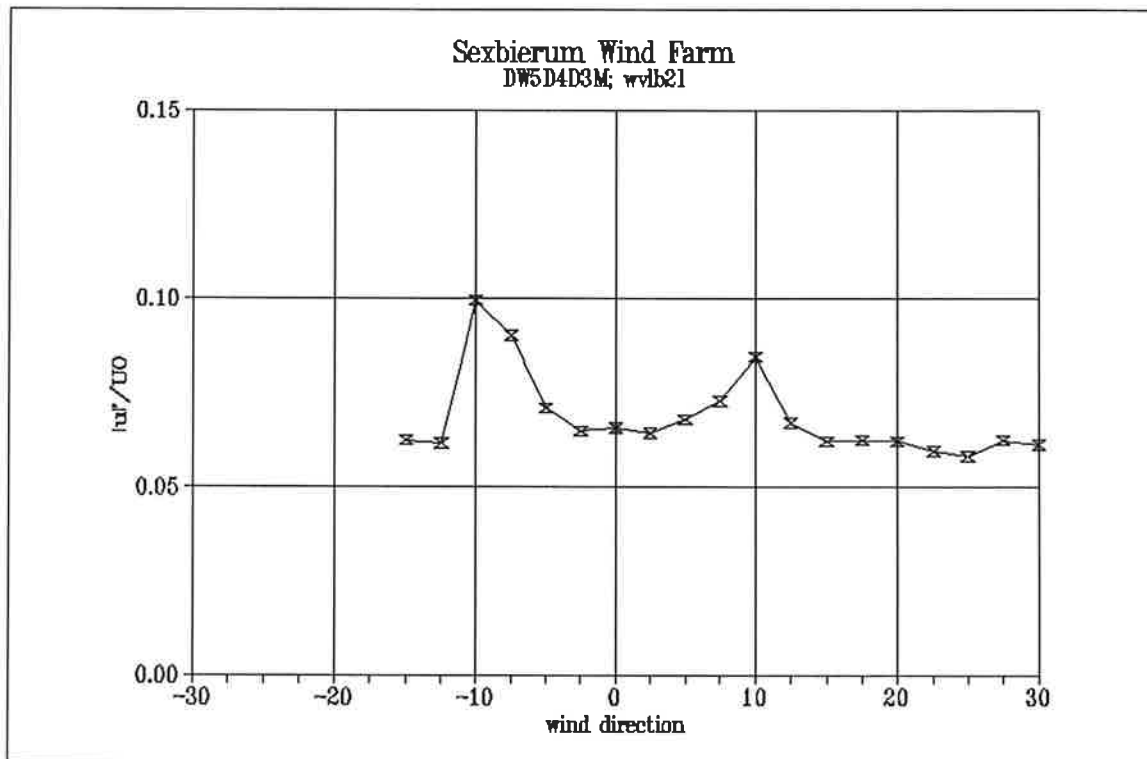


Figure 7 Non-dimensionalized turbulent fluctuations u'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

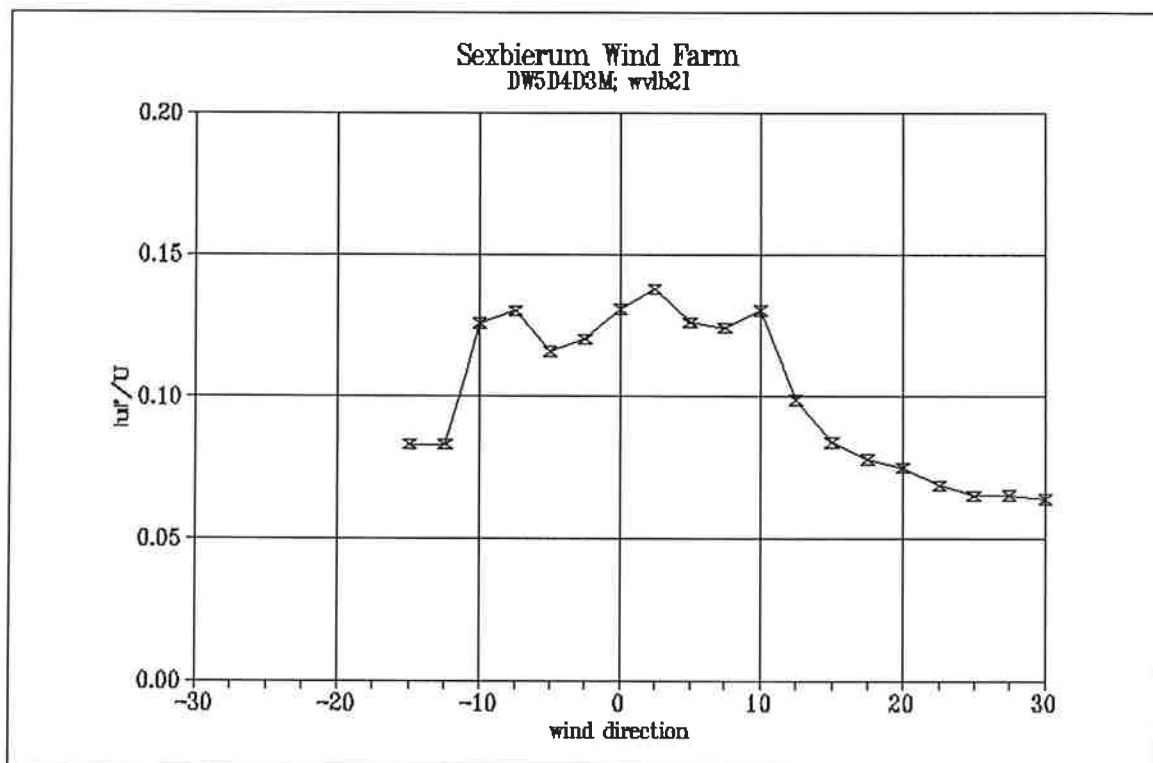


Figure 8 Non-dimensionalized turbulent fluctuations u'/U as a function of wind direction in the wind speed bin 5-10 m/s

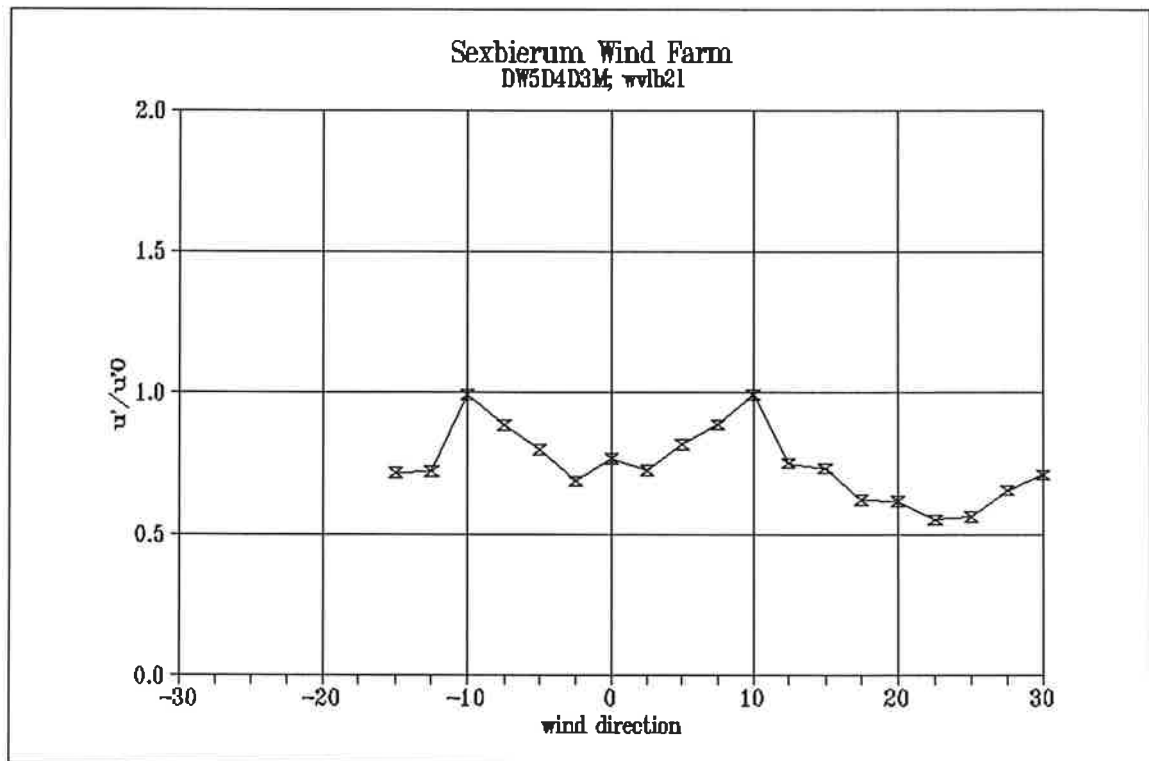


Figure 9 Turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.6 Sensor b3

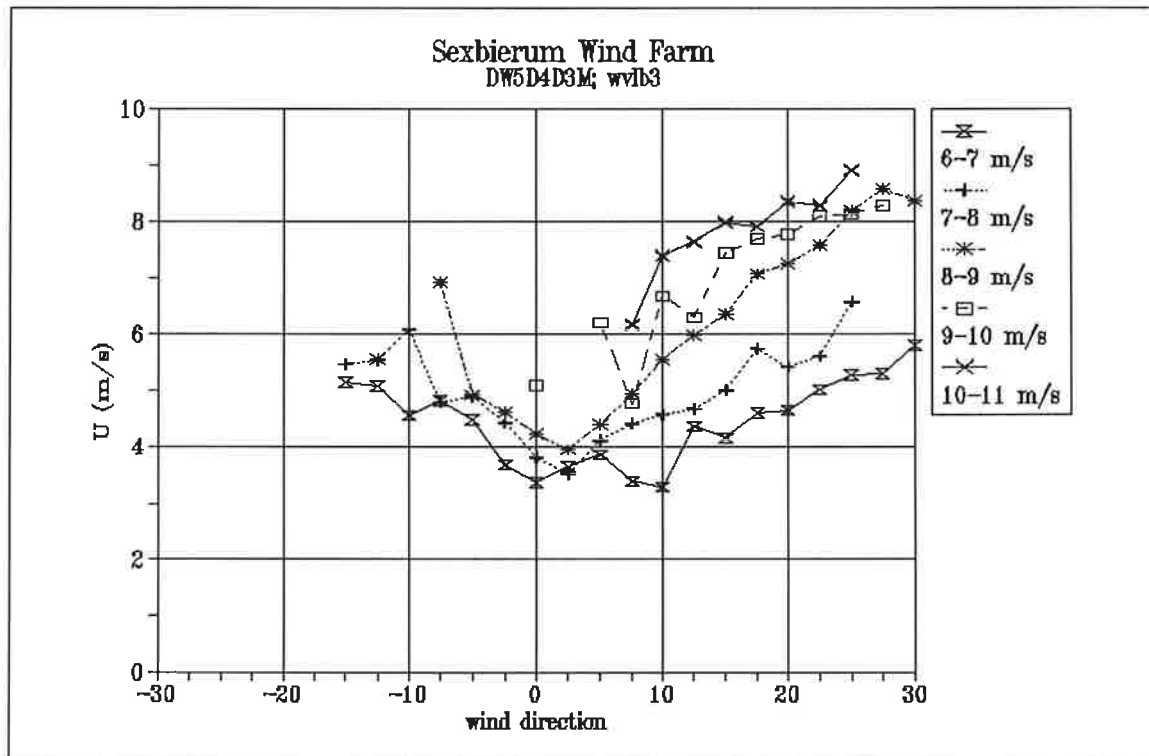


Figure 1 Horizontal wind speed U as a function of wind direction and wind speed bin

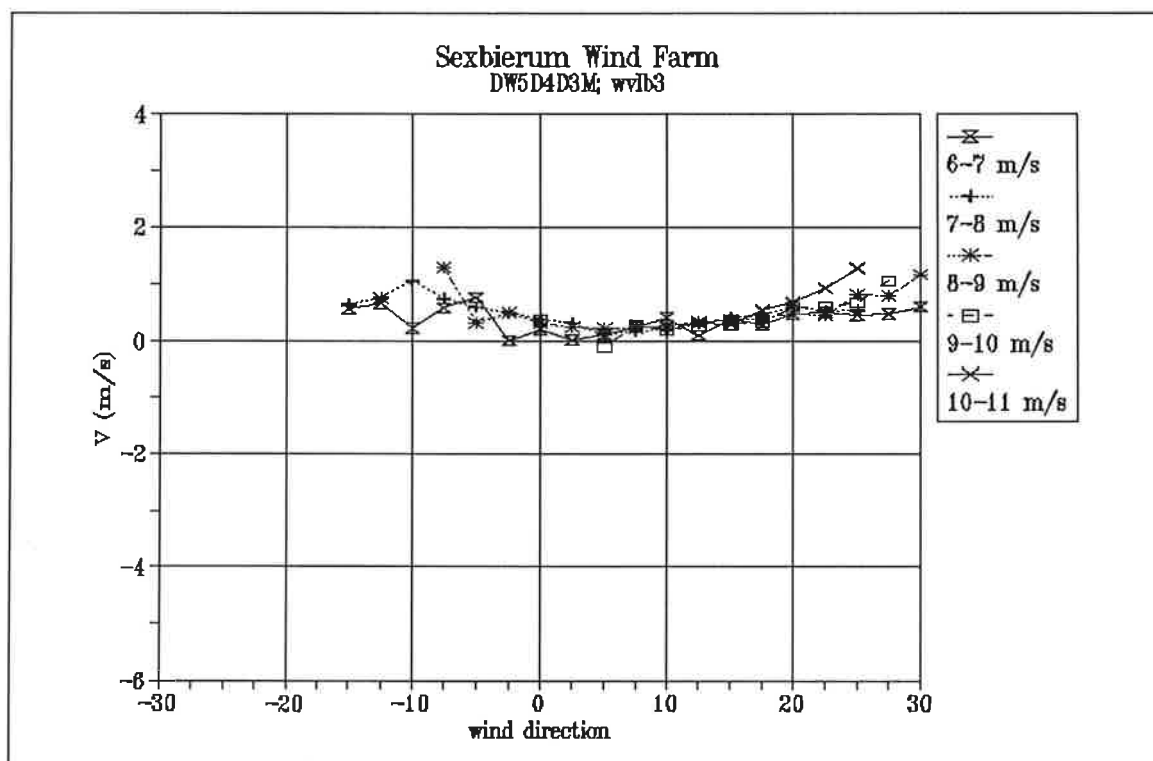


Figure 2 Lateral wind speed V as a function of wind direction and wind speed bin

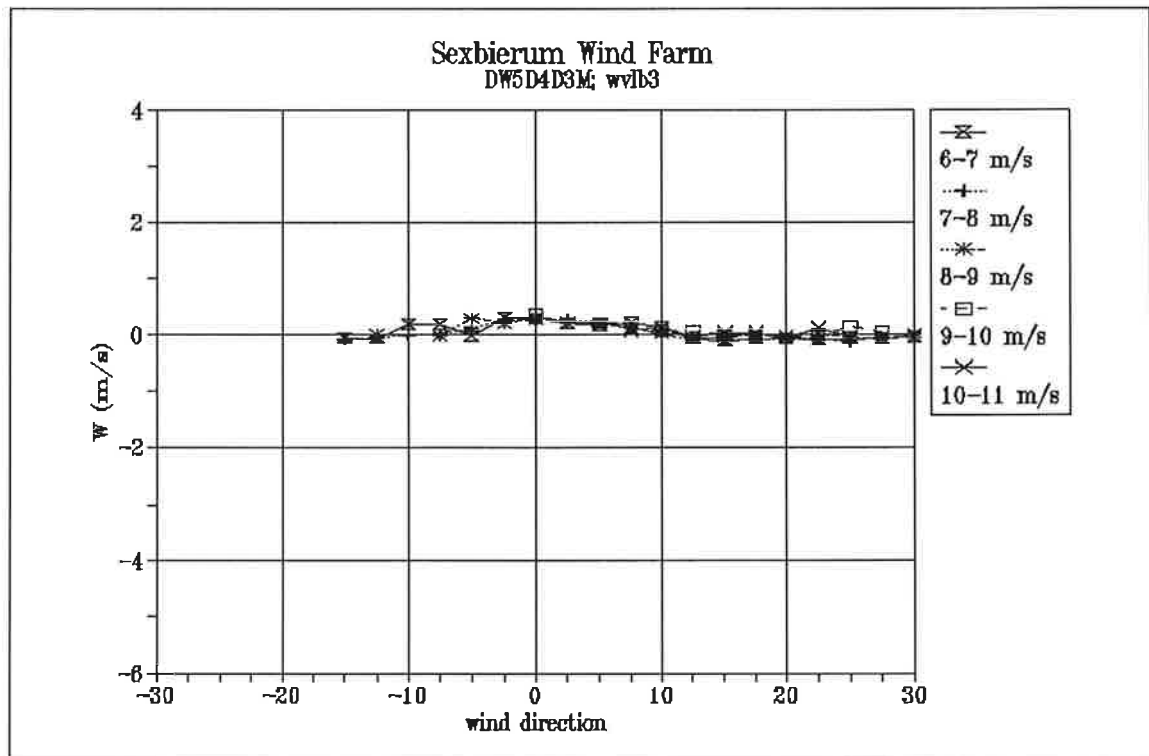


Figure 3 Vertical wind speed W as a function of wind direction and wind speed bin

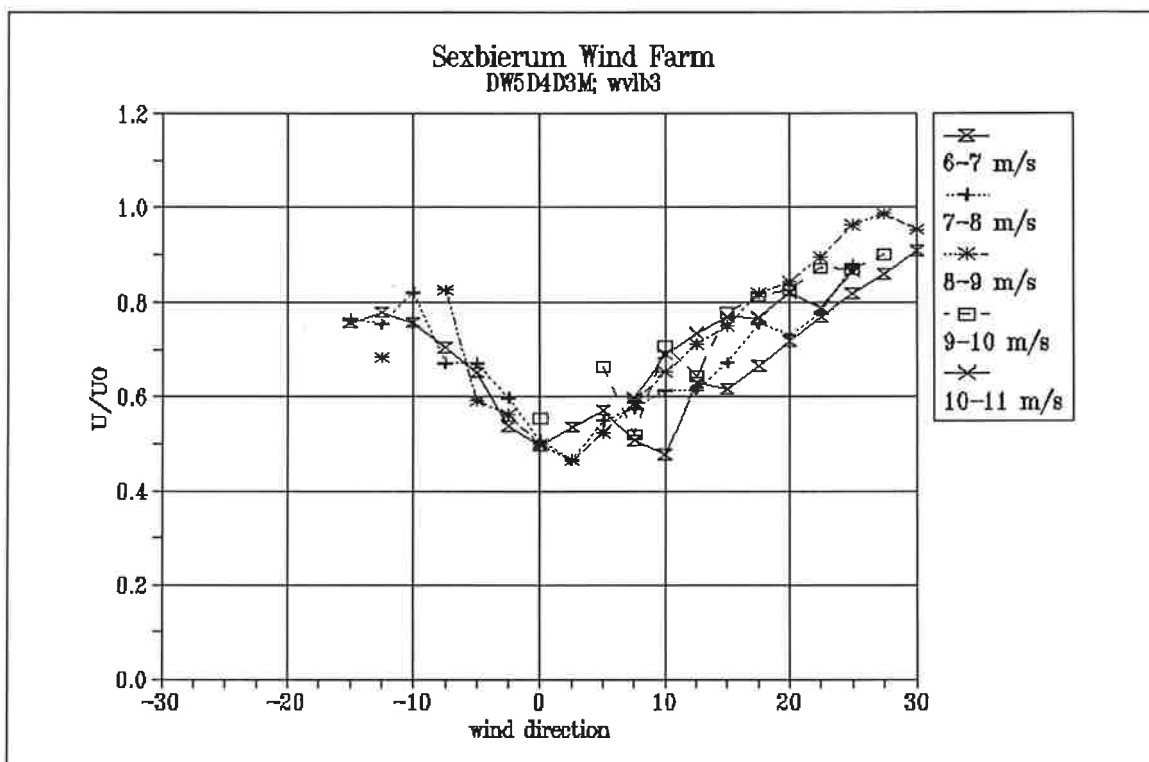


Figure 4 Wake deficit U/U_0 as a function of wind direction and wind speed bin

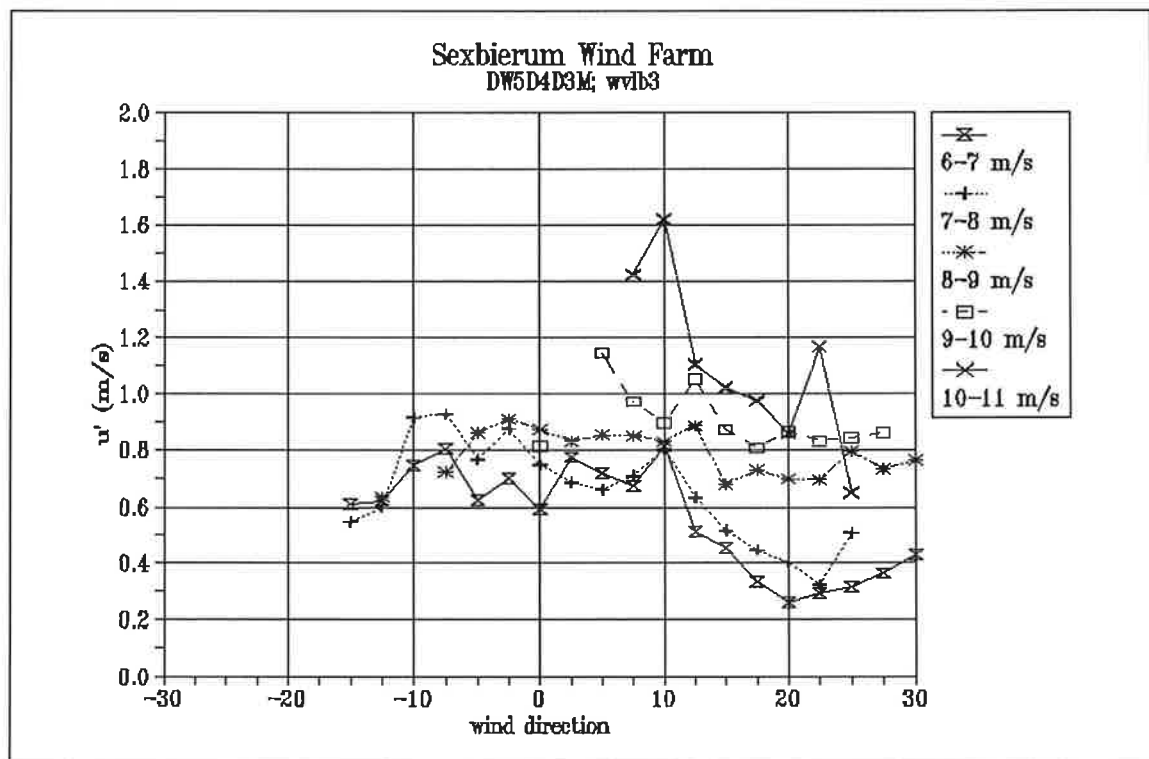


Figure 5 Longitudinal turbulent fluctuations u' as a function of wind direction and wind speed bin

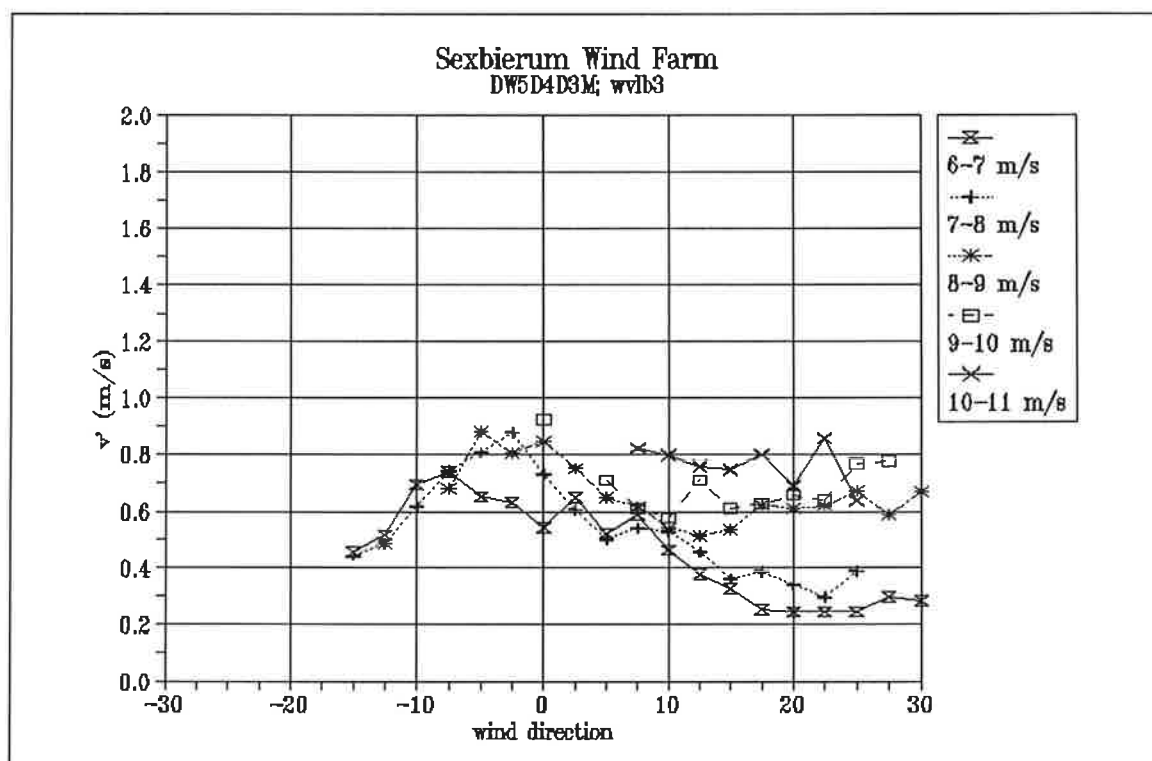


Figure 6 Lateral turbulent fluctuations v' as a function of wind direction and wind speed bin

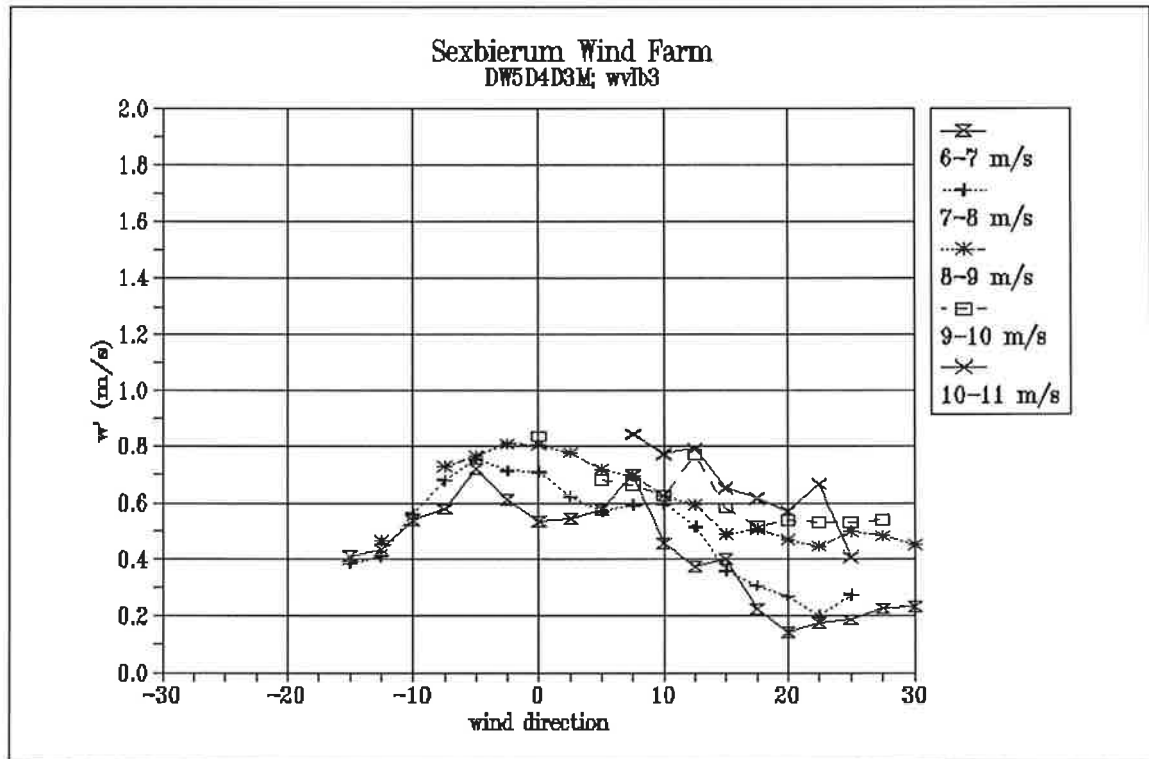


Figure 7 Vertical turbulent fluctuations w' as a function of wind direction and wind speed bin

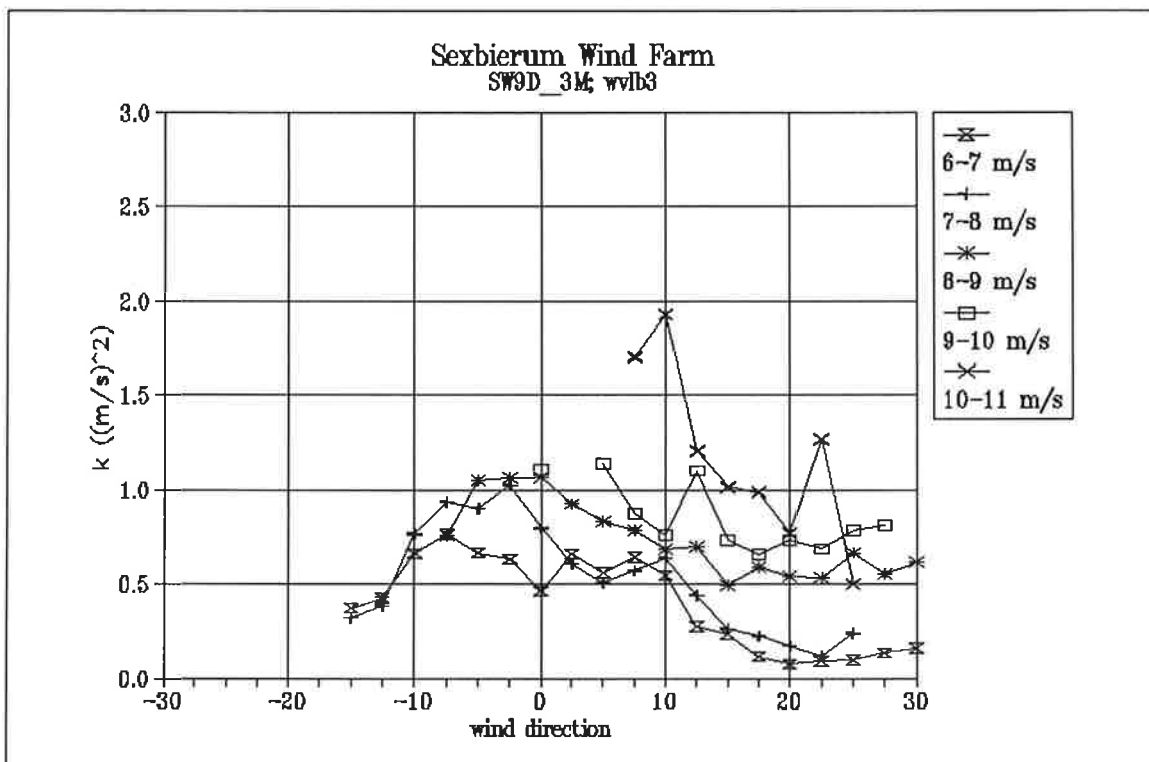


Figure 8 Turbulent kinetic energy per unit mass as a function of wind direction and wind speed bin

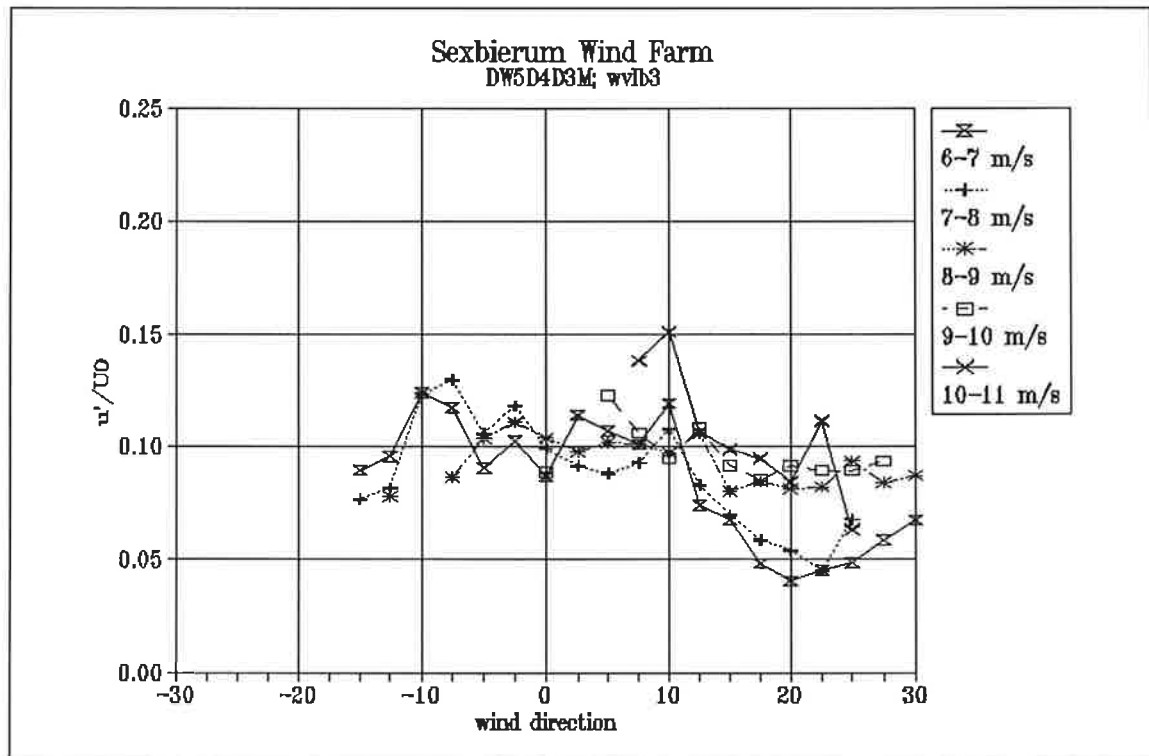


Figure 9 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

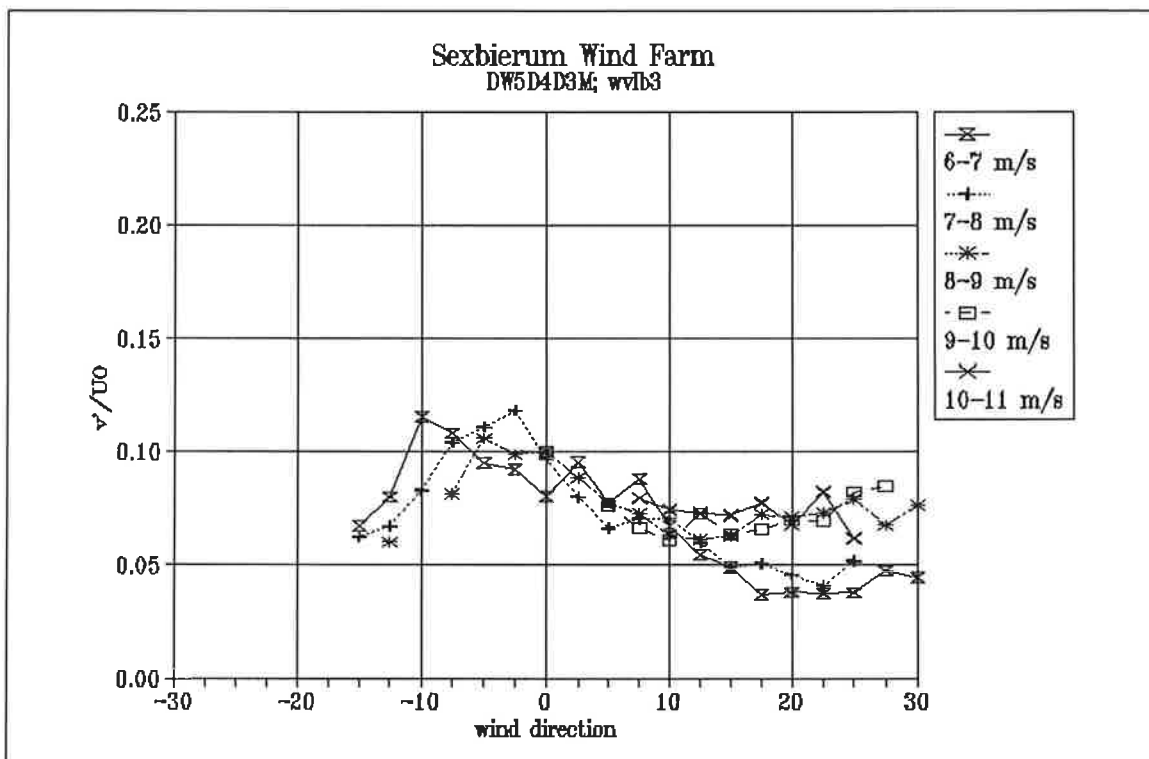


Figure 10 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction and wind speed bin

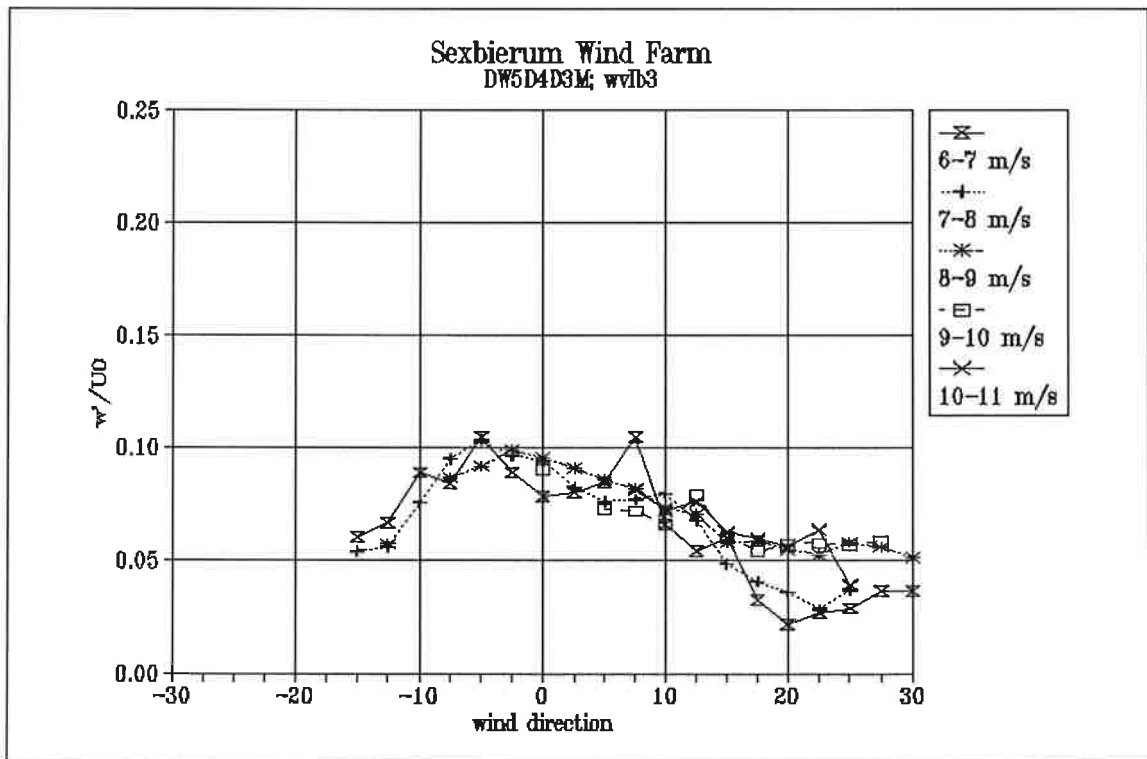


Figure 11 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction and wind speed bin

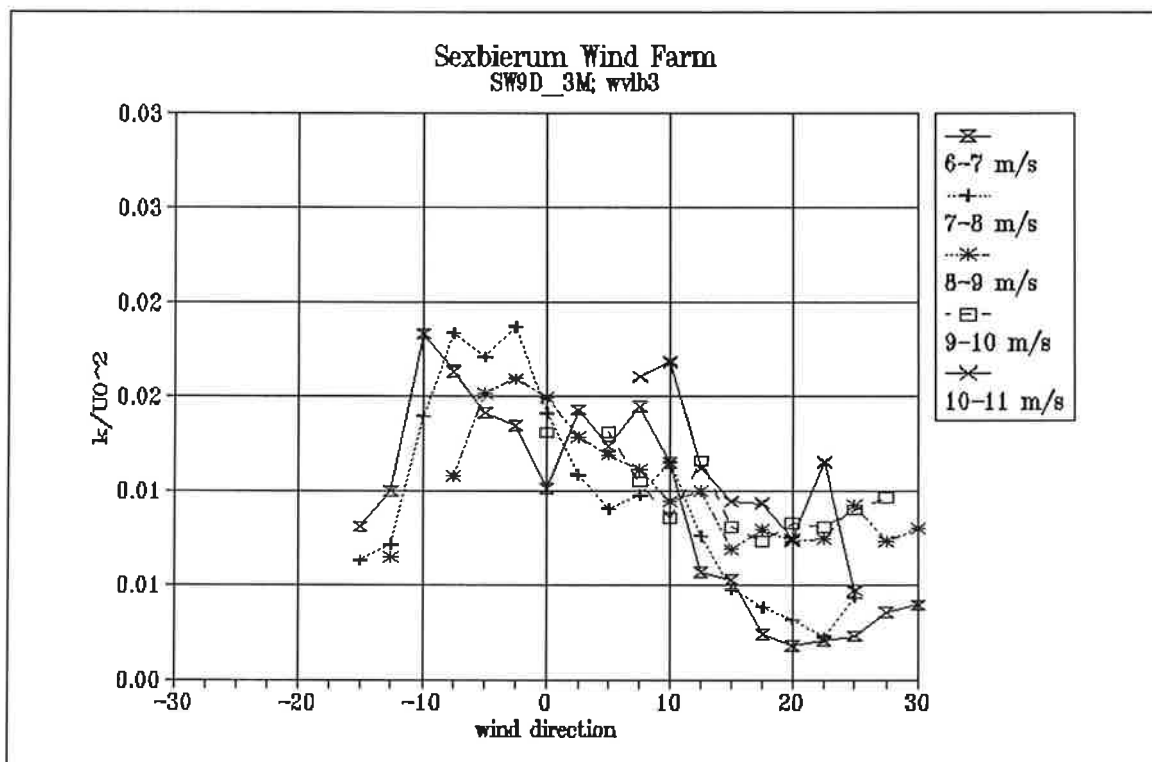


Figure 12 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction and wind speed bin

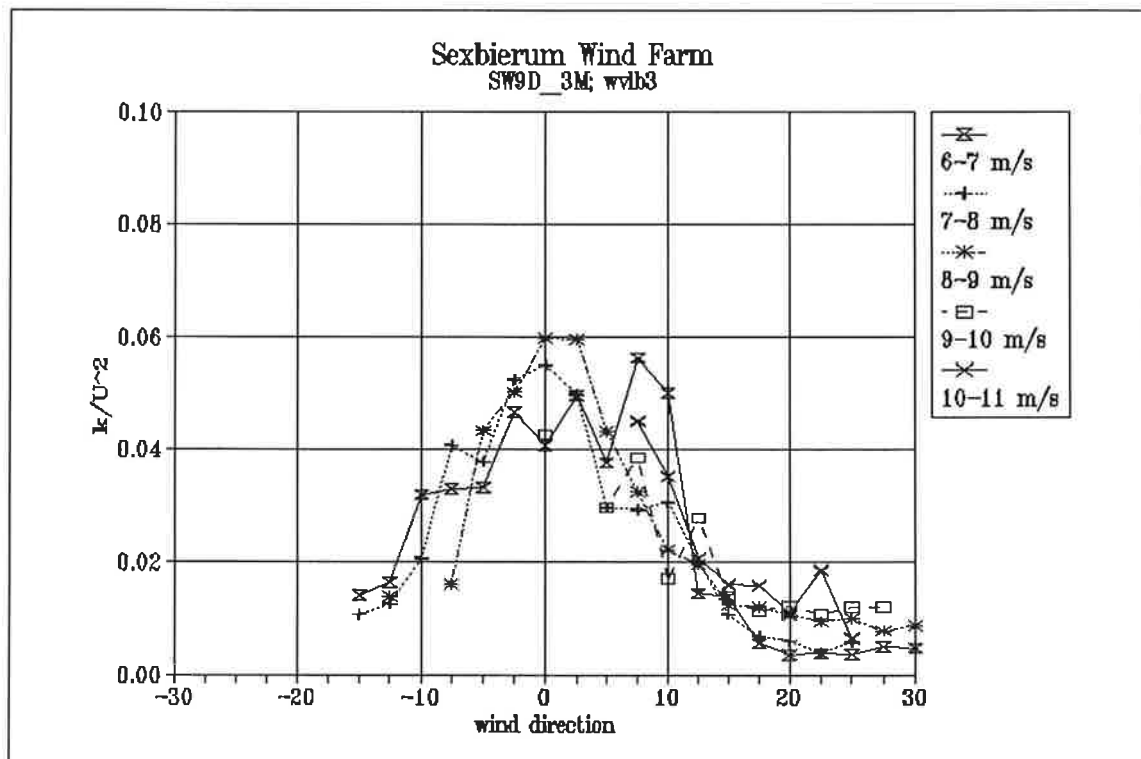


Figure 13 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction and wind speed bin

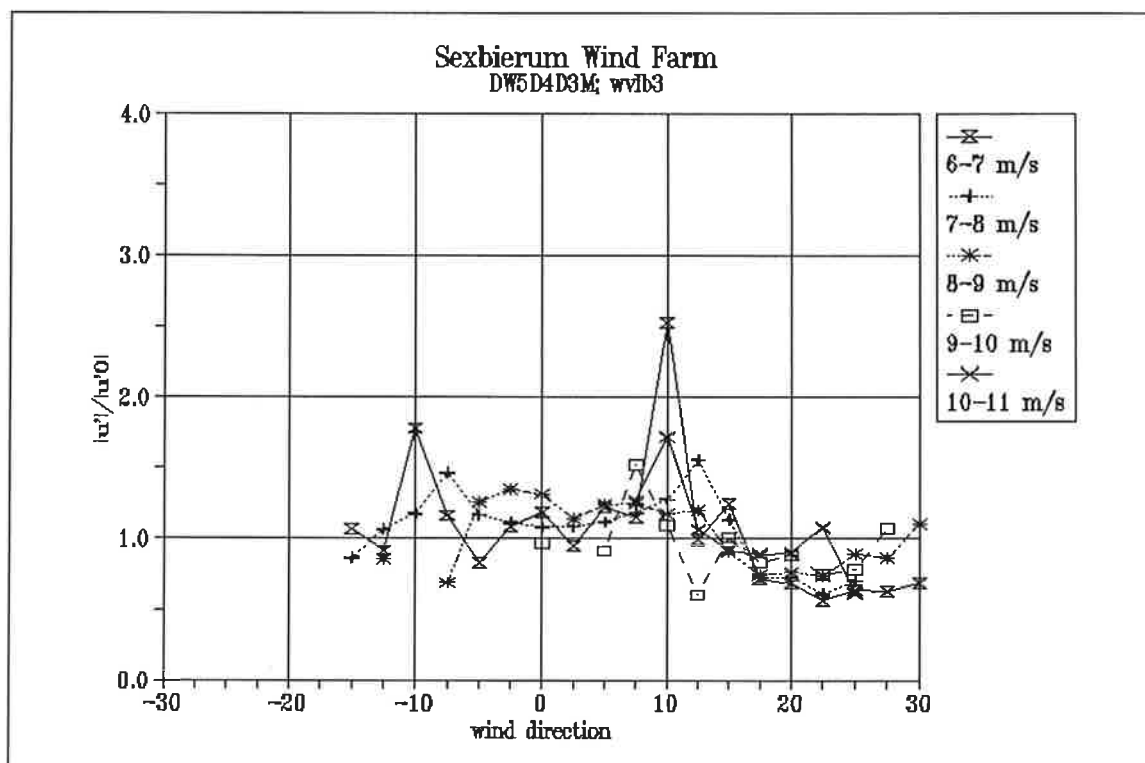


Figure 14 Longitudinal turbulence enhancement $u'u_0$ as a function of wind direction and wind speed bin

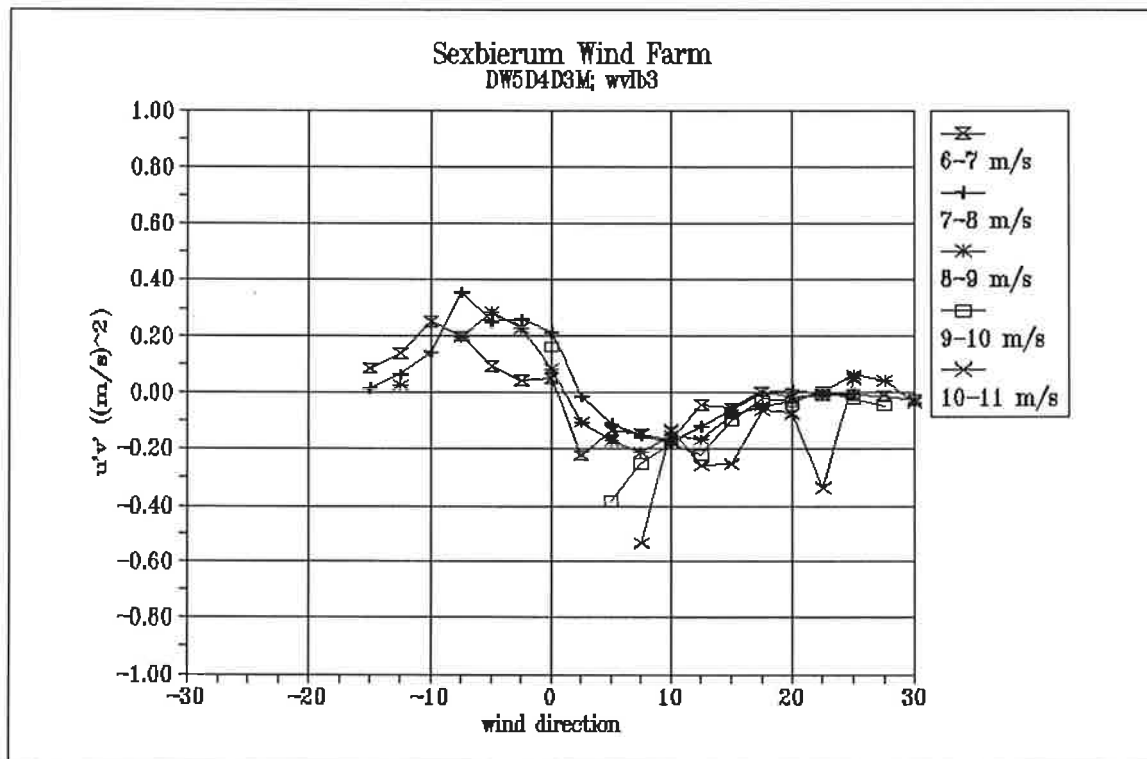


Figure 15 Shear stress $u'v'$ as a function of wind direction and wind speed bin

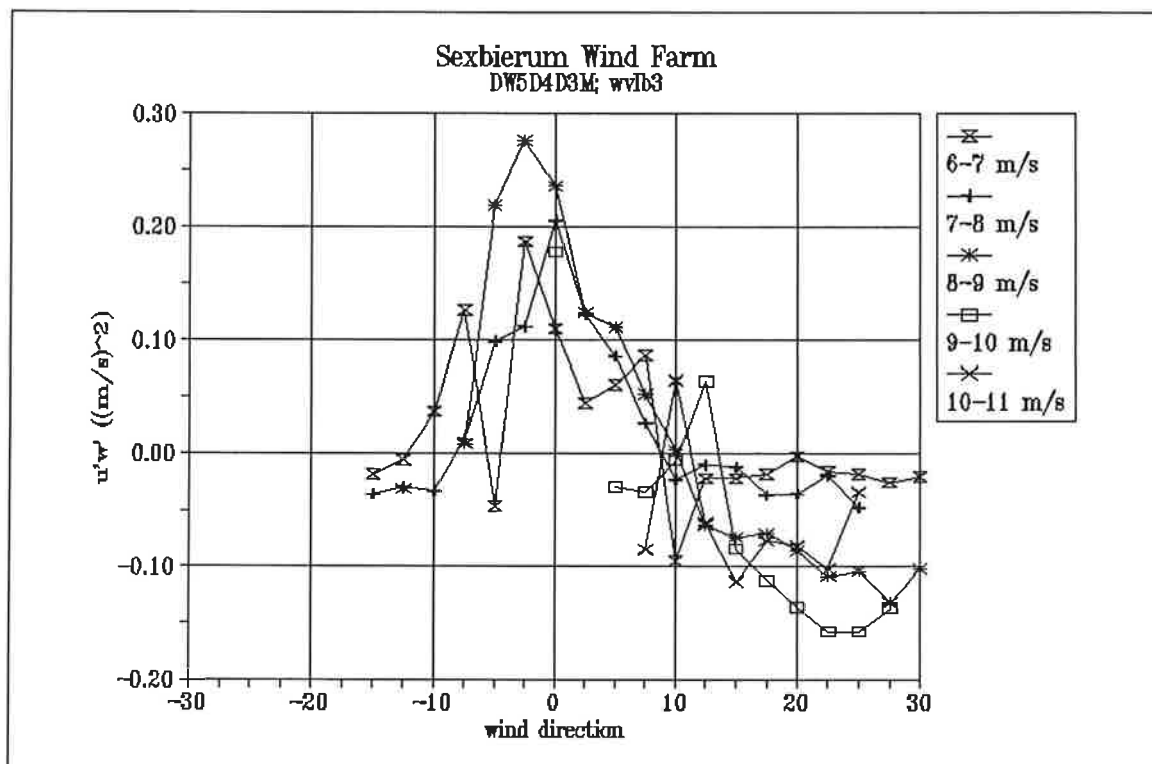


Figure 16 Shear stress $u'w'$ as a function of wind direction and wind speed bin

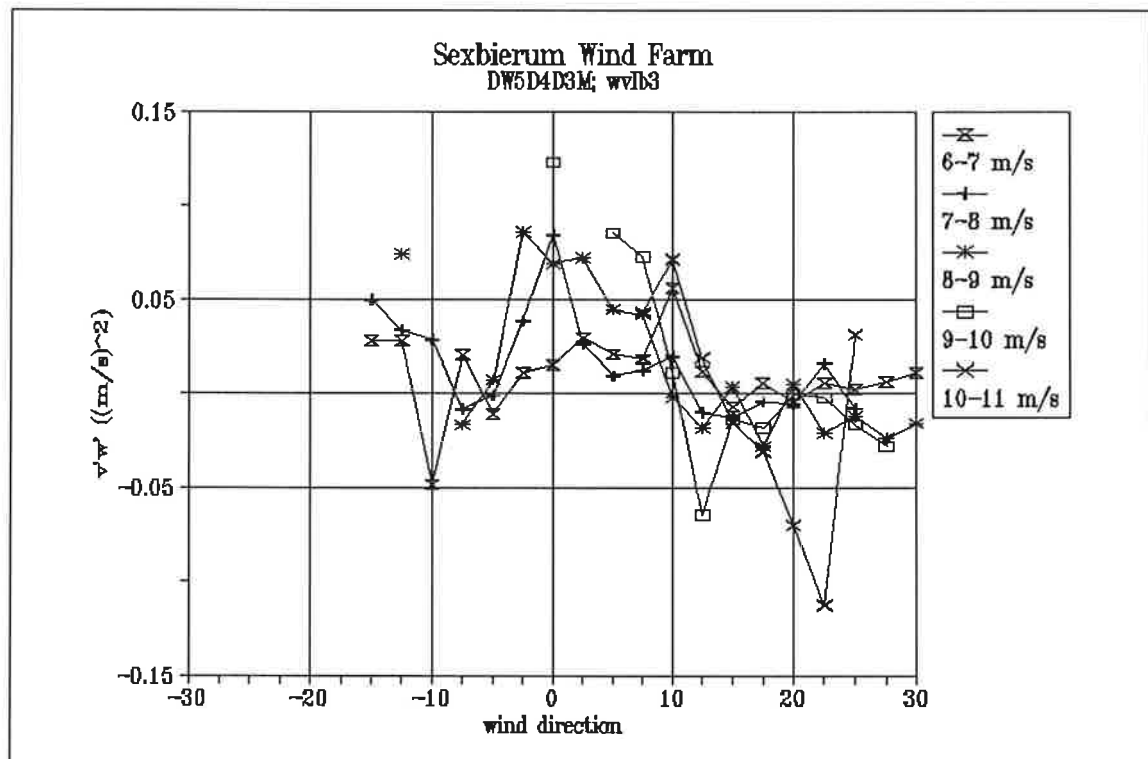


Figure 17 Shear stress $v'w'$ as a function of wind direction and wind speed bin

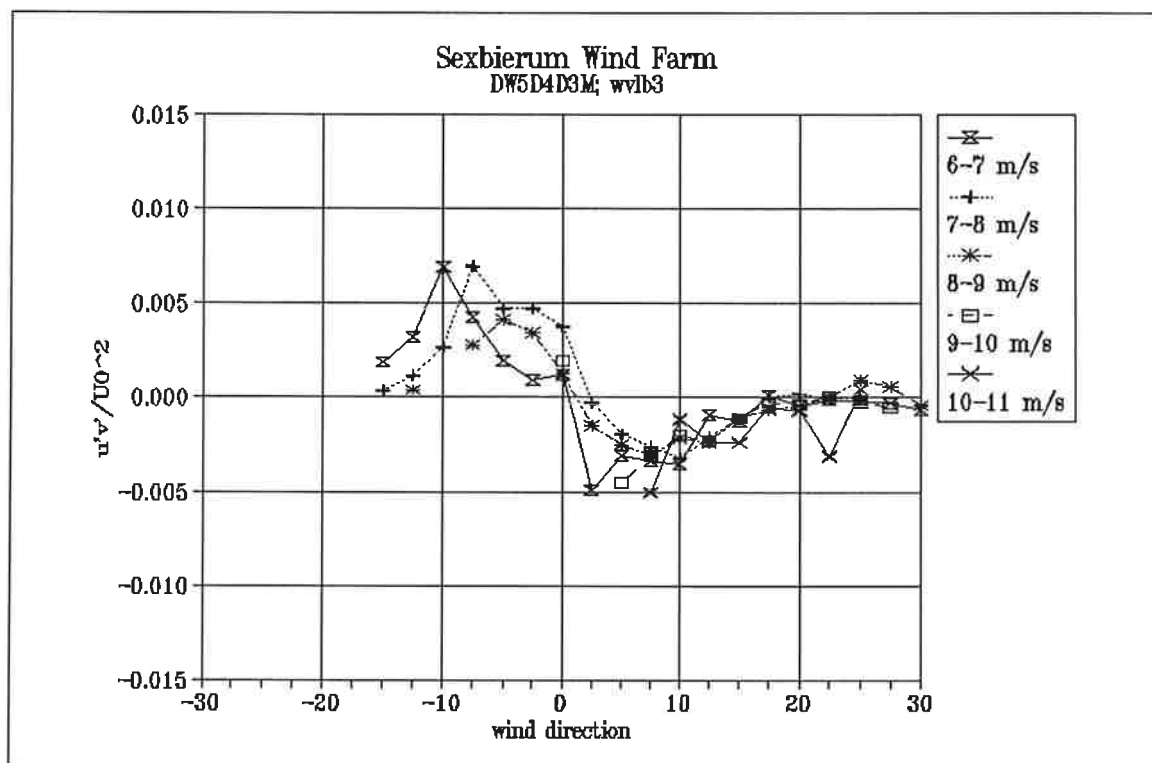


Figure 18 Non-dimensionalized shear stress $u'v'/U_0^2$ as a function of wind direction and wind speed bin

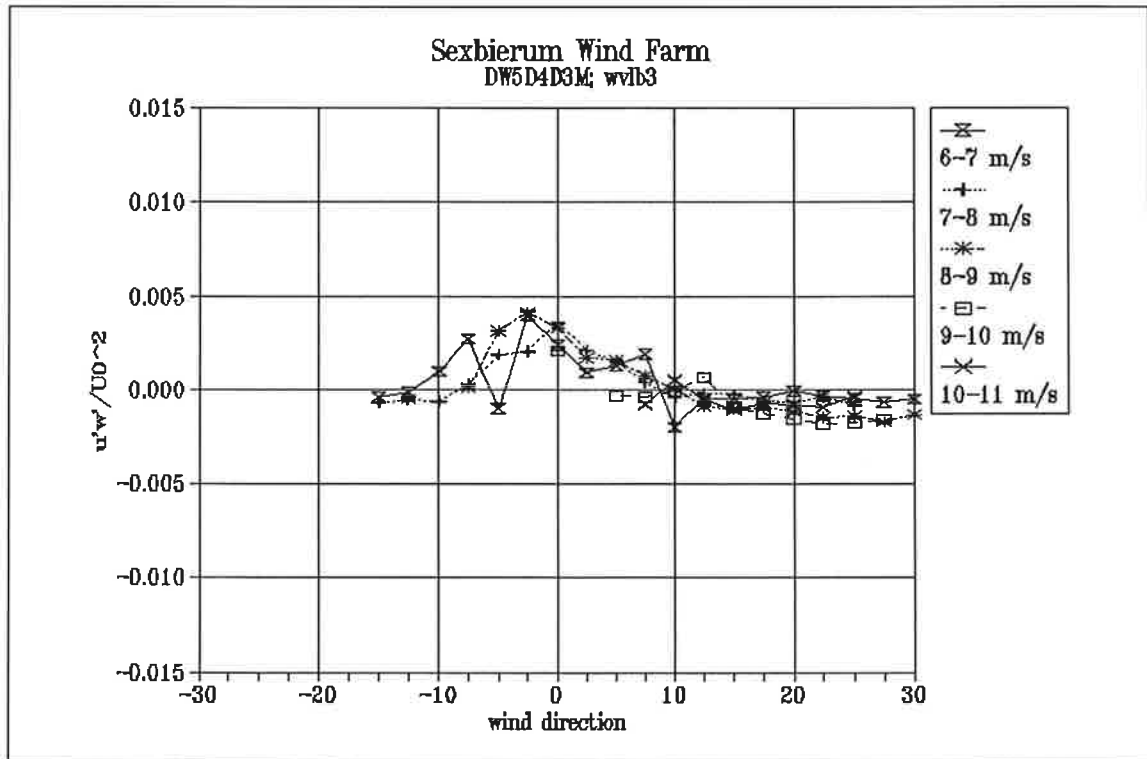


Figure 19 Non-dimensionalized shear stress $u'w'/U_0^2$ as a function of wind direction and wind speed bin

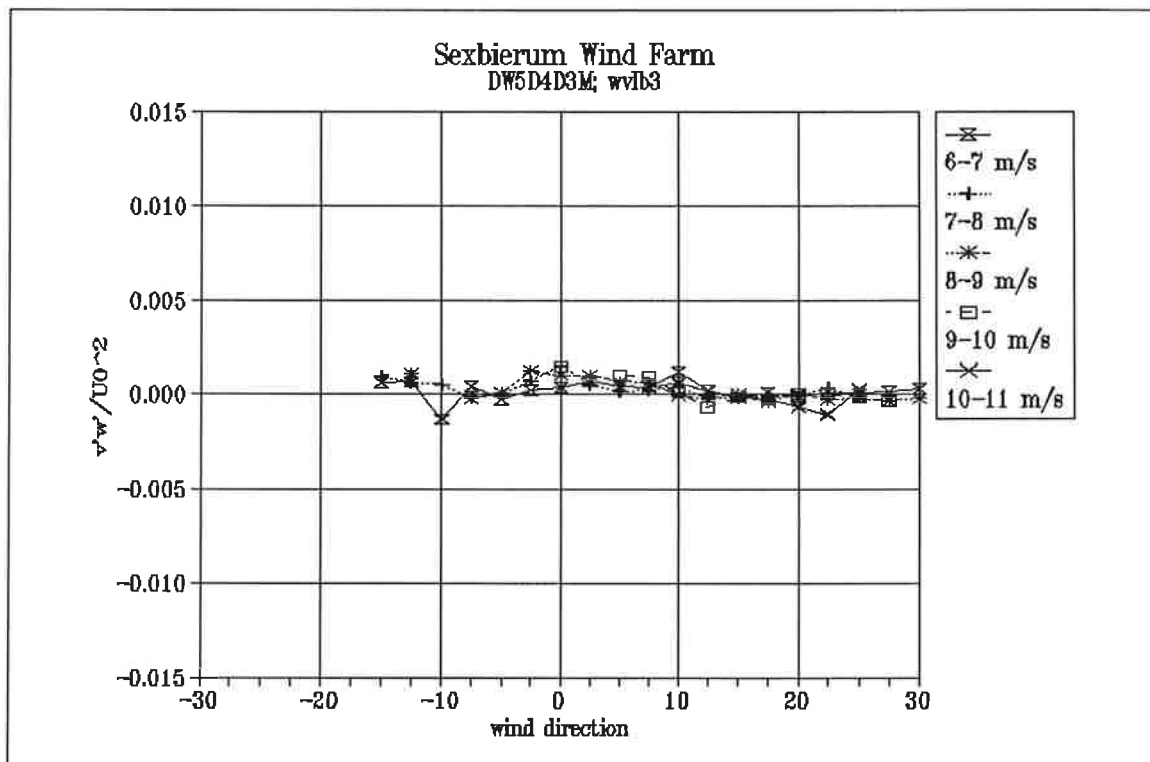


Figure 20 Non-dimensionalized shear stress $v'w'/U_0^2$ as a function of wind direction and wind speed bin

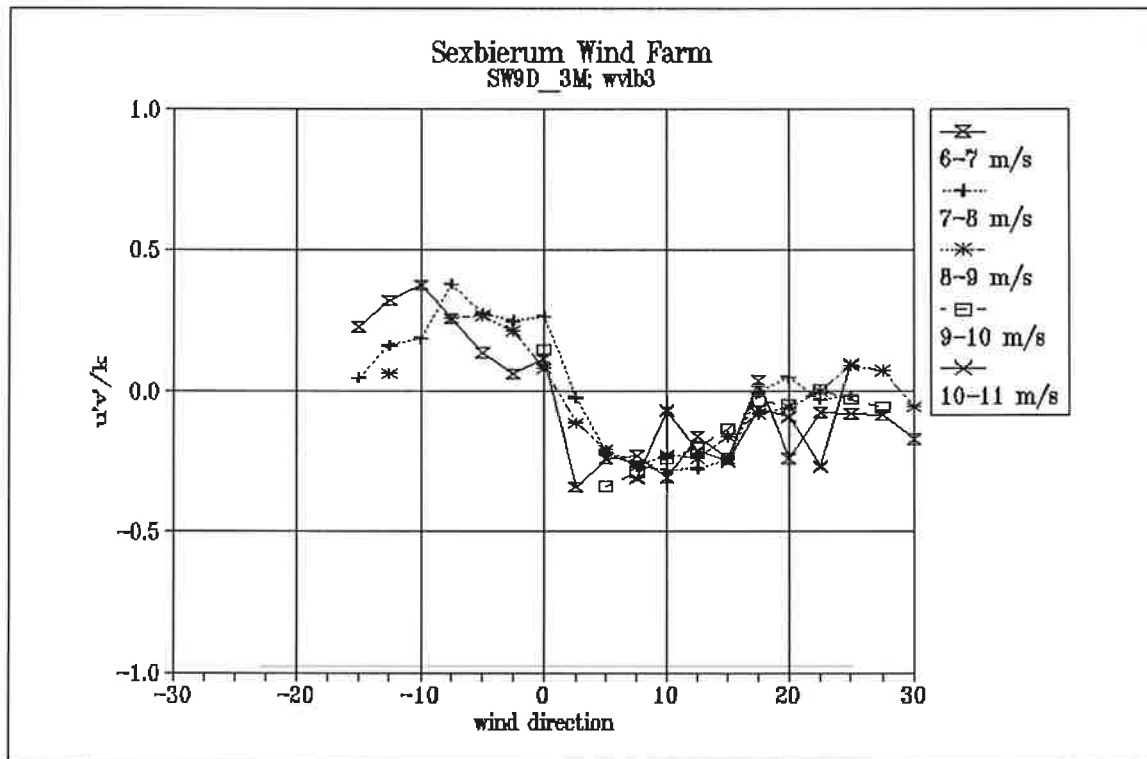


Figure 21 Non-dimensionalized shear stress $u'v'/k$ as a function of wind direction and wind speed bin

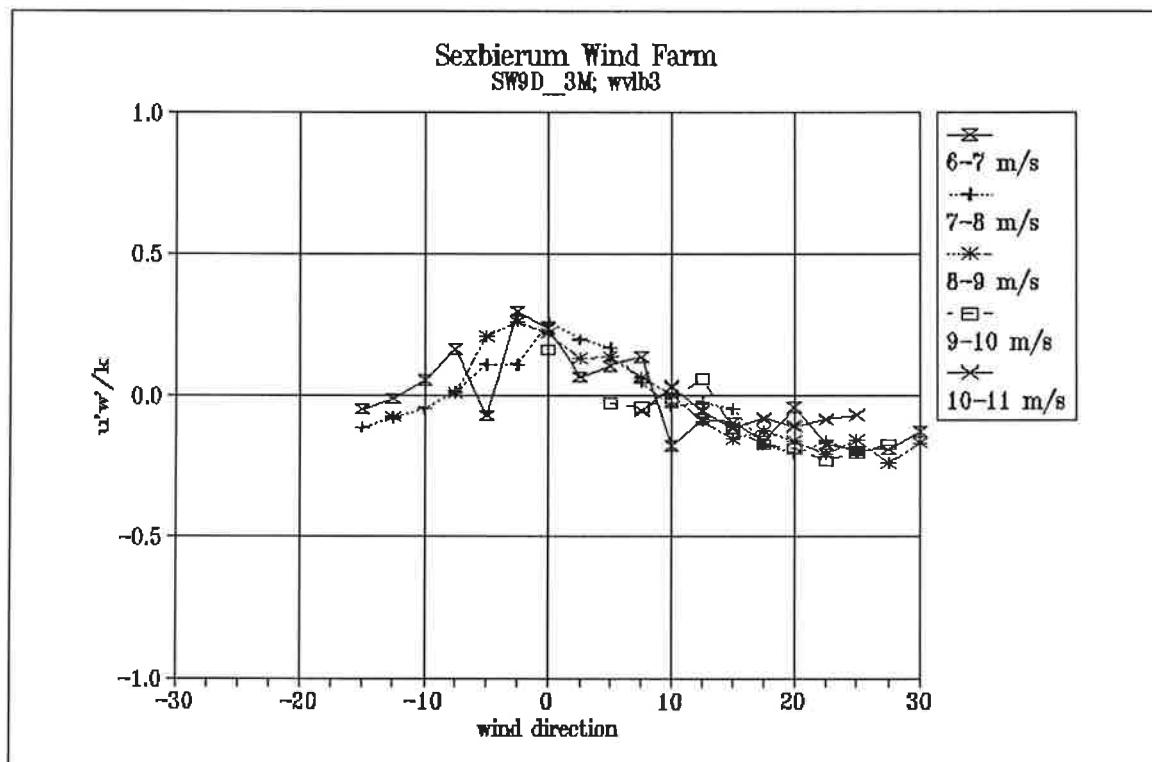


Figure 22 Non-dimensionalized shear stress $u'w'/k$ as a function of wind direction and wind speed bin

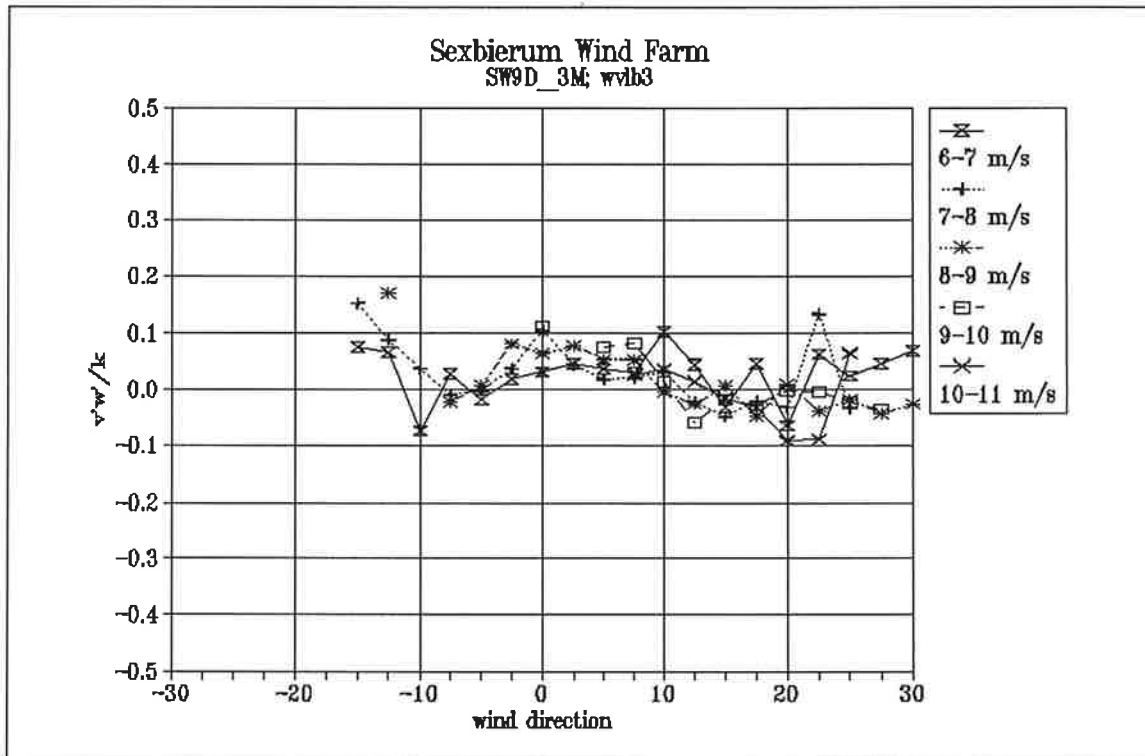


Figure 23 Non-dimensionalized shear stress $v'w'/k$ as a function of wind direction and wind speed bin

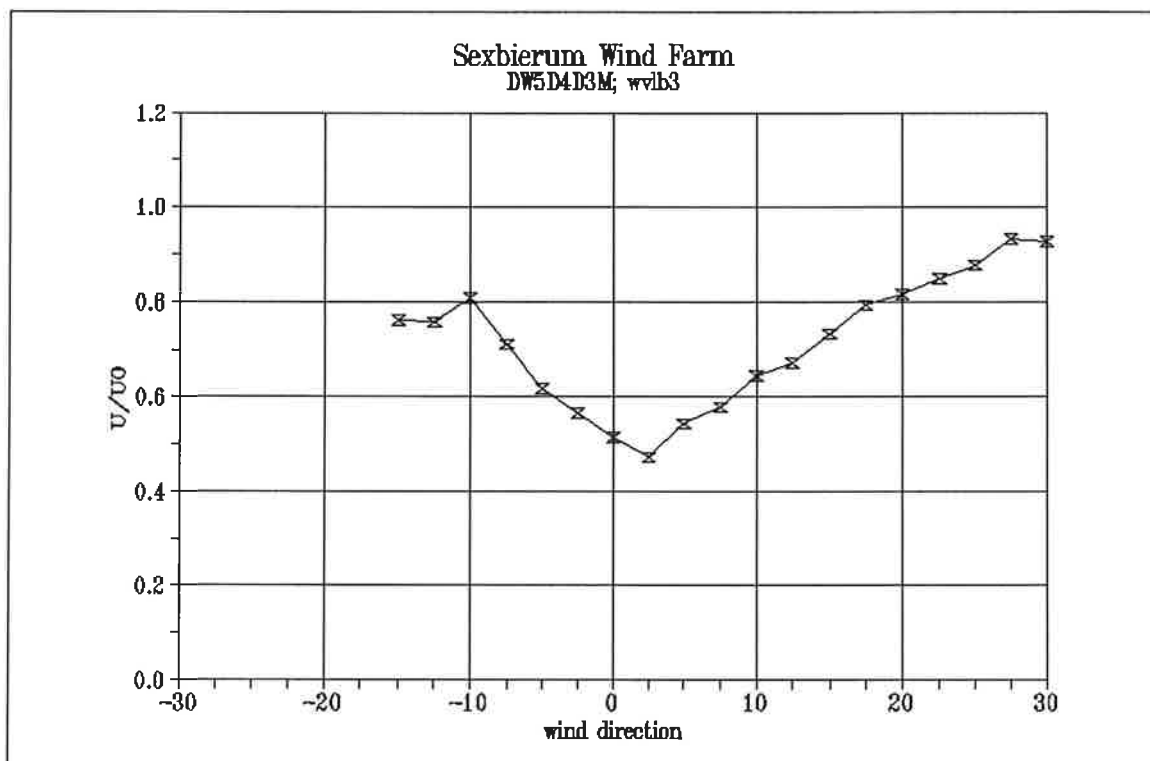


Figure 24 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

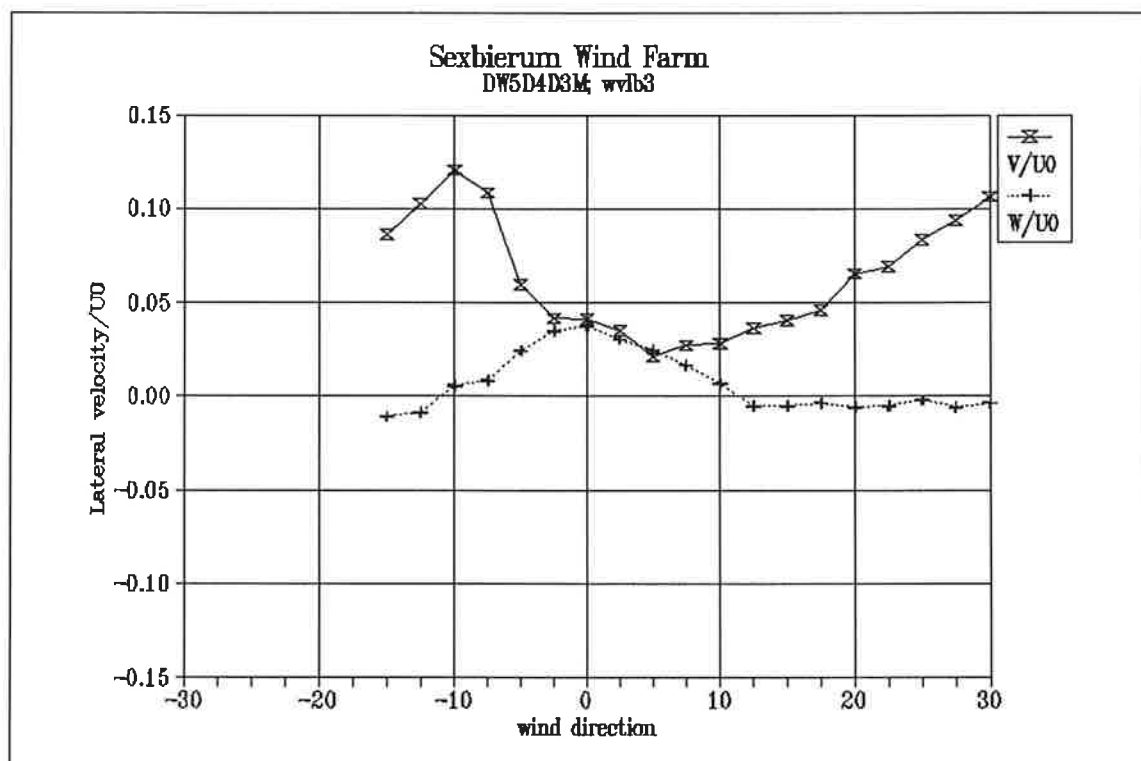


Figure 25 Lateral and vertical wind speed V/U_0 and W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

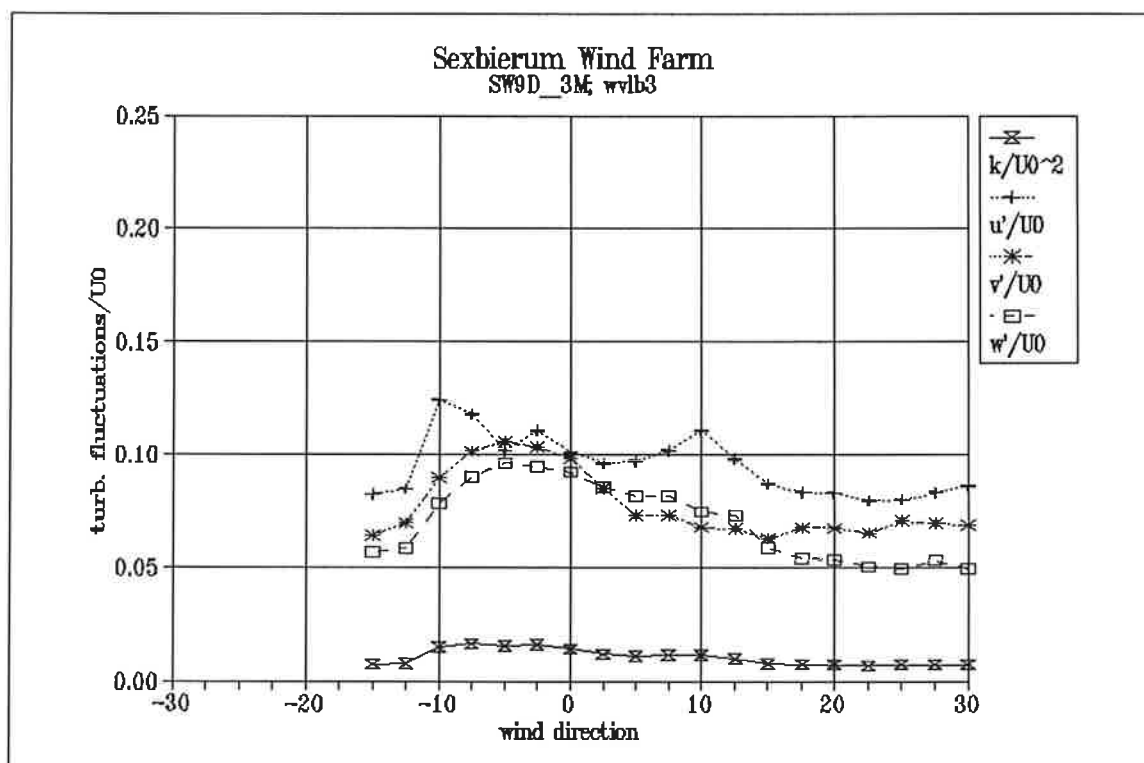


Figure 26 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U_0

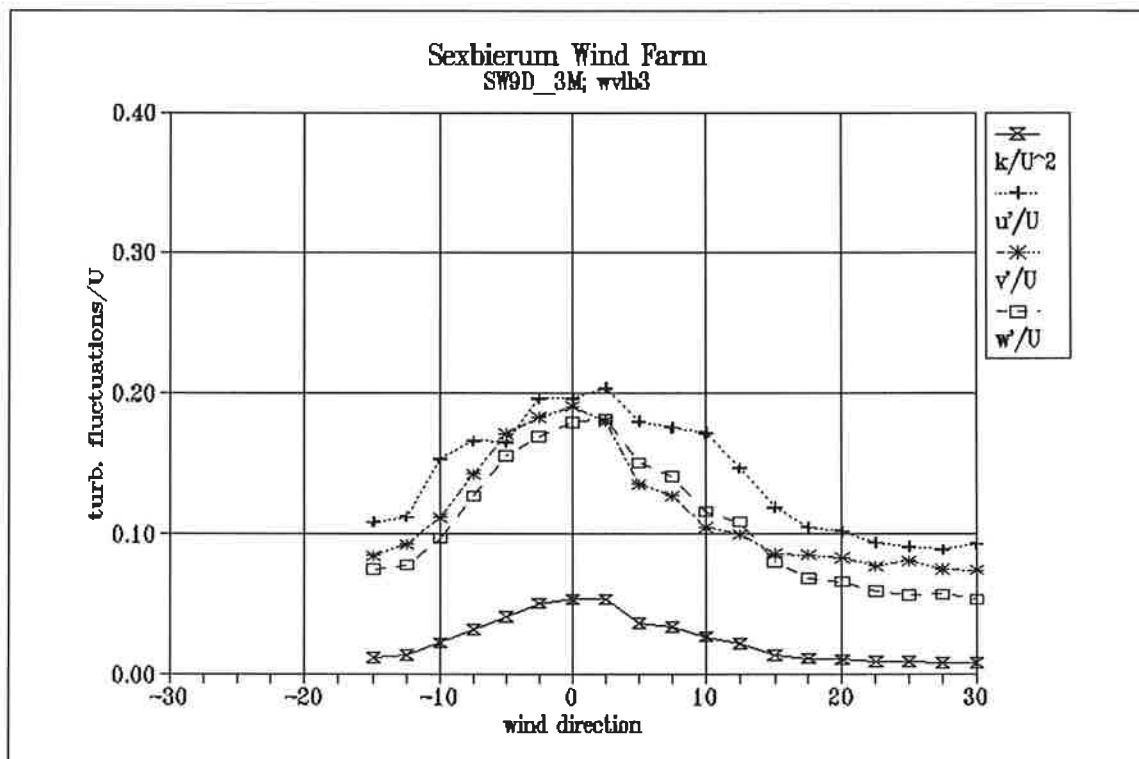


Figure 27 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U

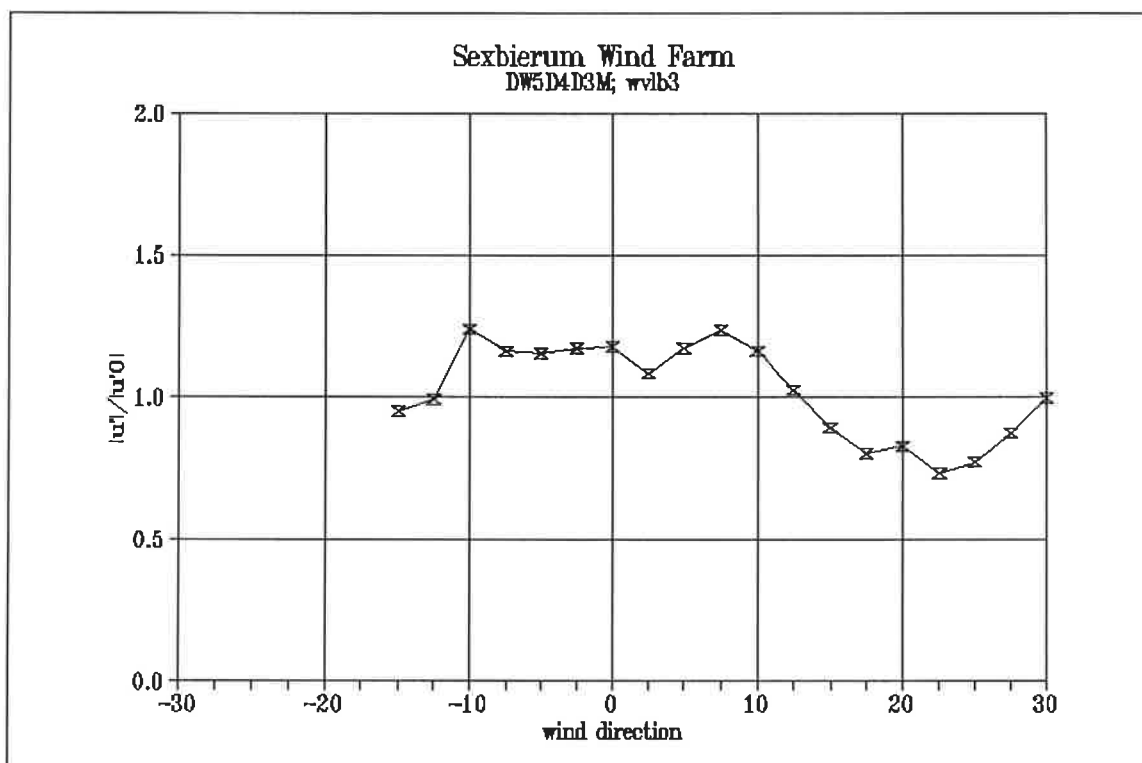


Figure 28 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

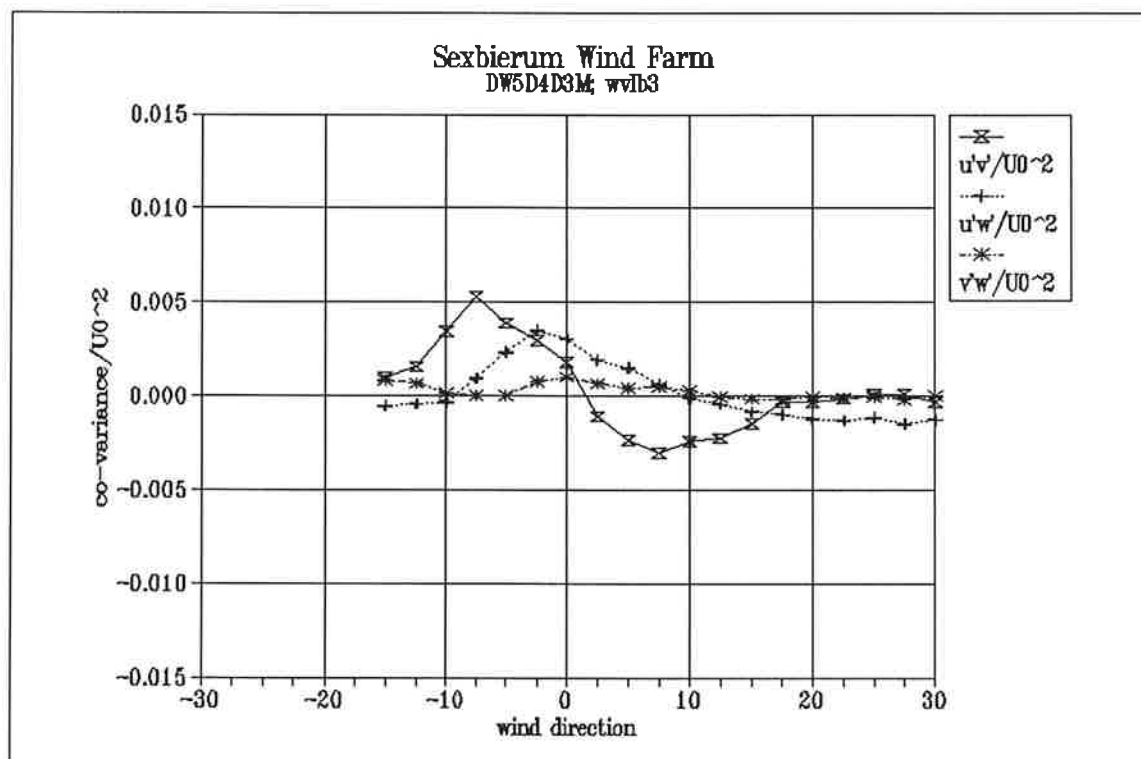


Figure 29 Non-dimensionalized shear stresses $u'v'/U_0^2$; $u'w'/U_0^2$; $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

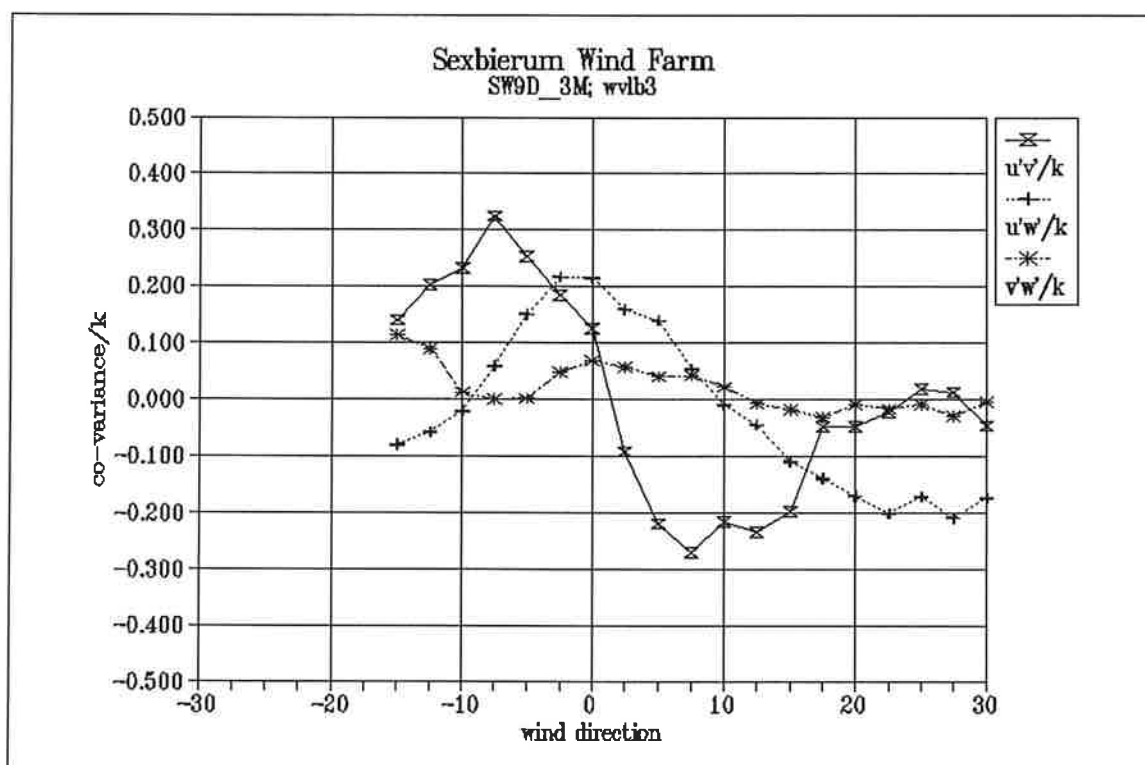


Figure 30 Non-dimensionalized shear stresses $u'v'/k$; $u'w'/k$; $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.7 Sensor c2

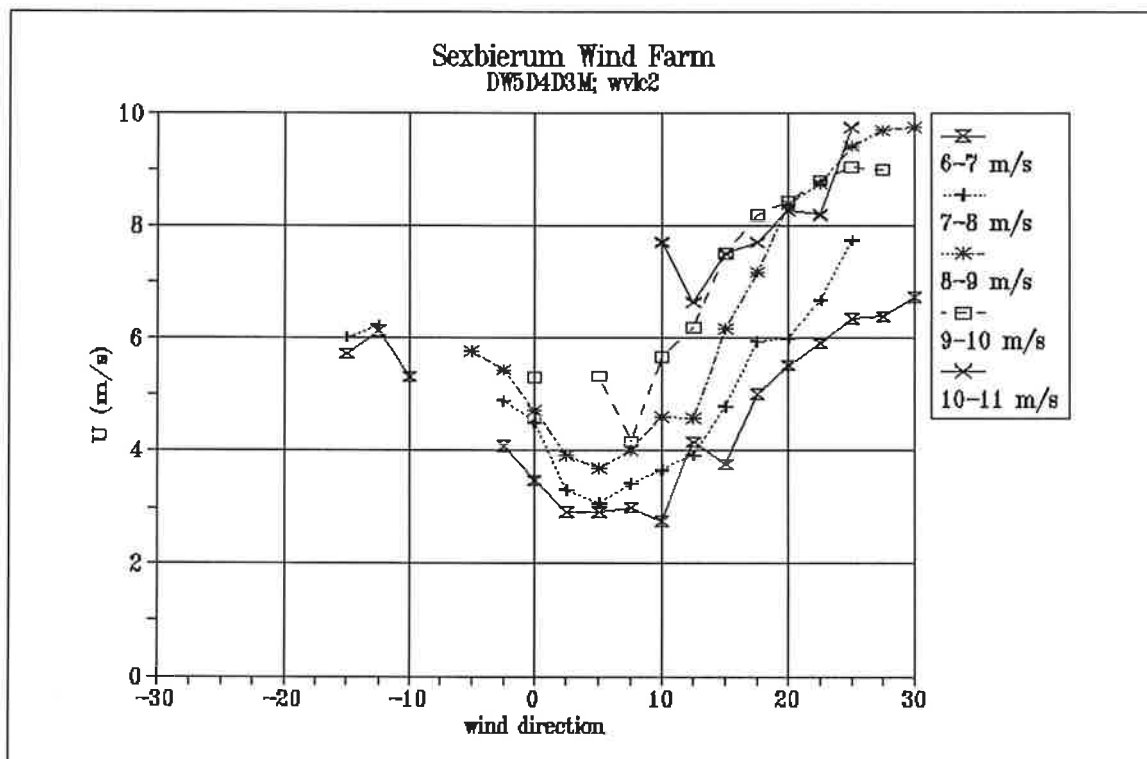


Figure 1 Horizontal wind speed U as a function of wind direction and wind speed bin

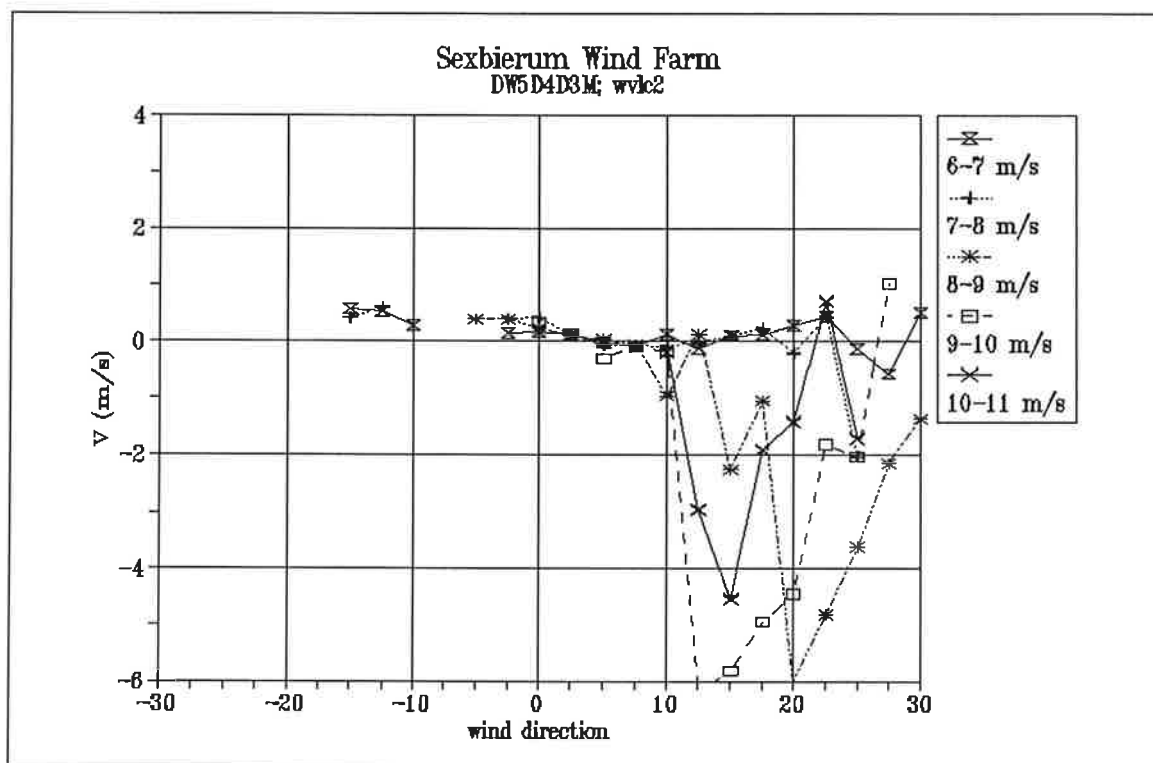


Figure 2 Lateral wind speed V as a function of wind direction and wind speed bin

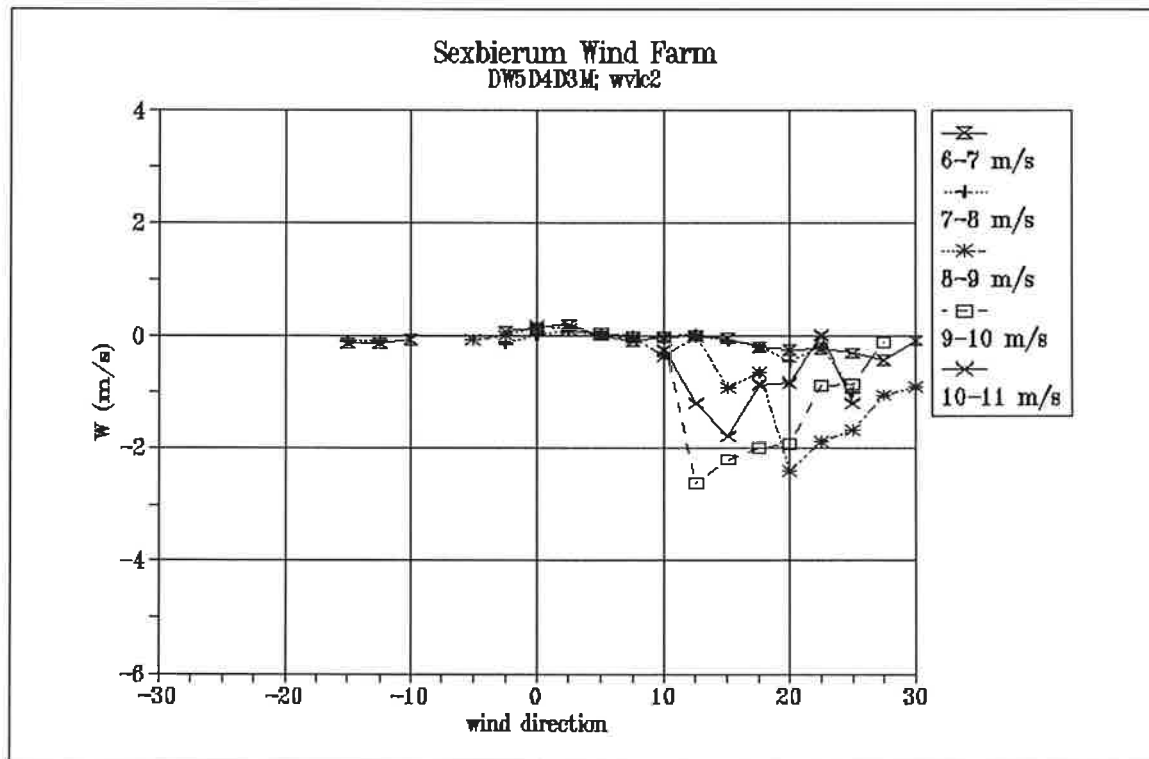


Figure 3 Vertical wind speed W as a function of wind direction and wind speed bin

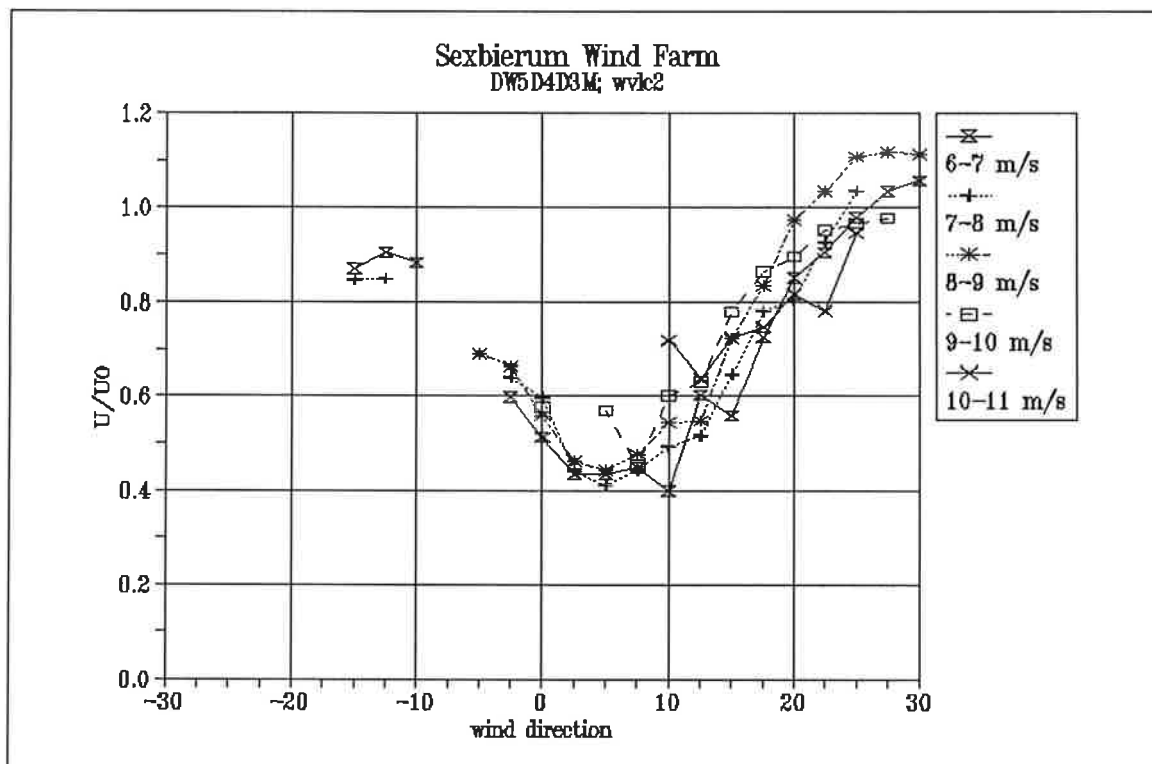


Figure 4 Wake deficit U/U_0 as a function of wind direction and wind speed bin

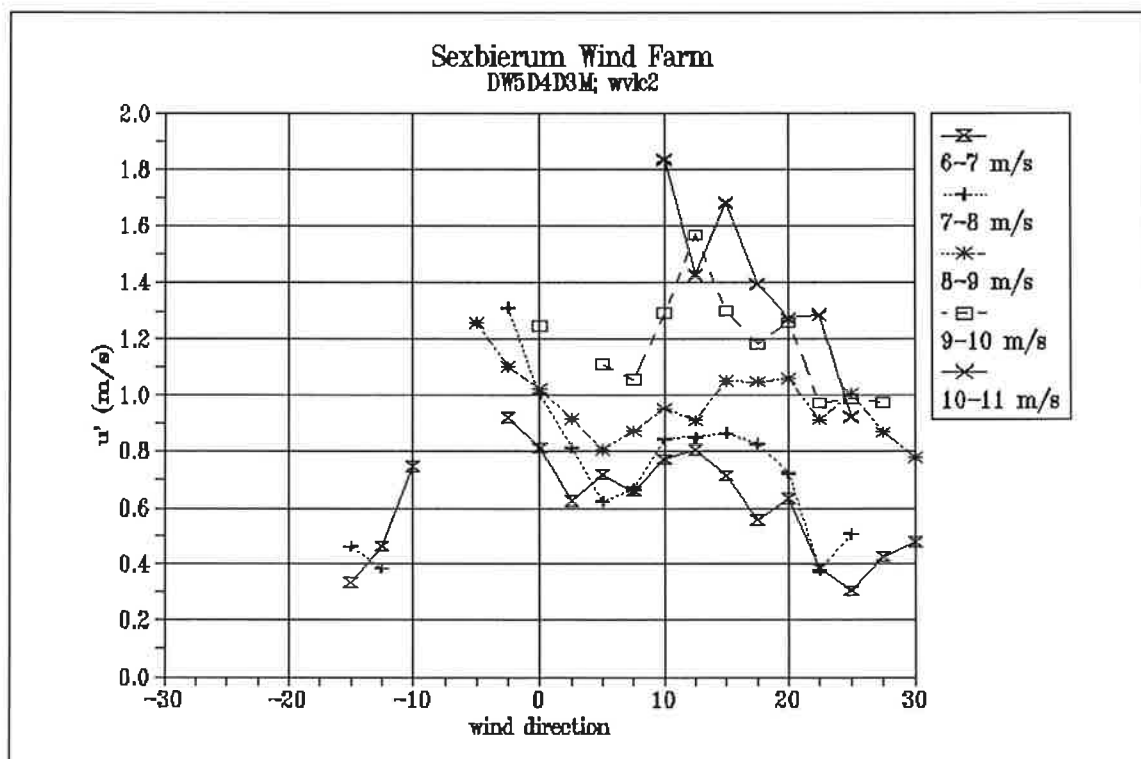


Figure 5 Longitudinal turbulent fluctuations u' as a function of wind direction and wind speed bin

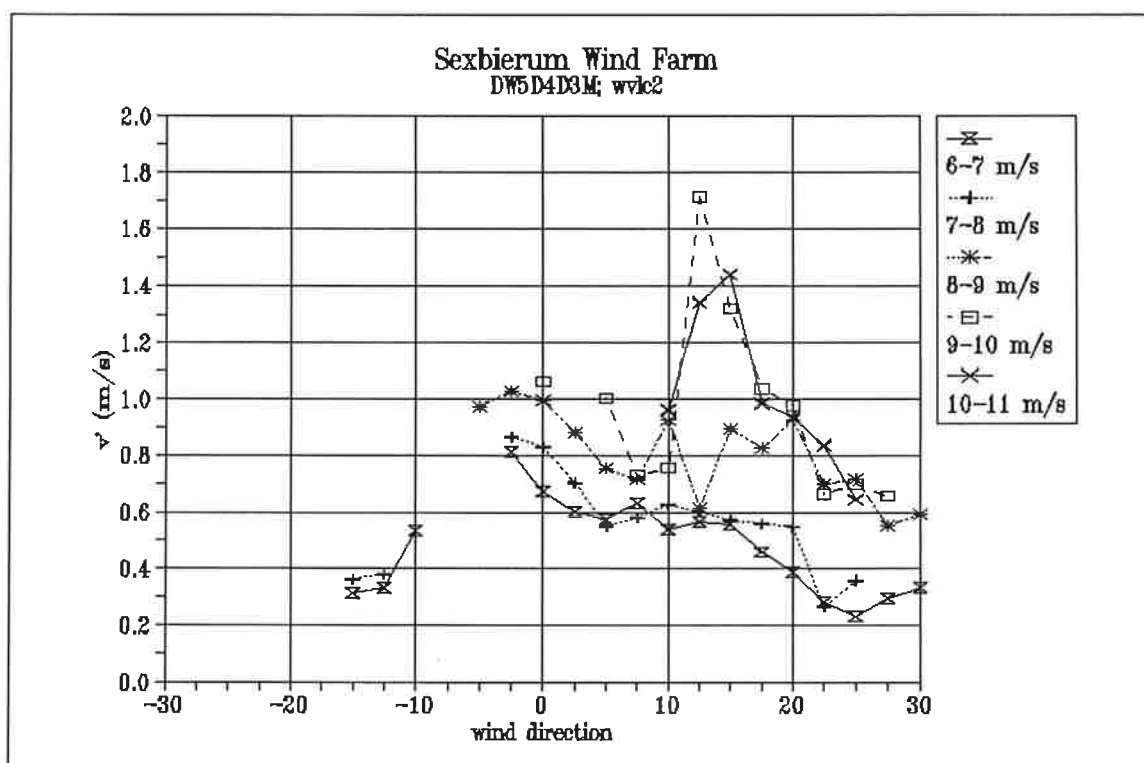


Figure 6 Lateral turbulent fluctuations v' as a function of wind direction and wind speed bin

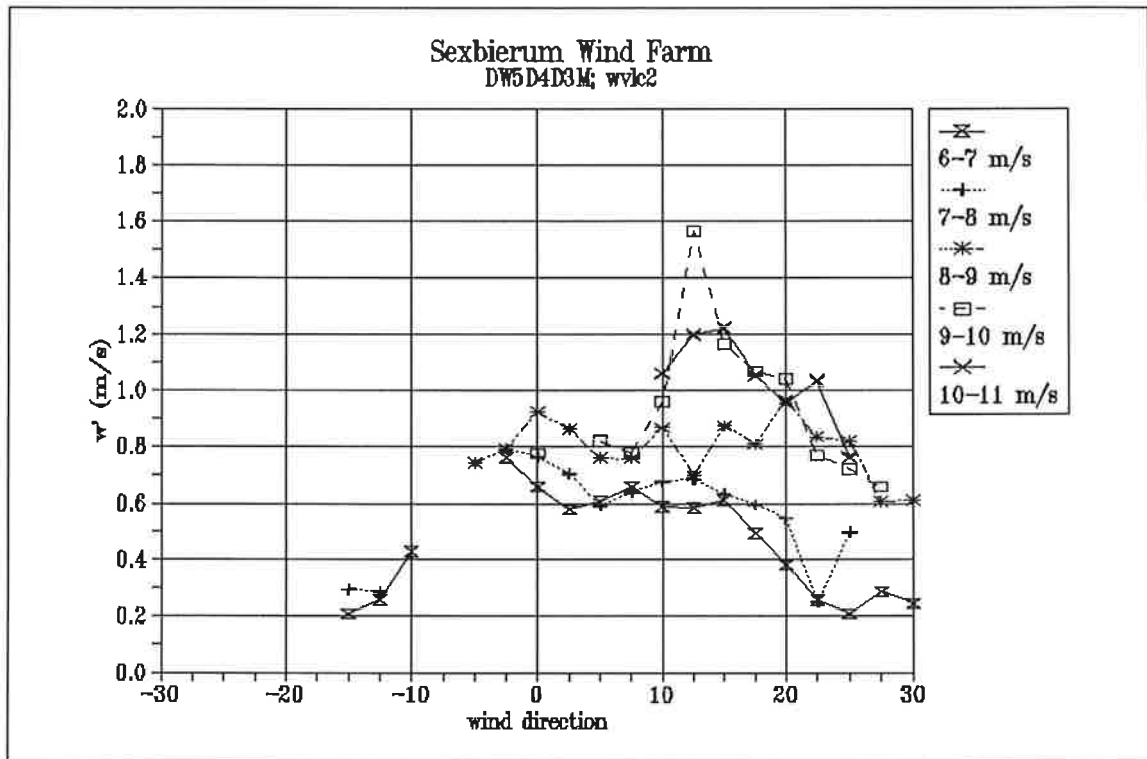


Figure 7 Vertical turbulent fluctuations w' as a function of wind direction and wind speed bin

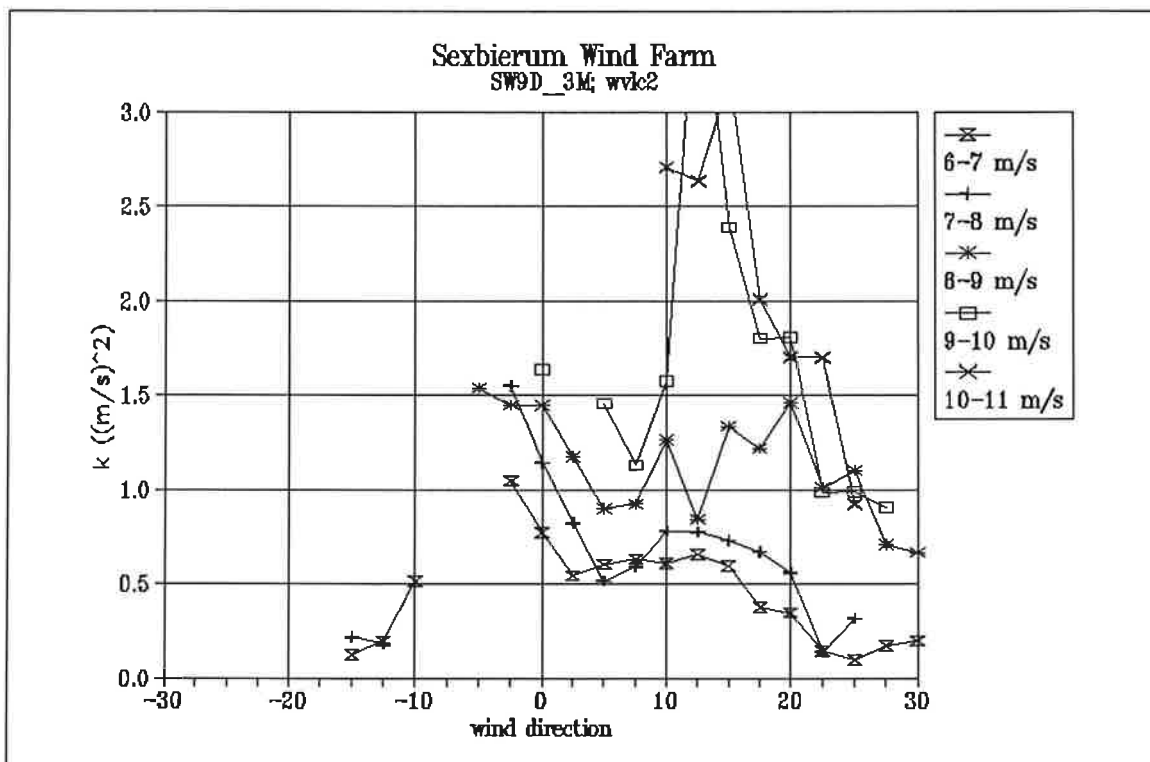


Figure 8 Turbulent kinetic energy per unit mass as a function of wind direction and wind speed bin

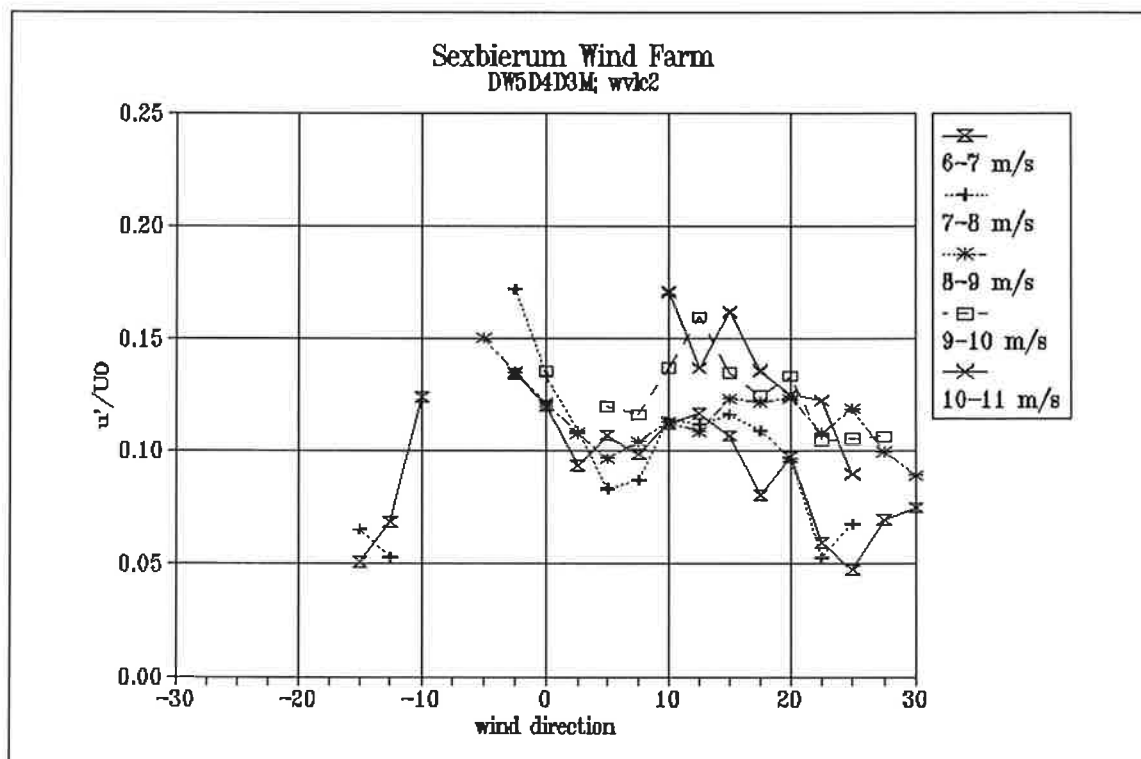


Figure 9 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction and wind speed bin

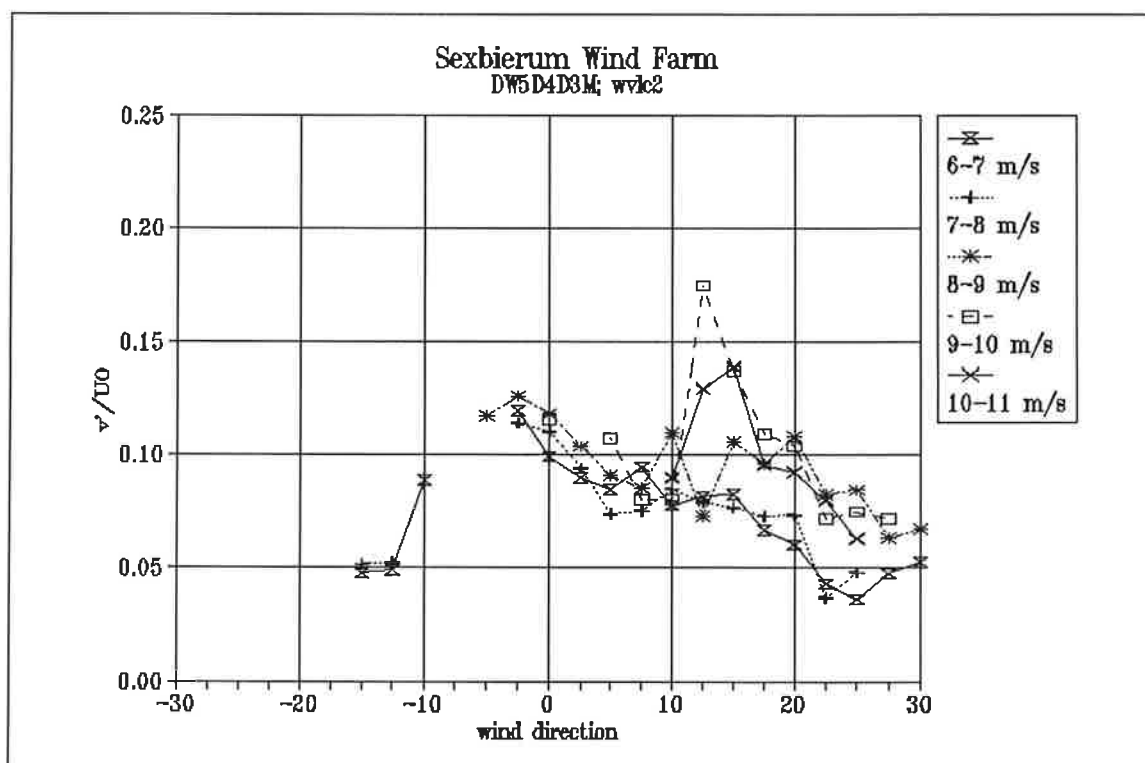


Figure 10 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction and wind speed bin

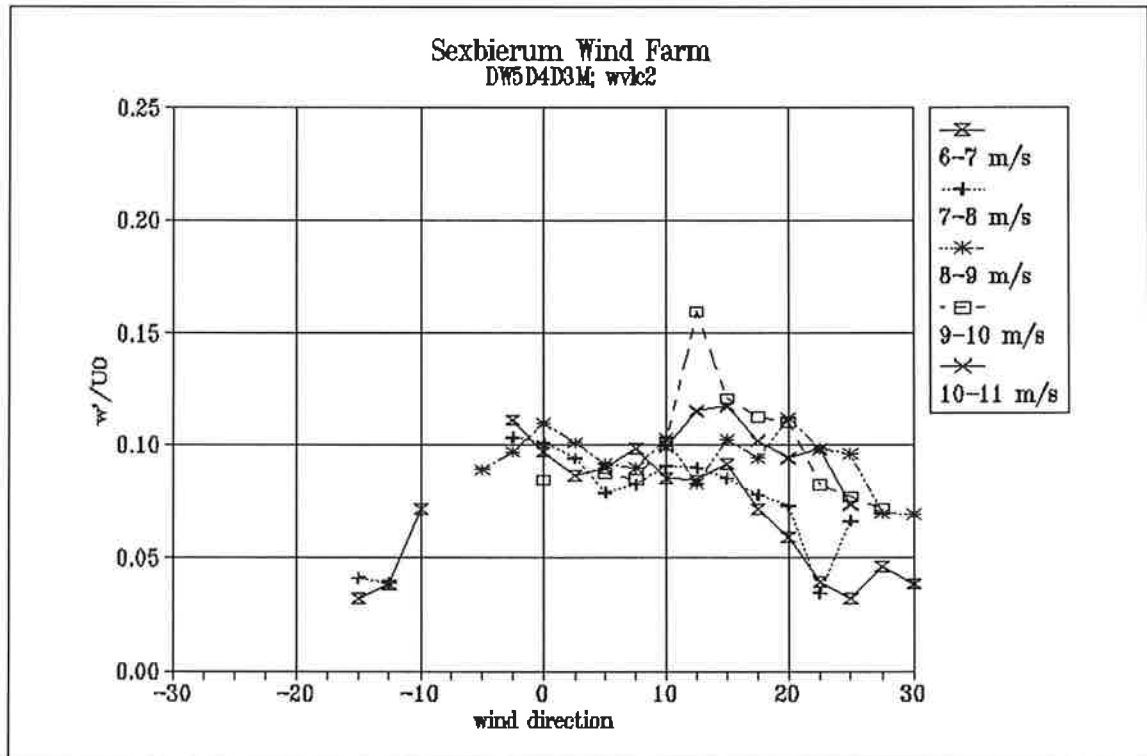


Figure 11 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction and wind speed bin

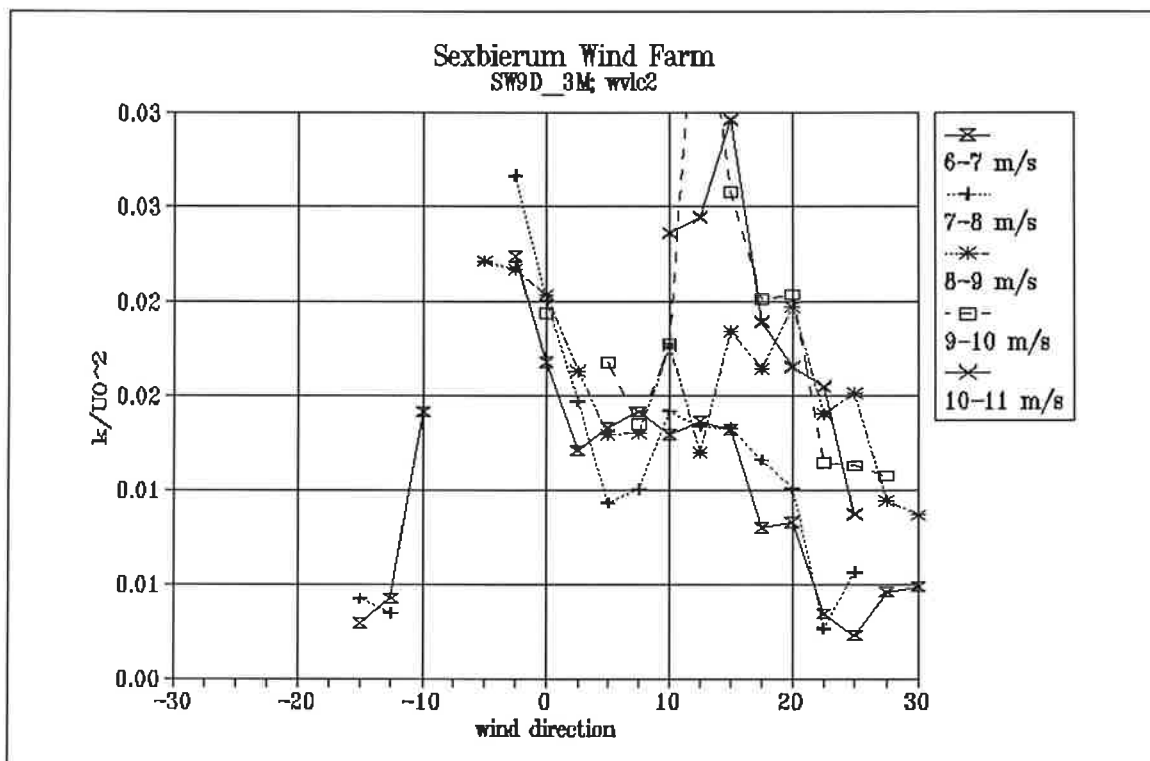


Figure 12 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction and wind speed bin

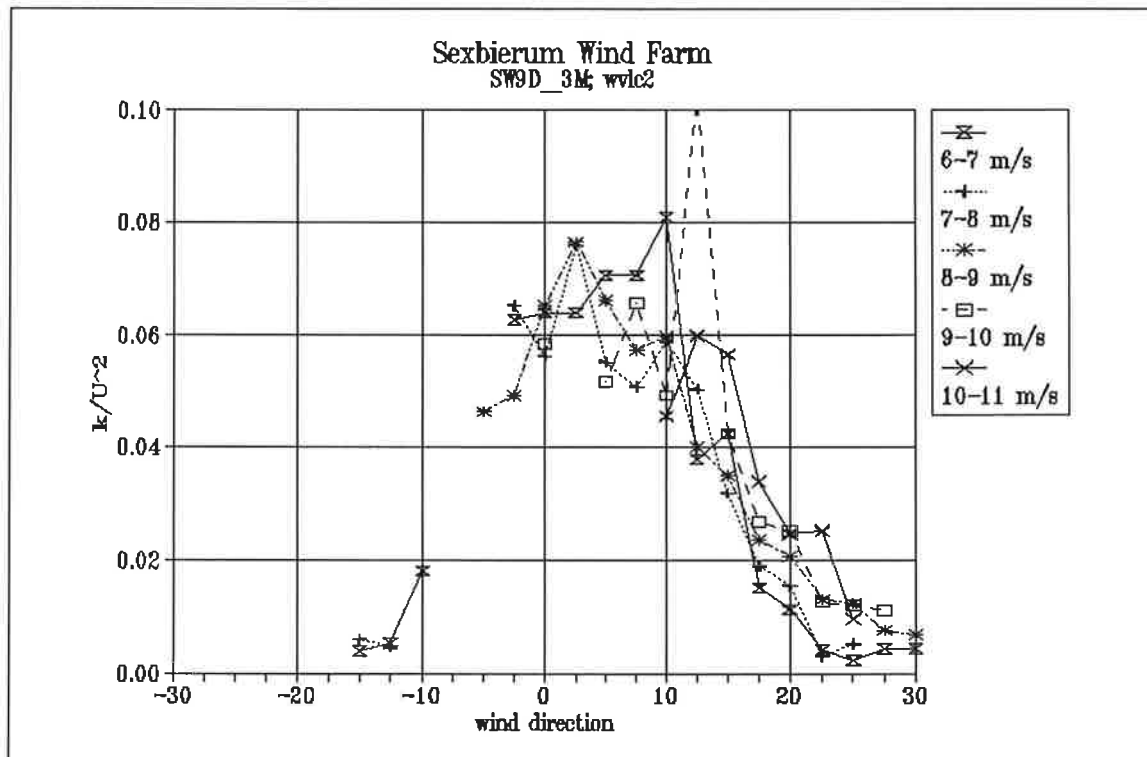


Figure 13 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction and wind speed bin

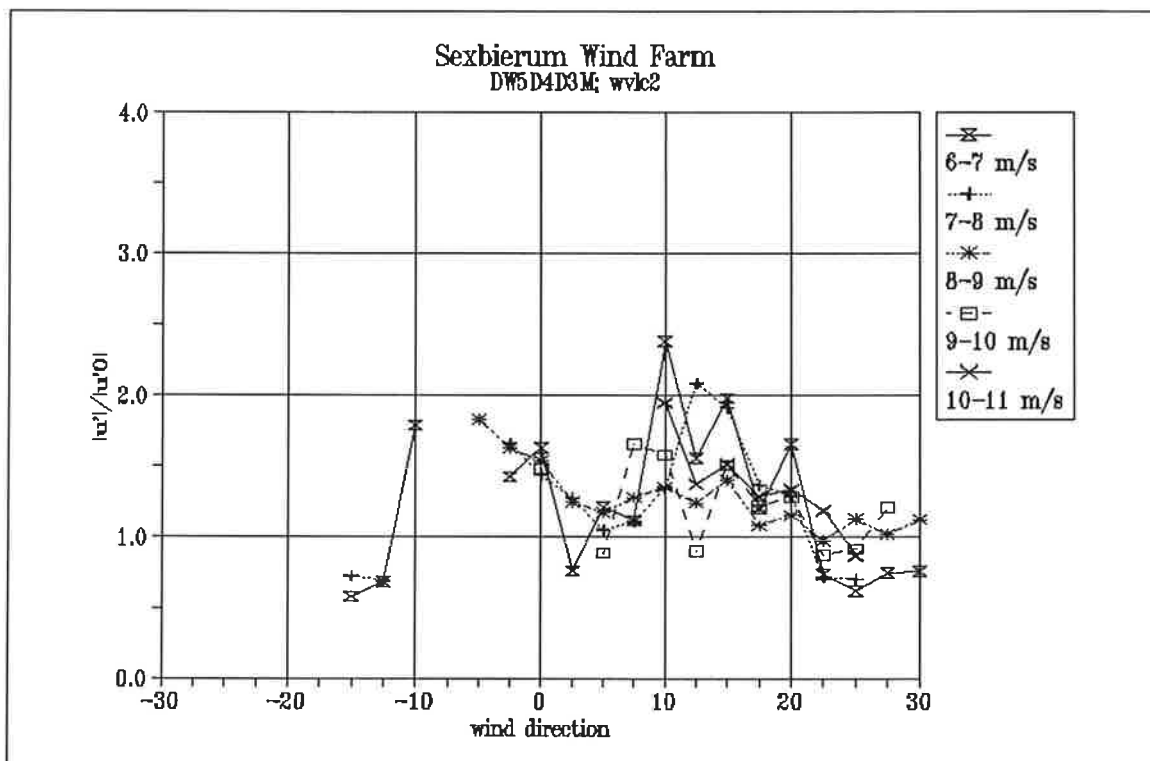


Figure 14 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction and wind speed bin

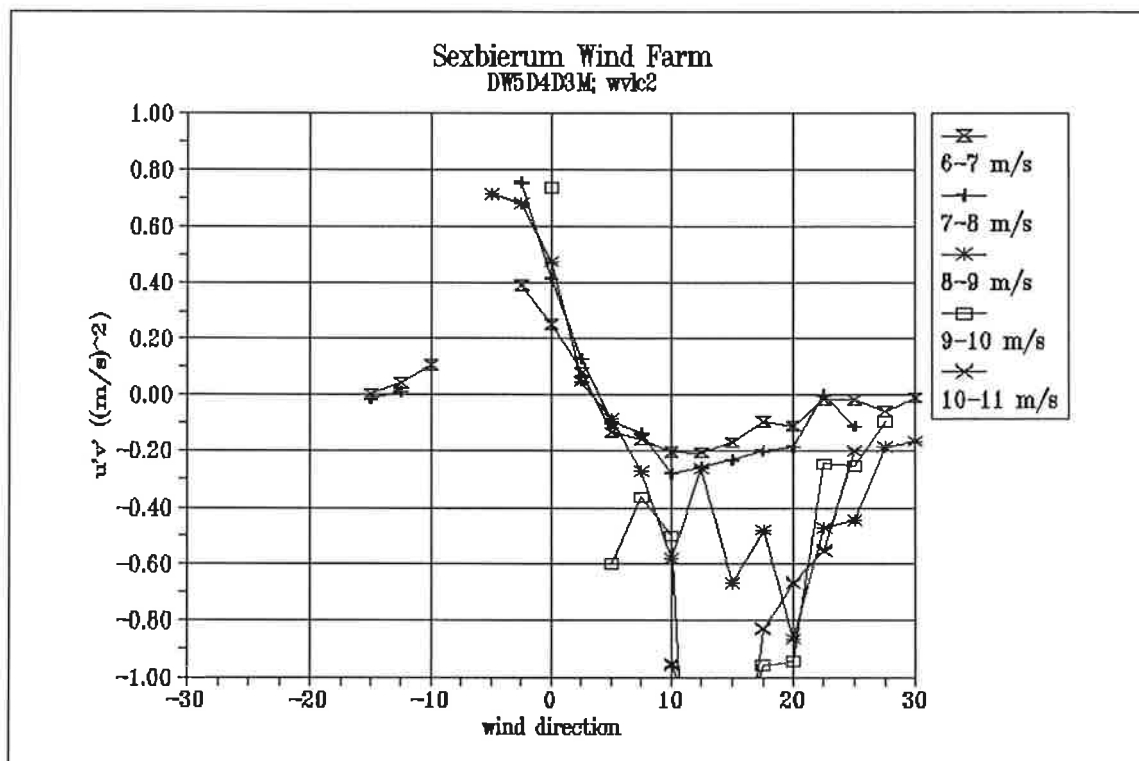


Figure 15 Shear stress $u'v'$ as a function of wind direction and wind speed bin

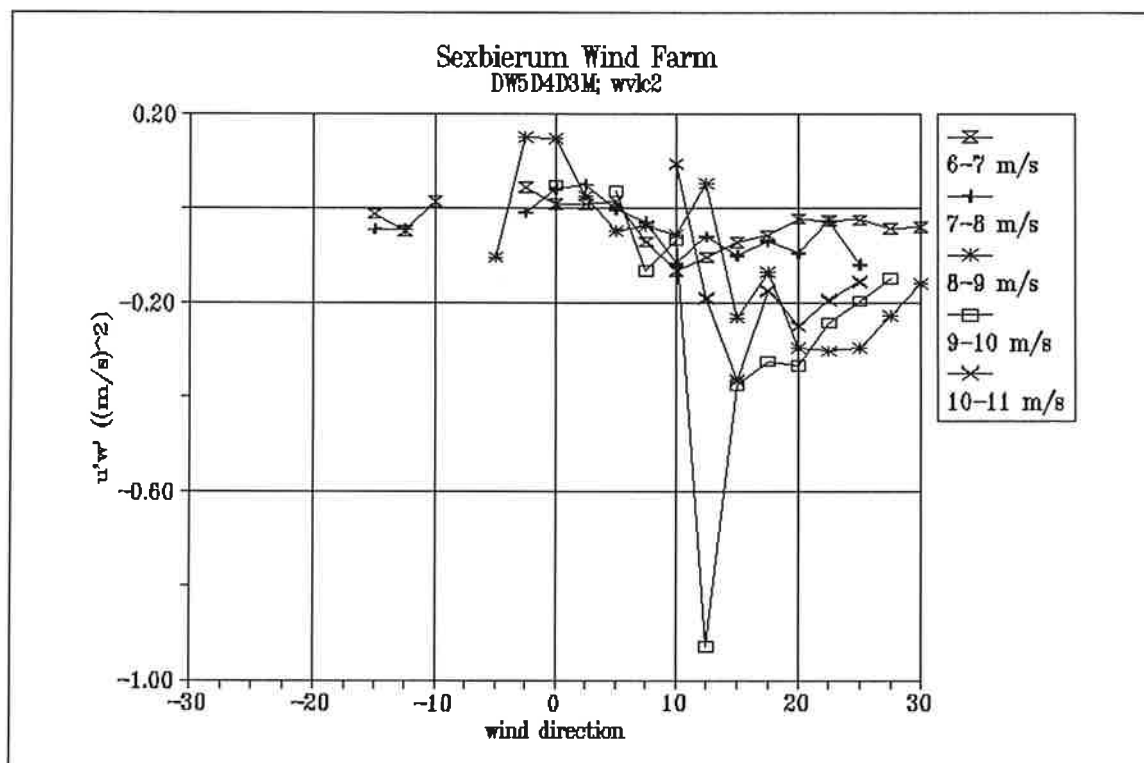


Figure 16 Shear stress $u'w'$ as a function of wind direction and wind speed bin

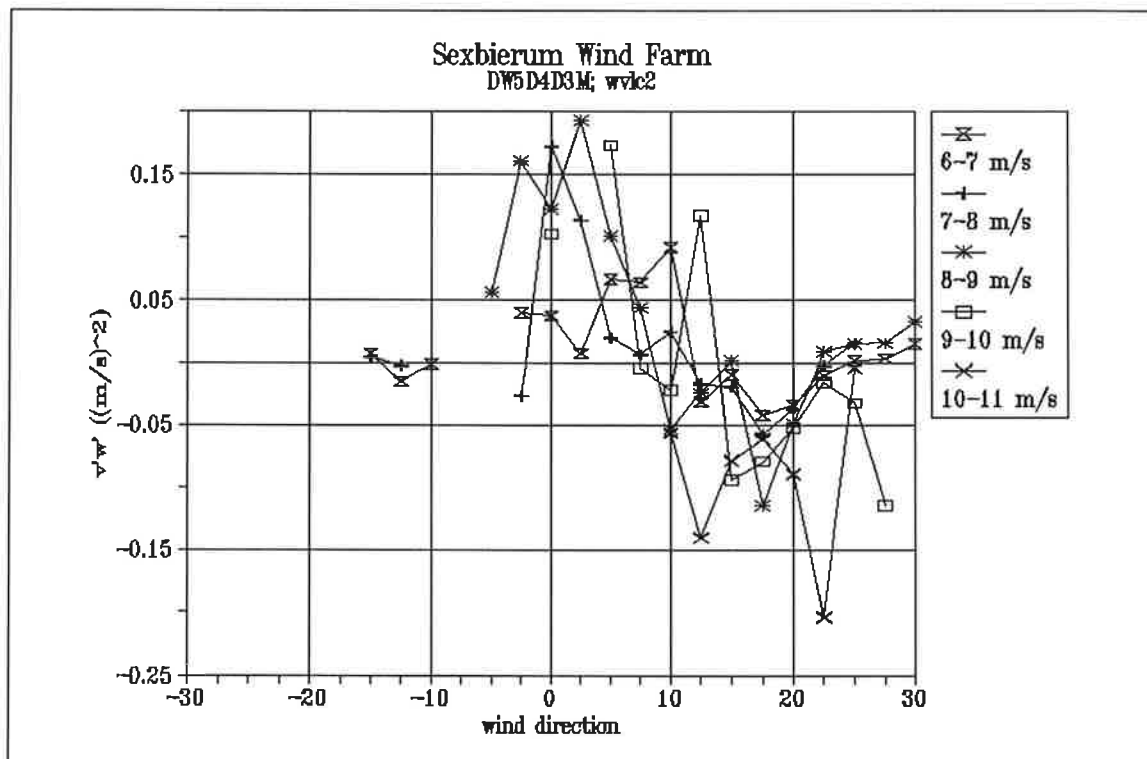


Figure 17 Shear stress $v'w'$ as a function of wind direction and wind speed bin

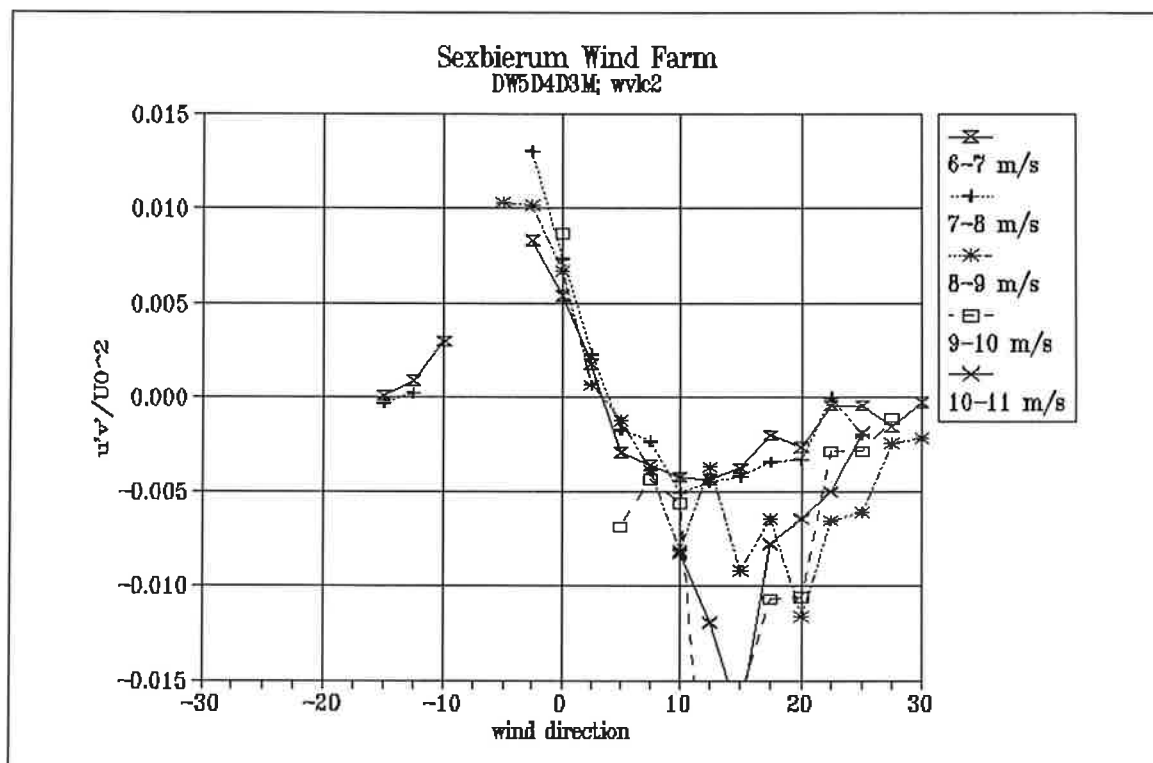


Figure 18 Non-dimensionalized shear stress $u'v'/U_0^2$ as a function of wind direction and wind speed bin

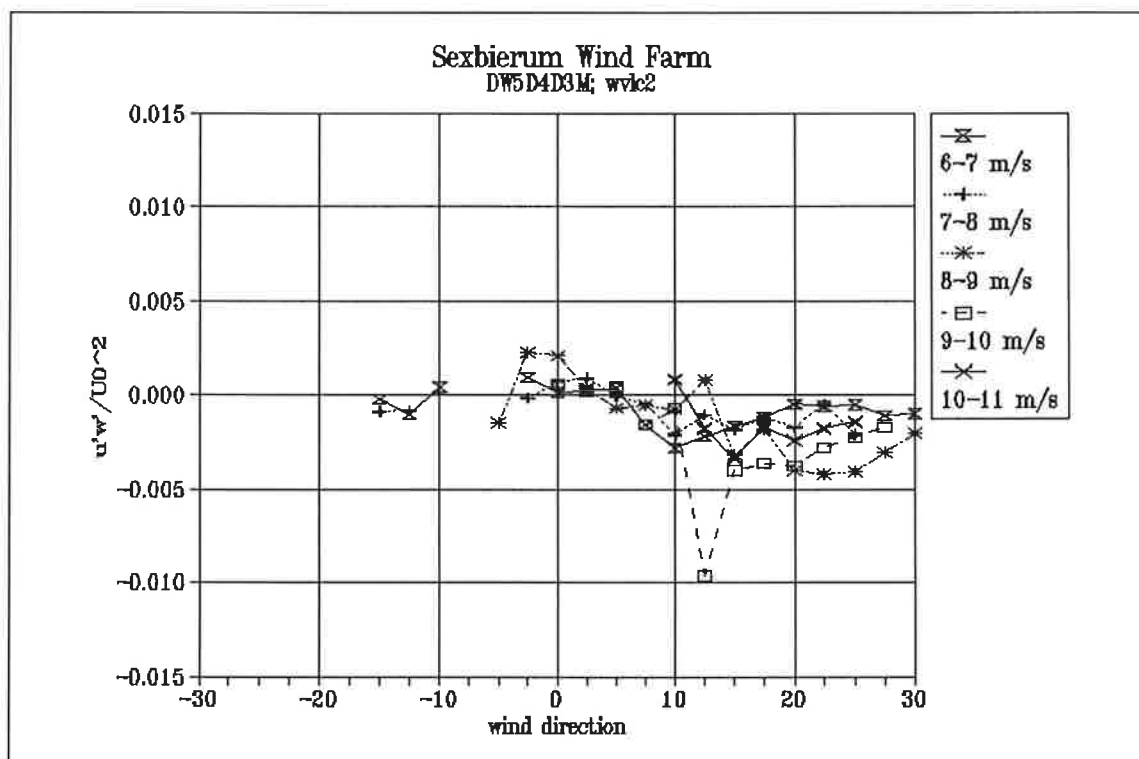


Figure 19 Non-dimensionalized shear stress $u'w'/U_0^2$ as a function of wind direction and wind speed bin

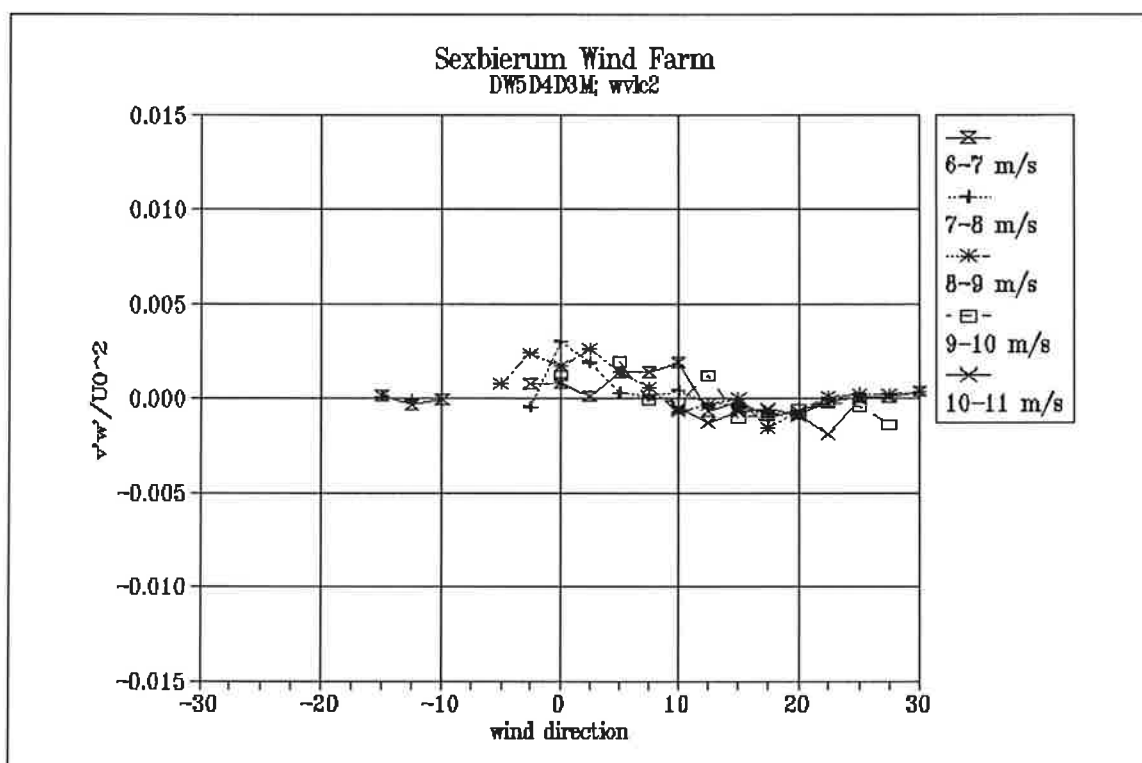


Figure 20 Non-dimensionalized shear stress $v'w'/U_0^2$ as a function of wind direction and wind speed bin

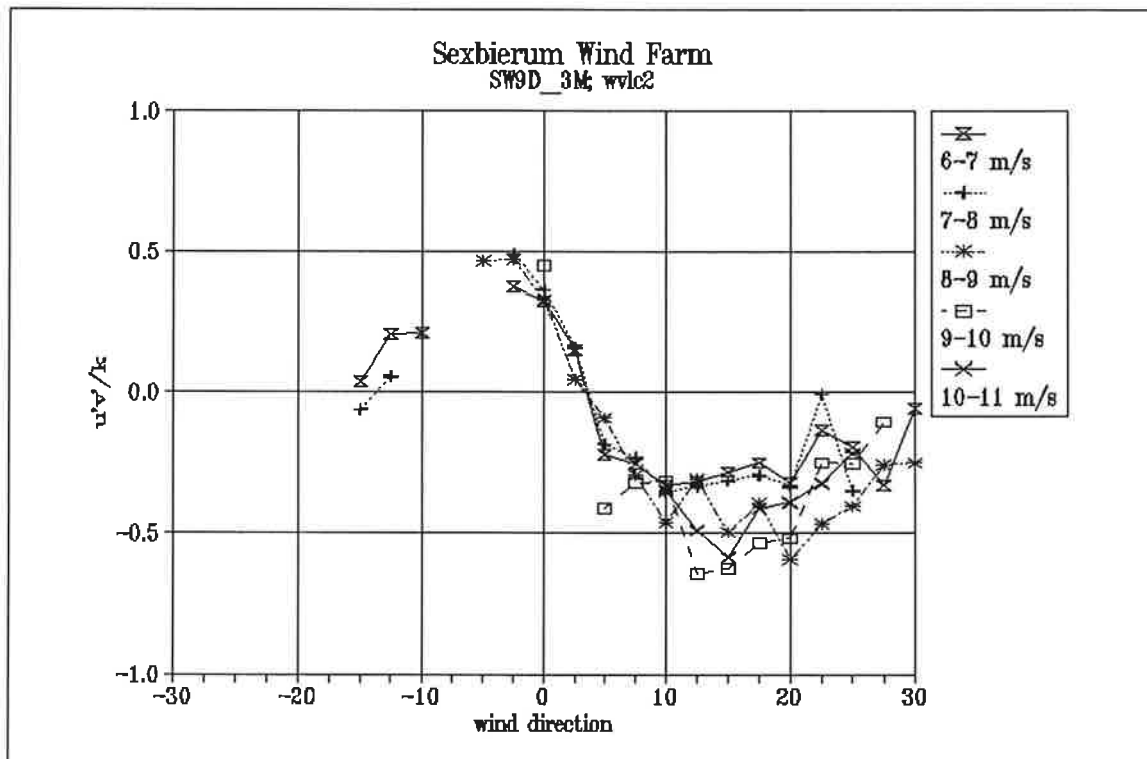


Figure 21 Non-dimensionalized shear stress $u'v'/k$ as a function of wind direction and wind speed bin

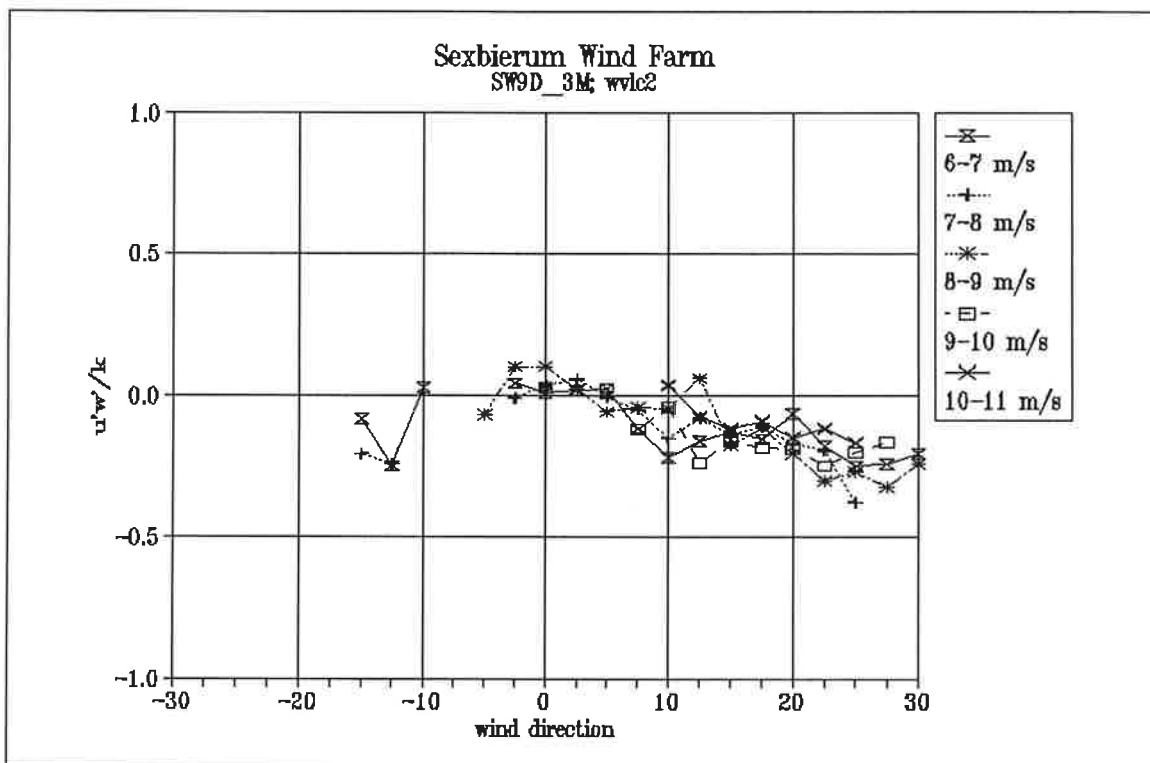


Figure 22 Non-dimensionalized shear stress $u'w'/k$ as a function of wind direction and wind speed bin

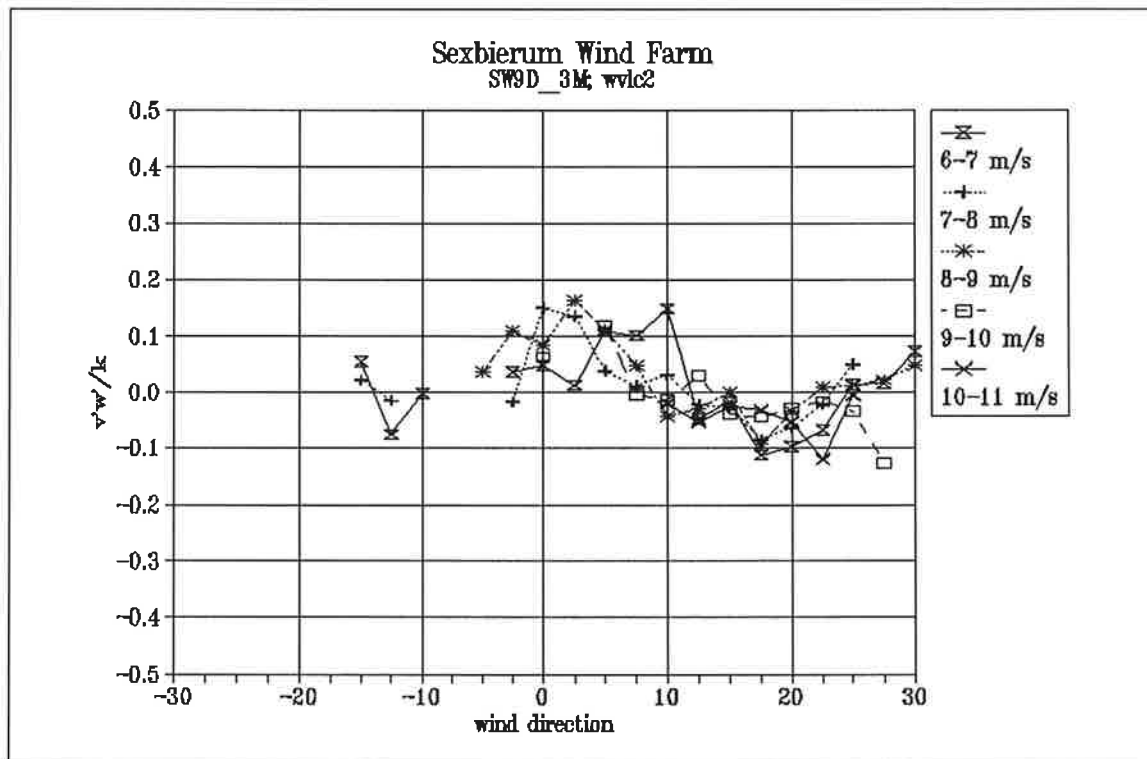


Figure 23 Non-dimensionalized shear stress $v'w'/k$ as a function of wind direction and wind speed bin

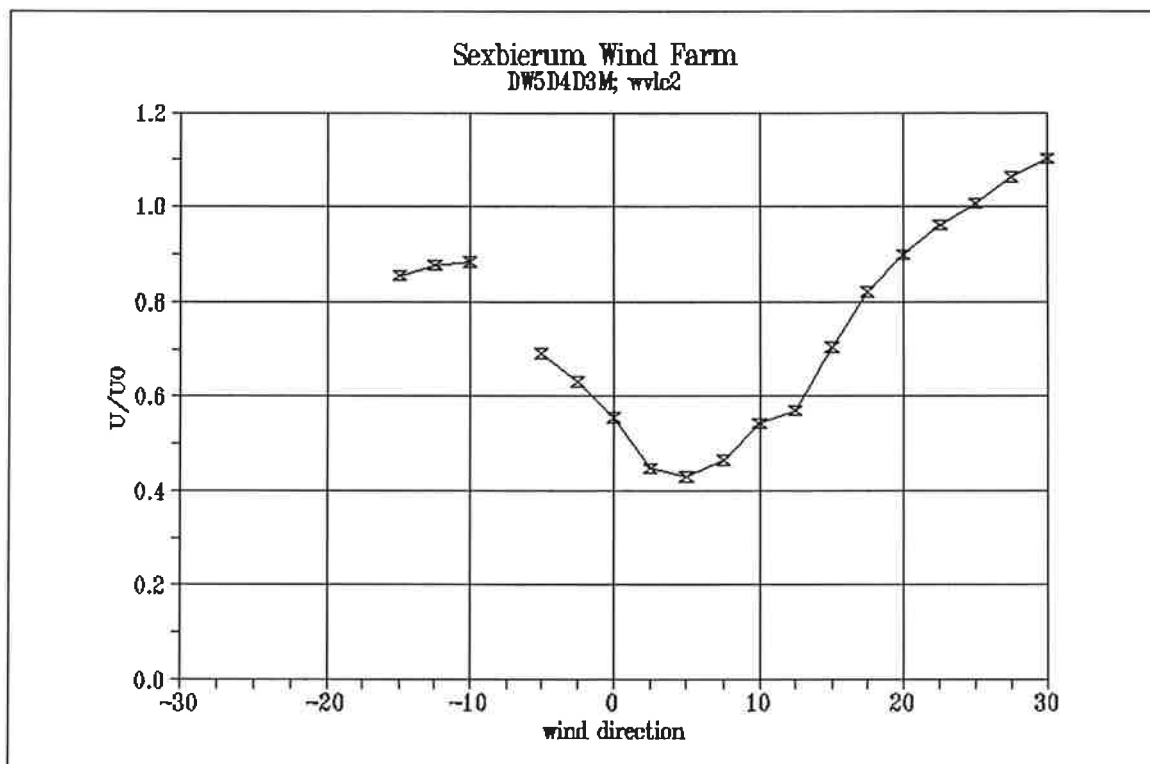


Figure 24 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

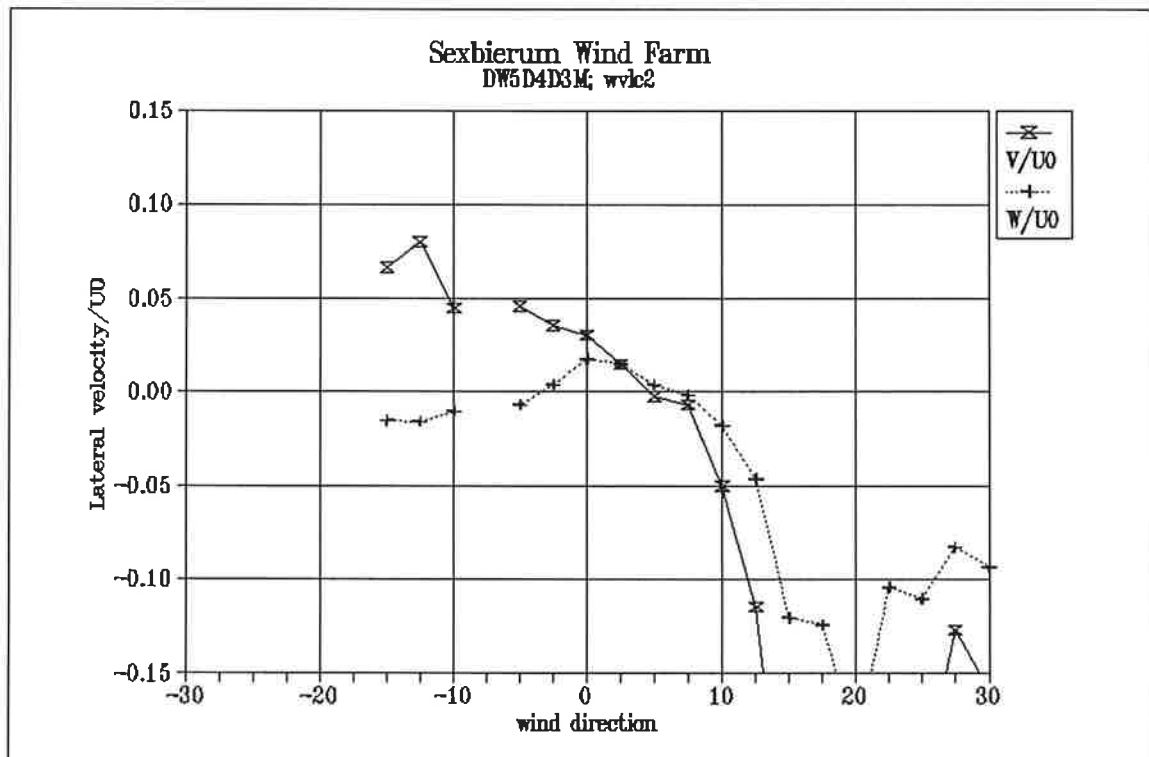


Figure 25 Lateral and vertical wind speed V/U_0 and W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

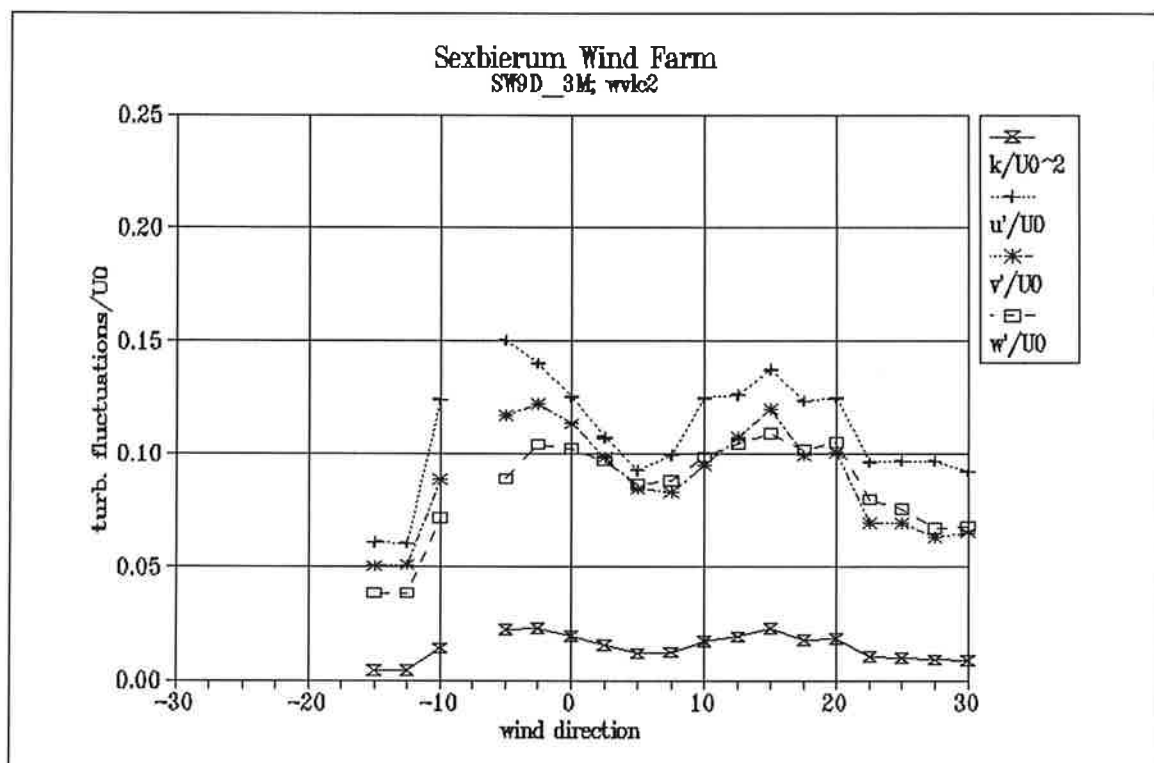


Figure 26 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U_0

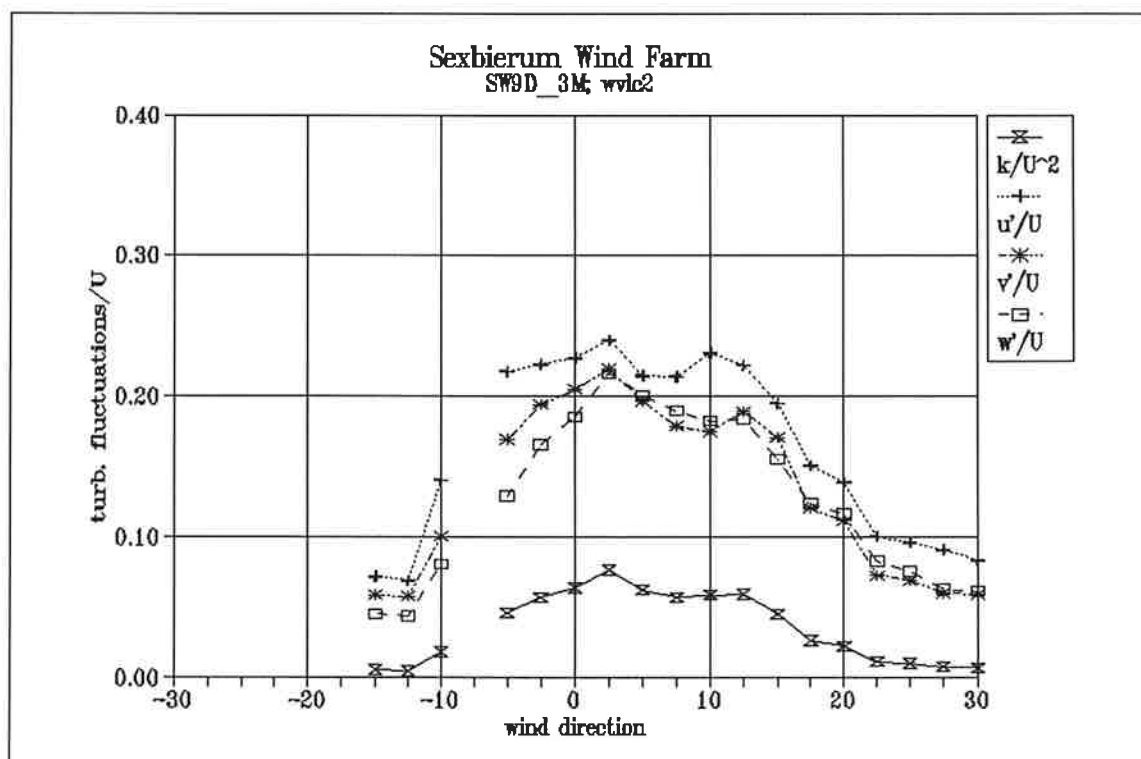


Figure 27 Turbulent fluctuations as a function of wind direction in the wind speed bin 5-10 m/s, non-dimensionalized with U

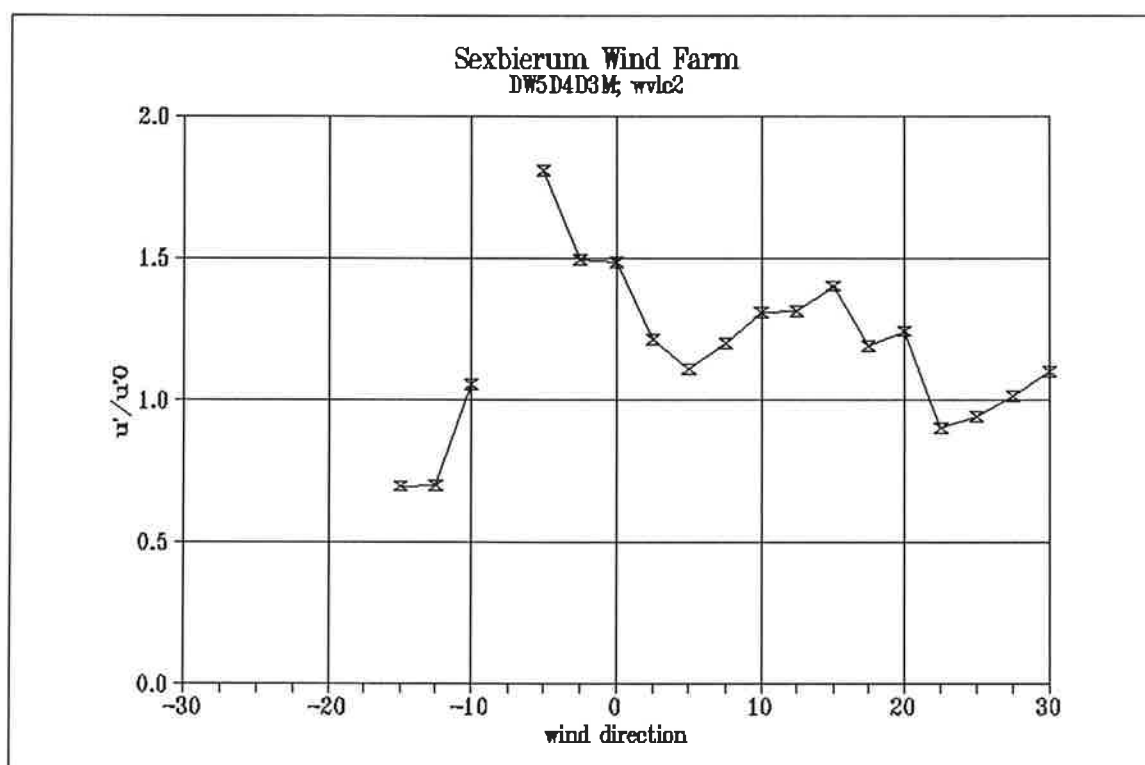


Figure 28 Longitudinal turbulence enhancement u'/u'_0 as a function of wind direction in the wind speed bin 5-10 m/s

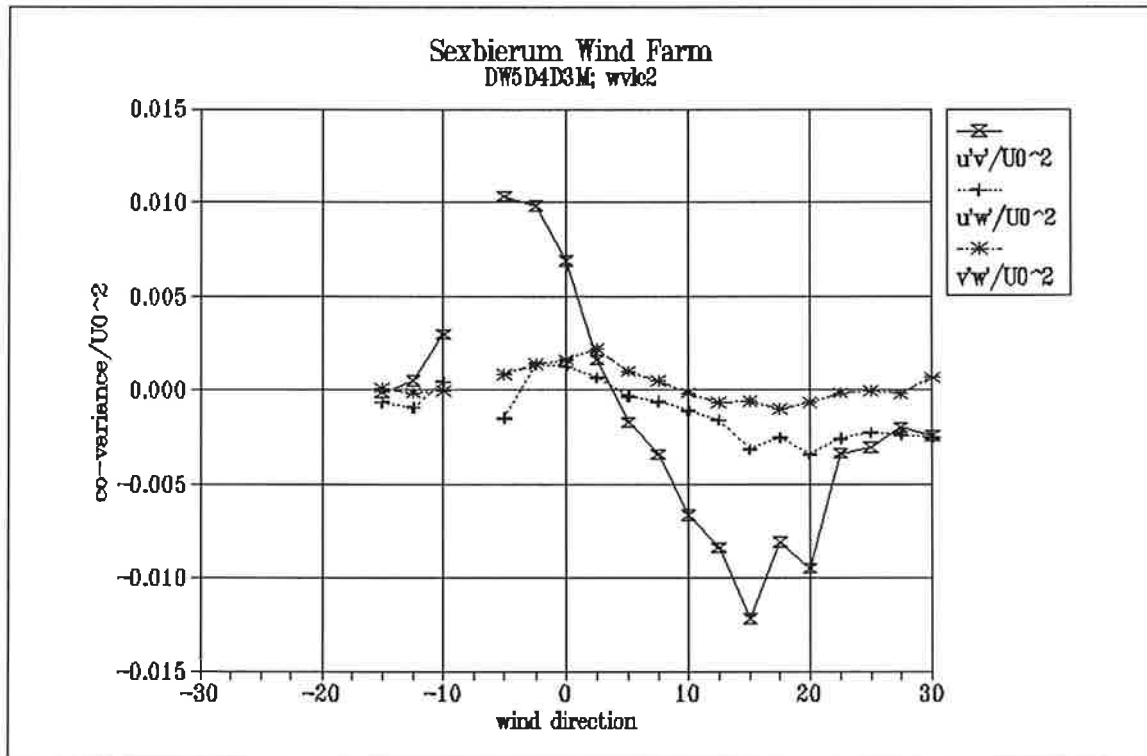


Figure 29 Non-dimensionalized shear stresses $u'v'/U_0^2$; $u'w'/U_0^2$; $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

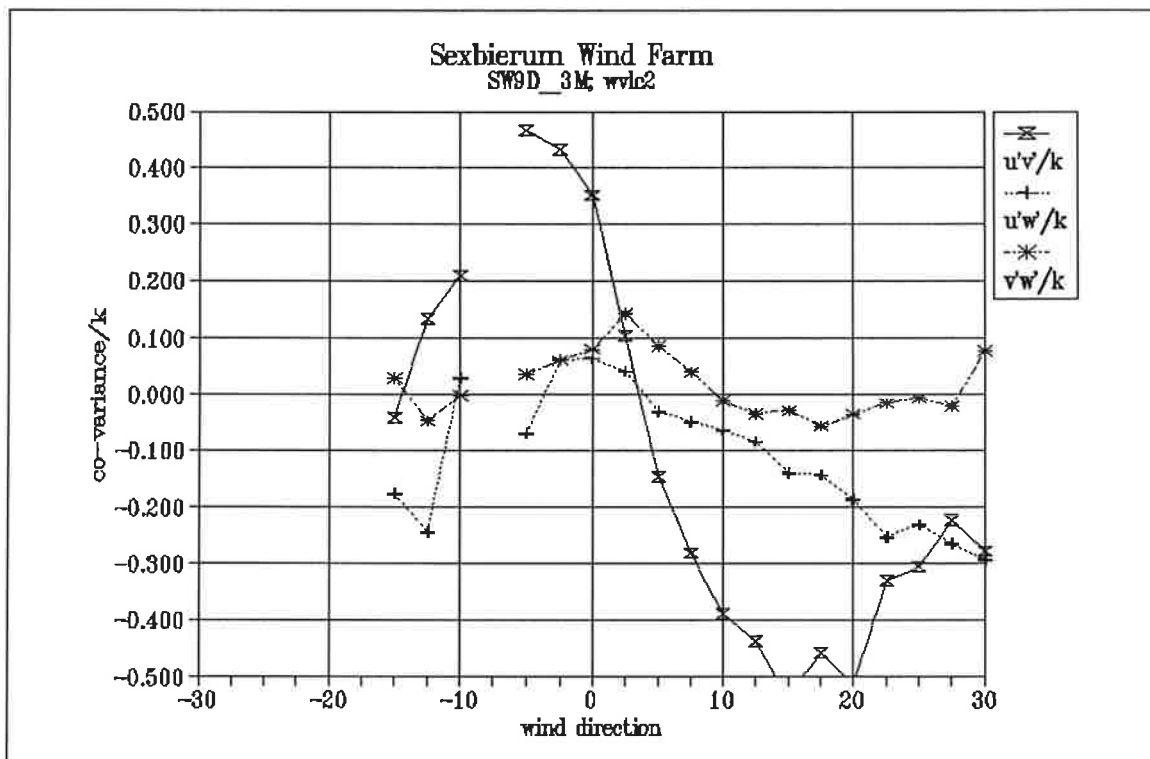


Figure 30 Non-dimensionalized shear stresses $u'v'/k$; $u'w'/k$; $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.8 Vertical profiles

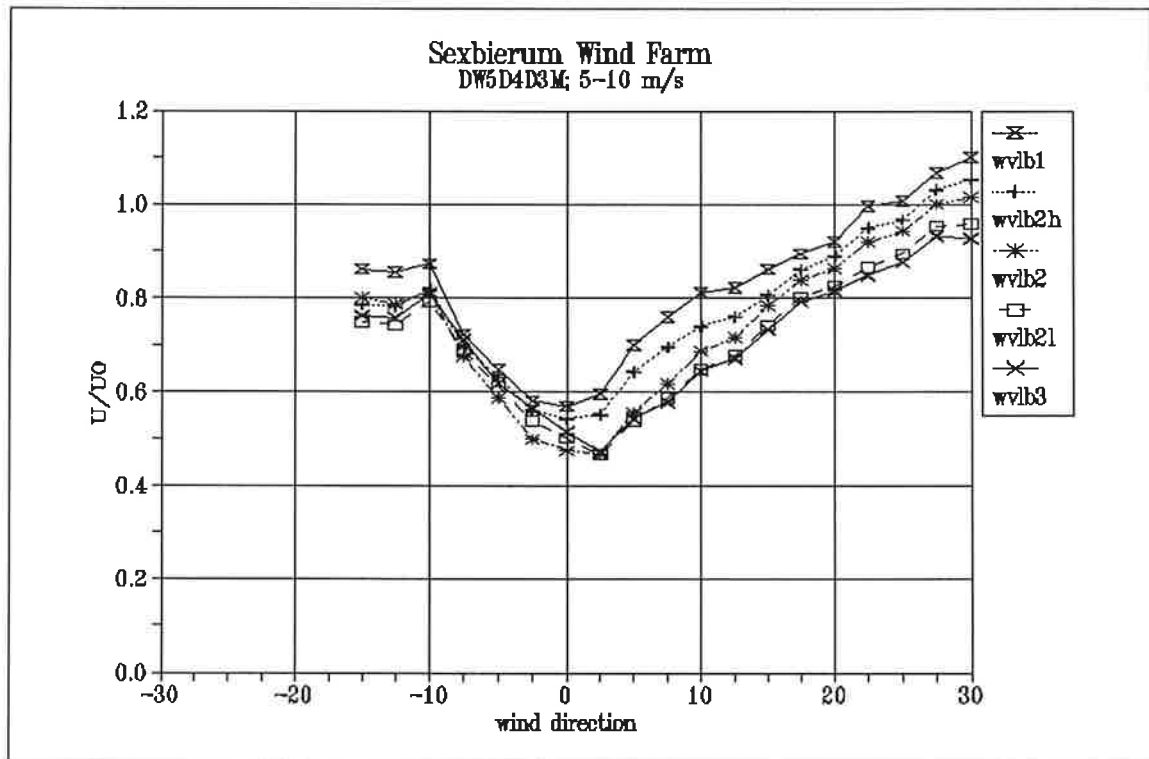


Figure 1 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

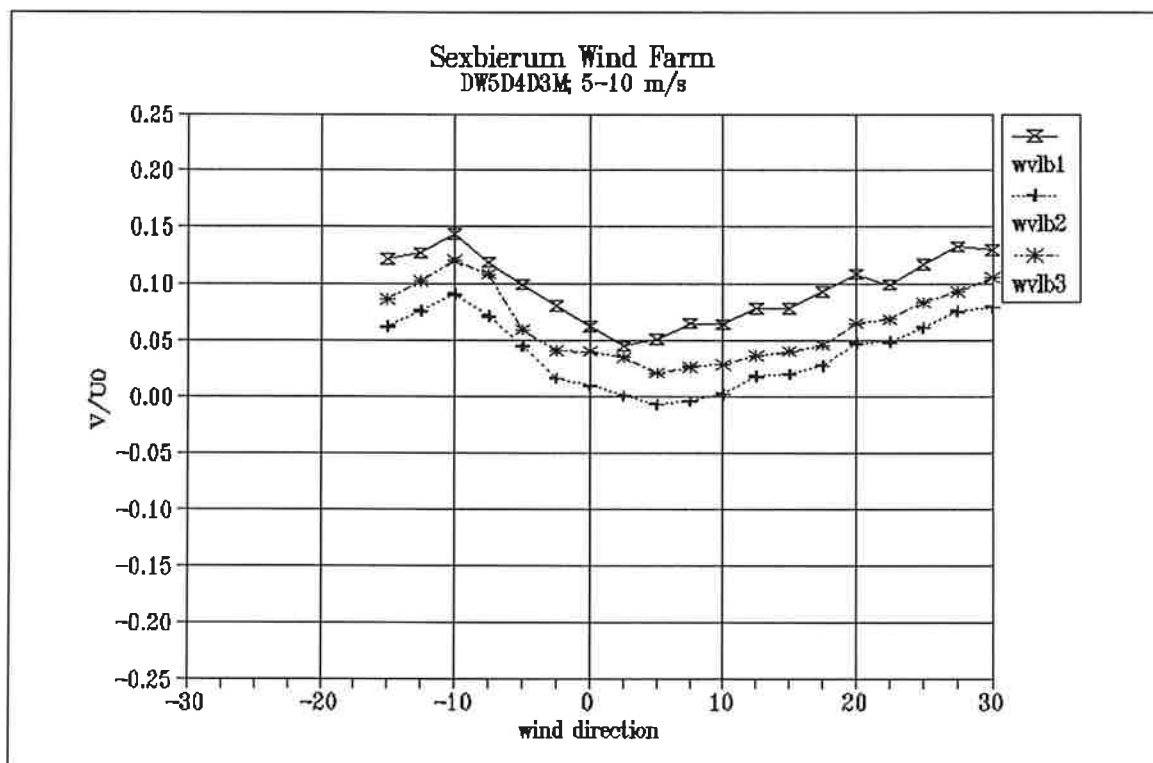


Figure 2 Lateral wind speed V/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

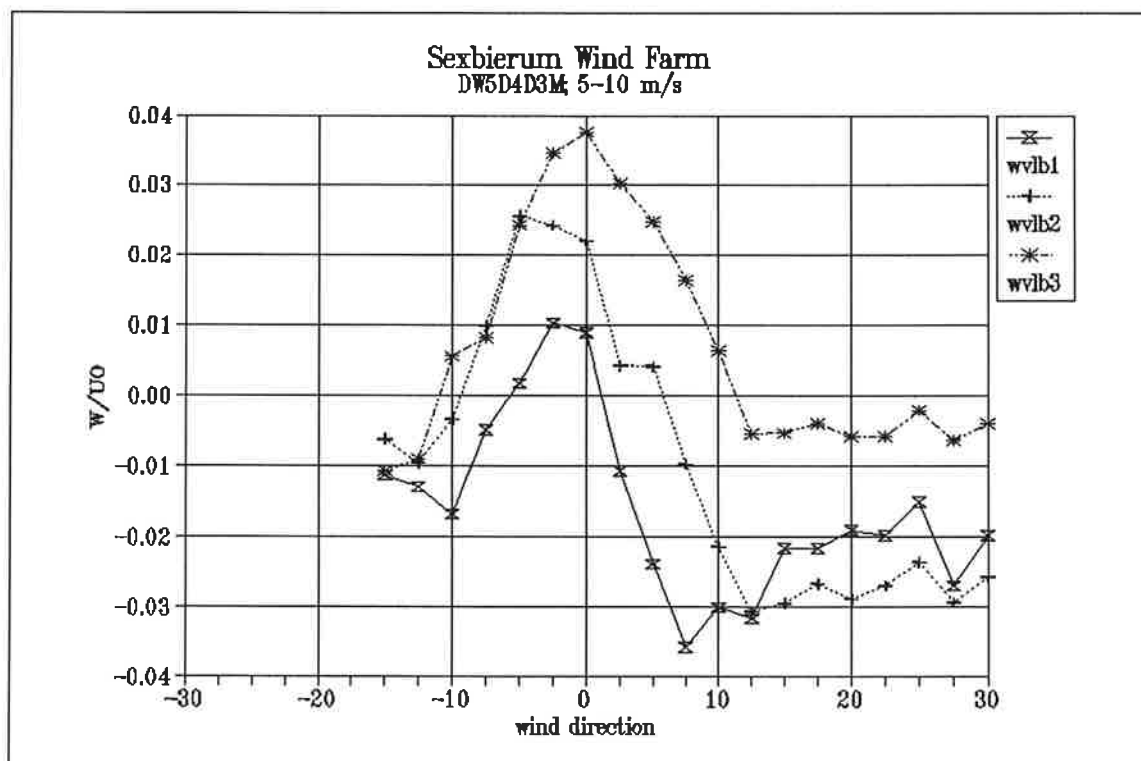


Figure 3 Vertical wind speed W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

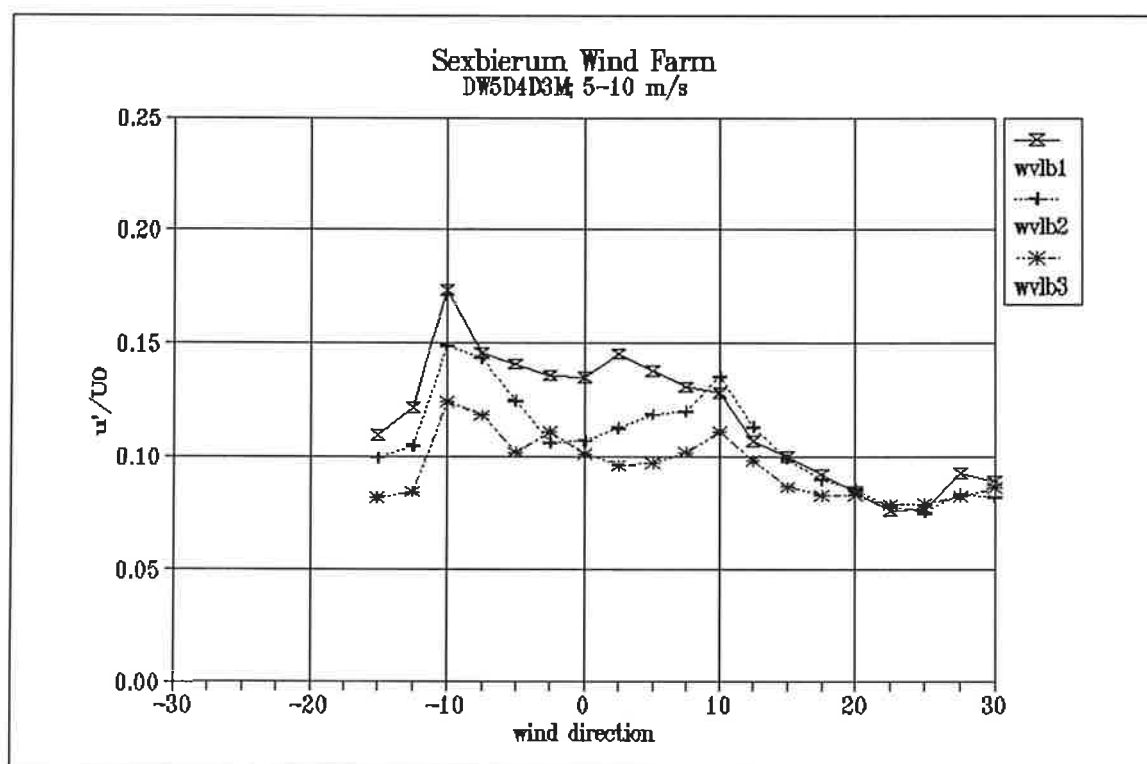


Figure 4 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

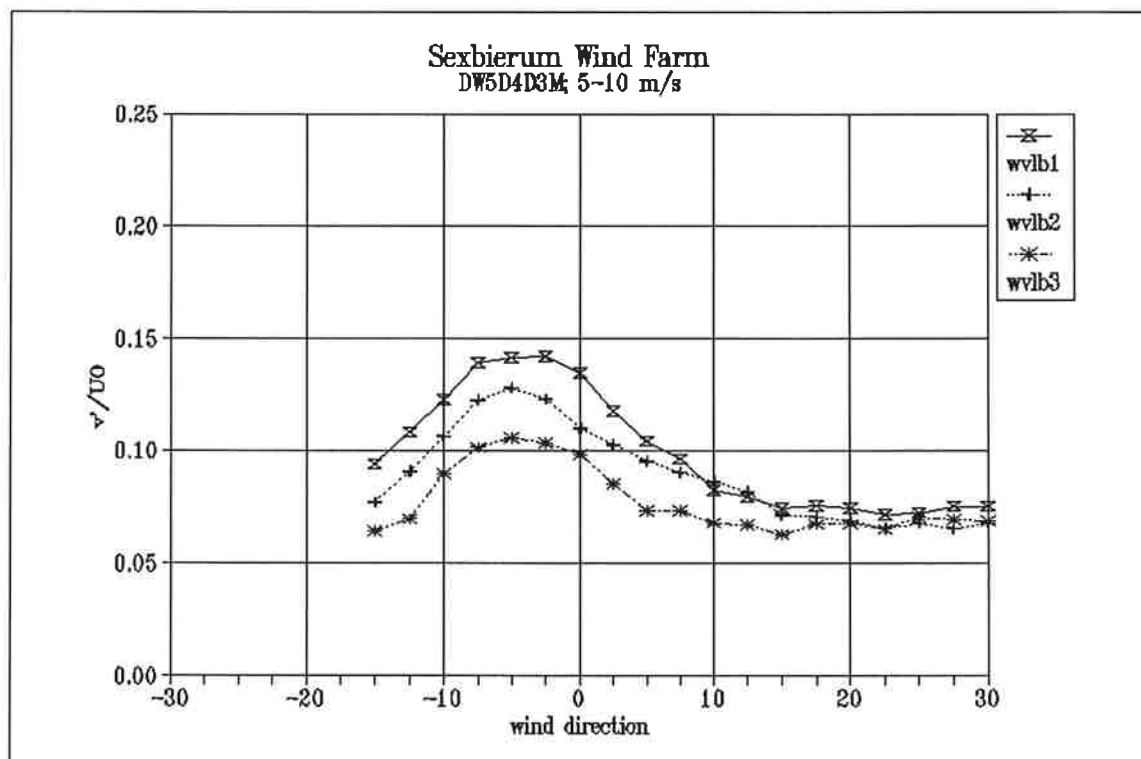


Figure 5 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

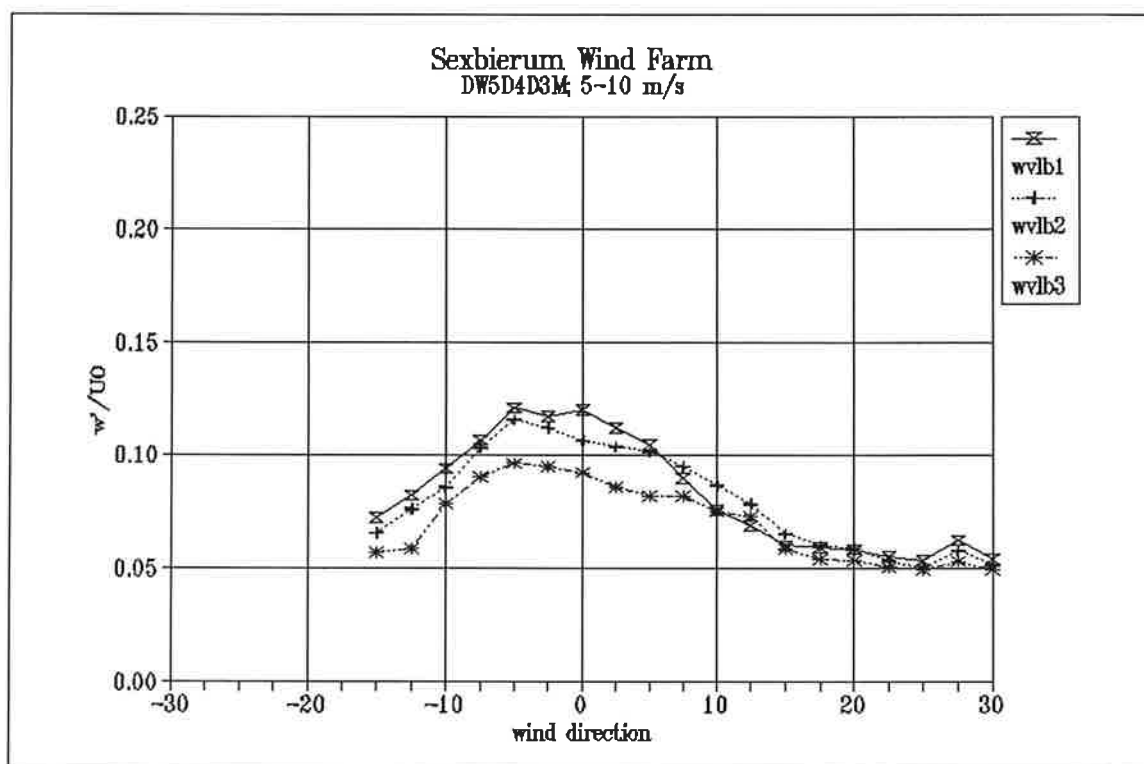


Figure 6 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

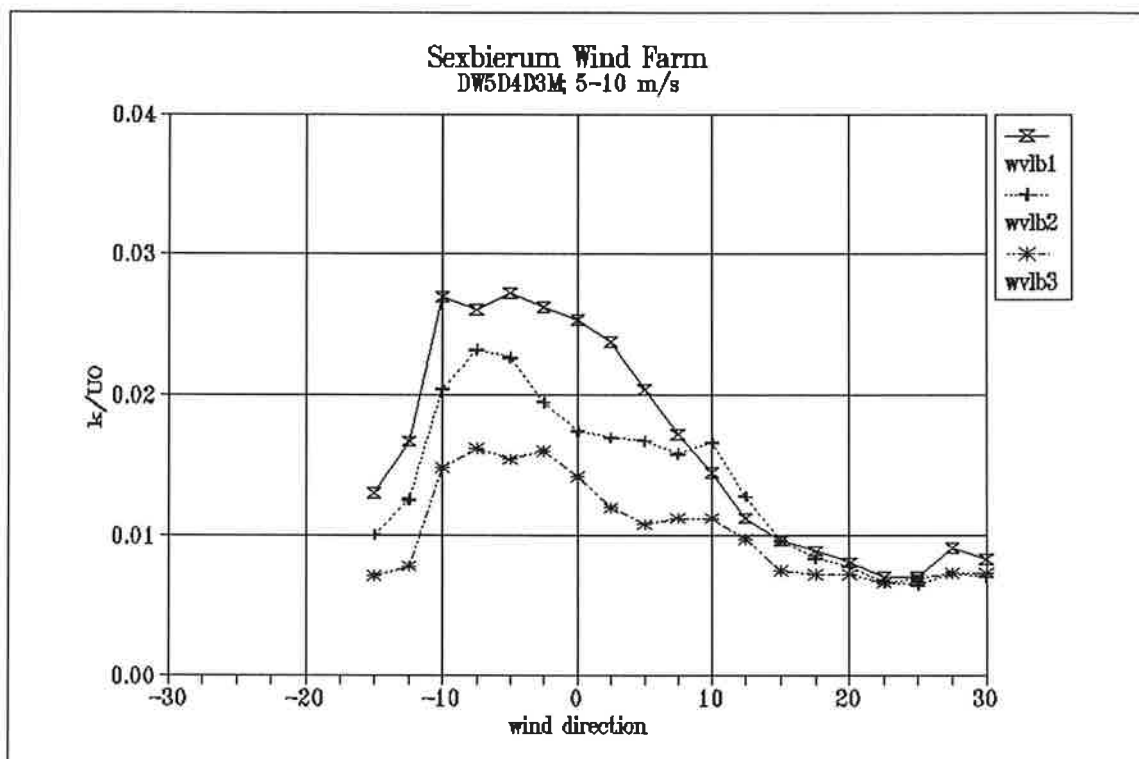


Figure 7 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction in the wind speed bin 5-10 m/s

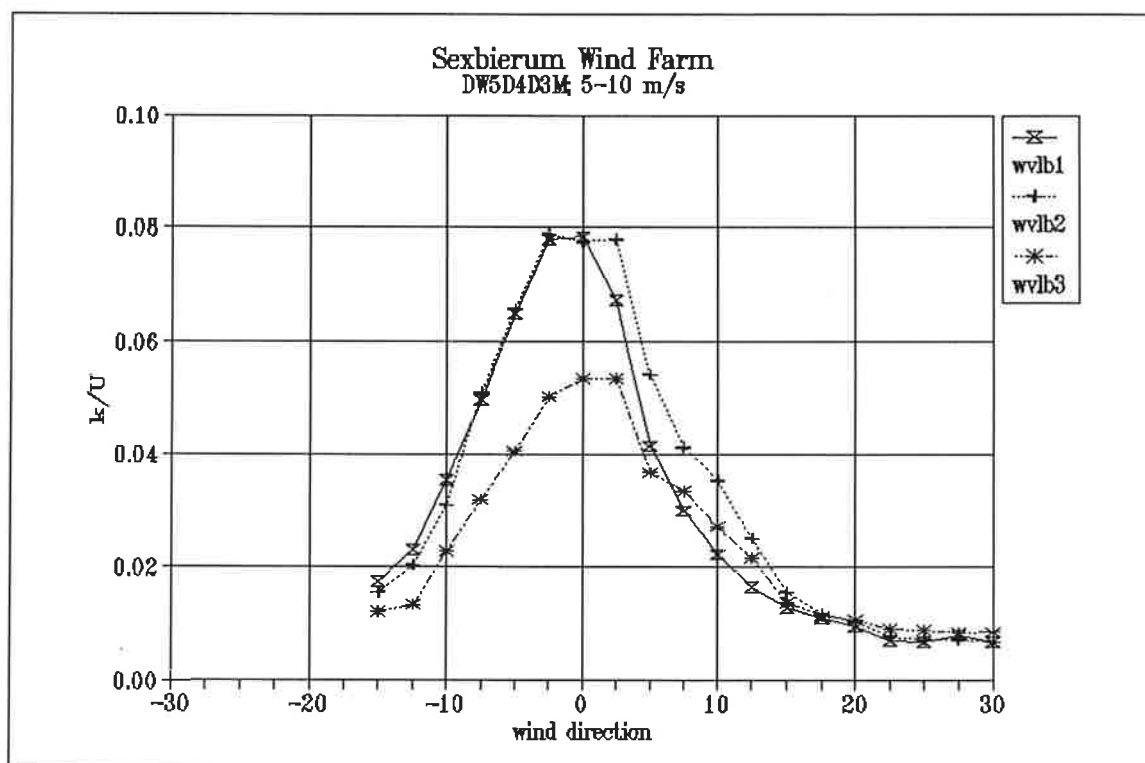


Figure 8 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction in the wind speed bin 5-10 m/s

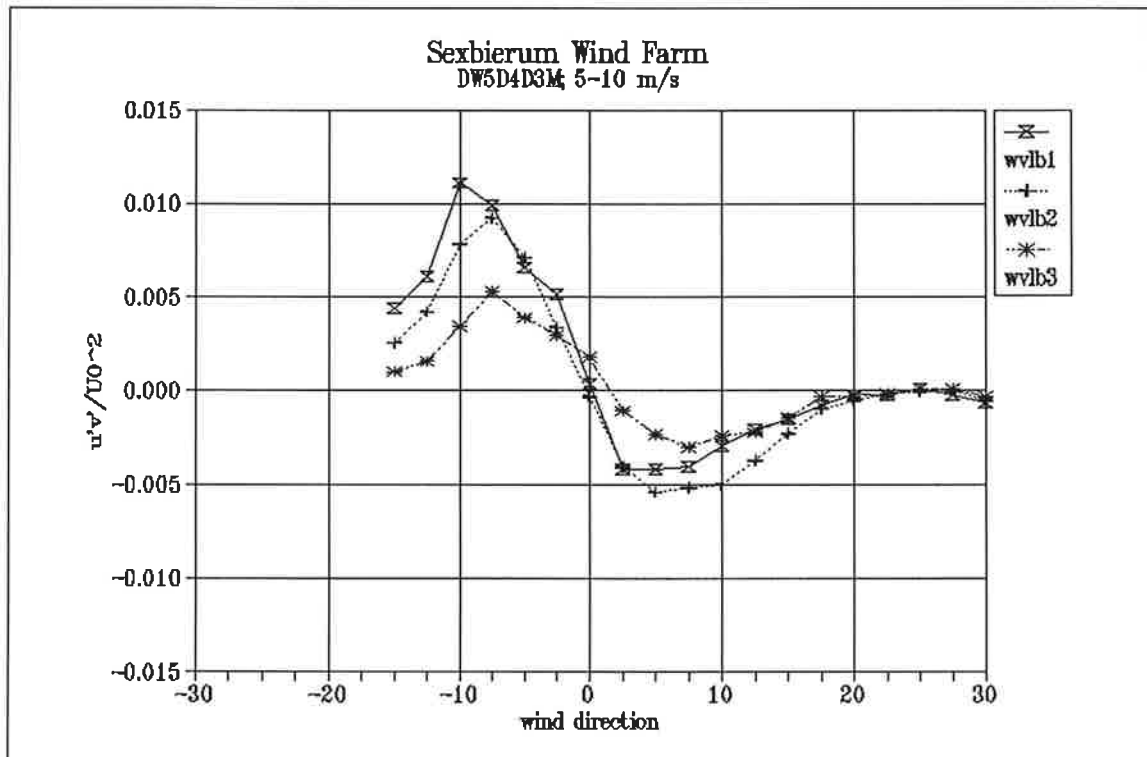


Figure 9 Non-dimensionalized shear stresses $u'v'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

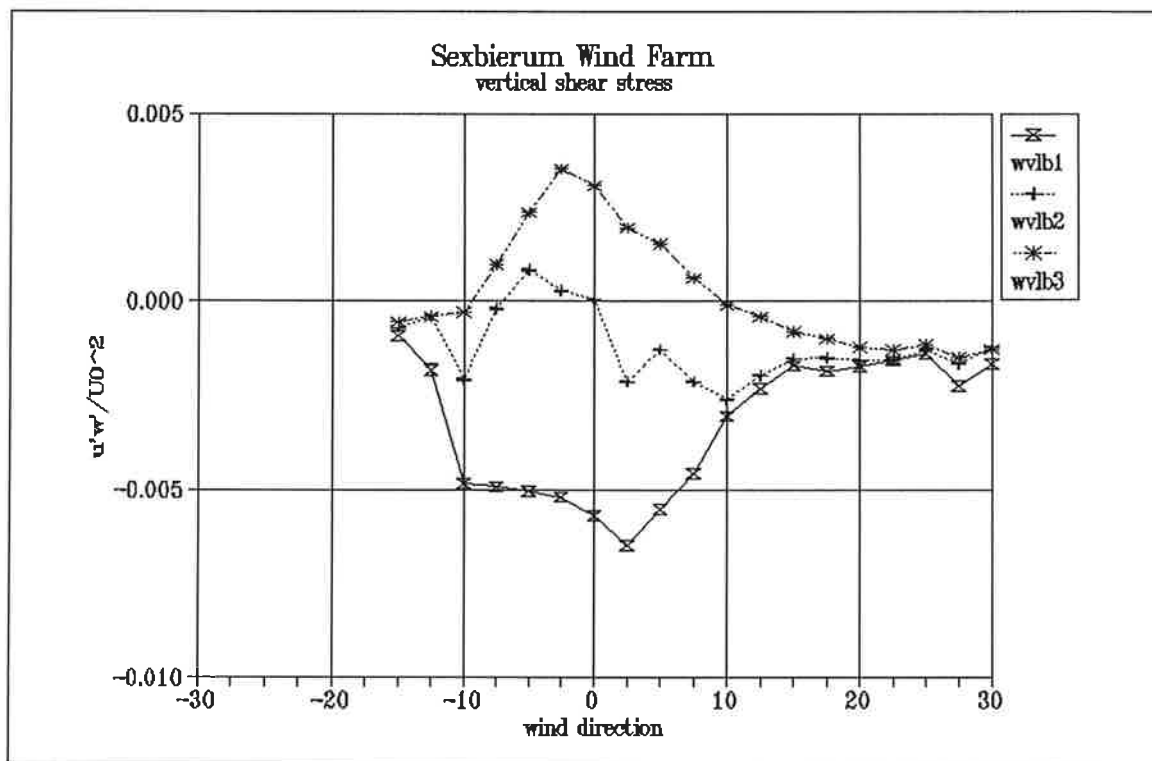


Figure 10 Non-dimensionalized shear stresses $u'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

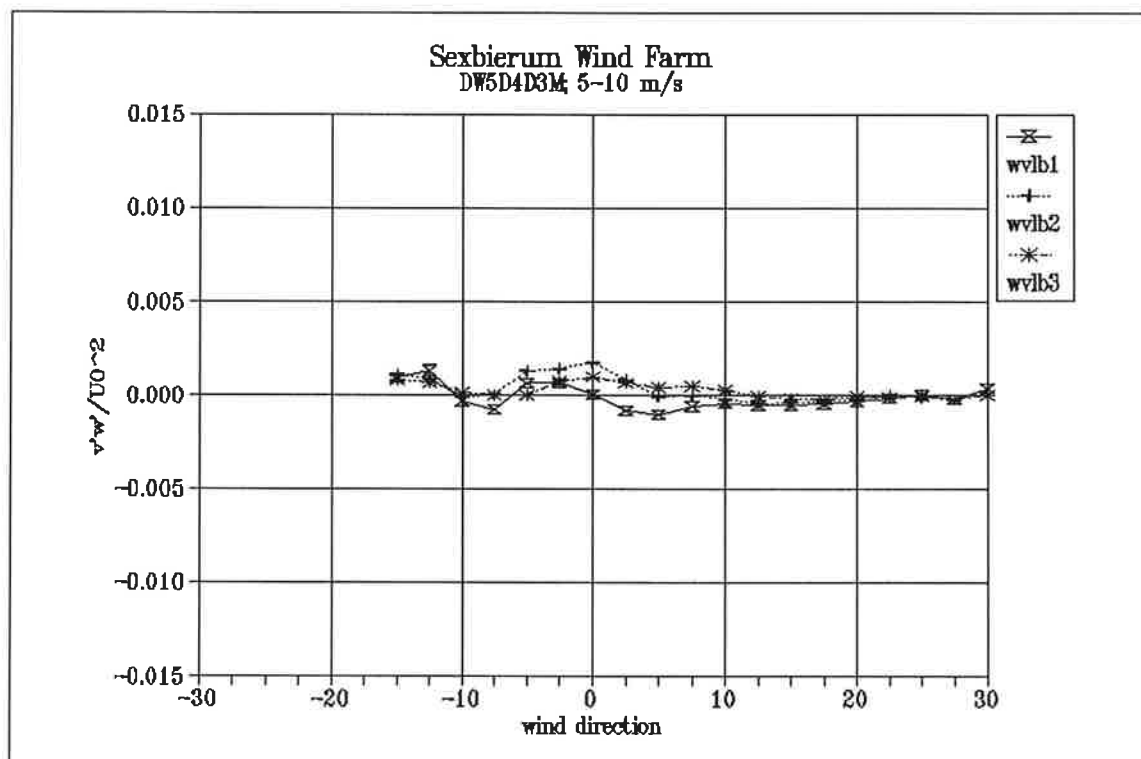


Figure 11 Non-dimensionalized shear stresses $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

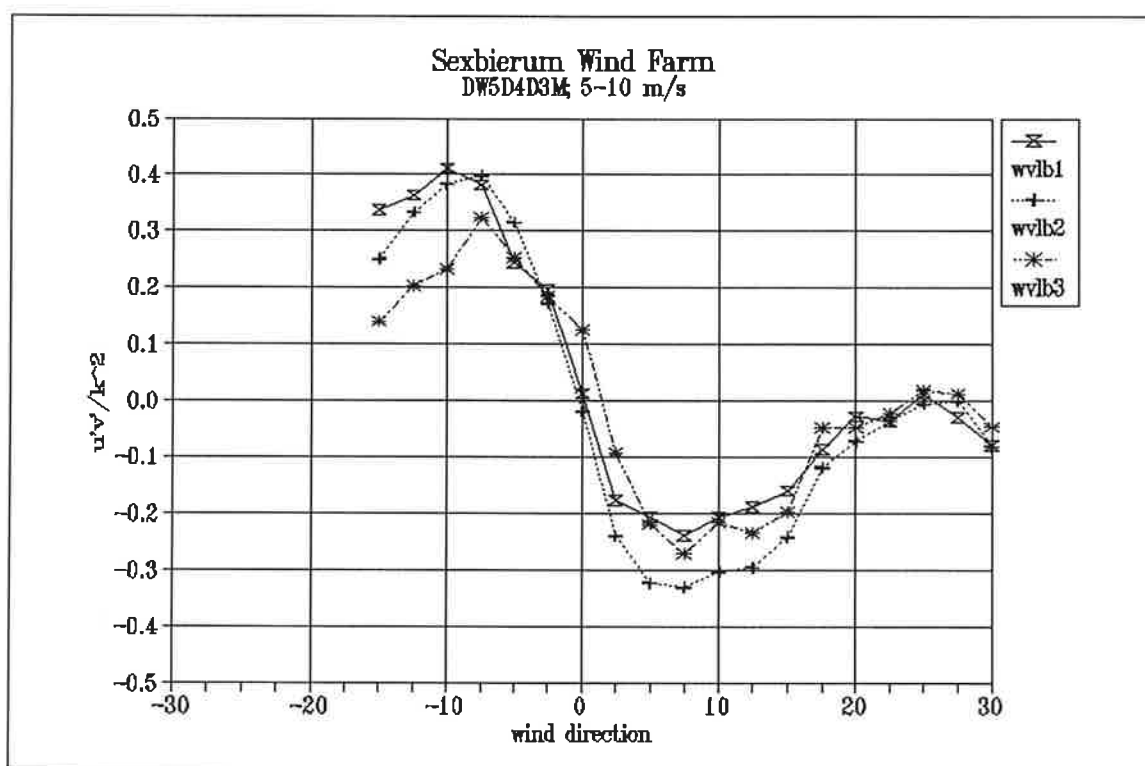


Figure 12 Non-dimensionalized shear stresses $u'v'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

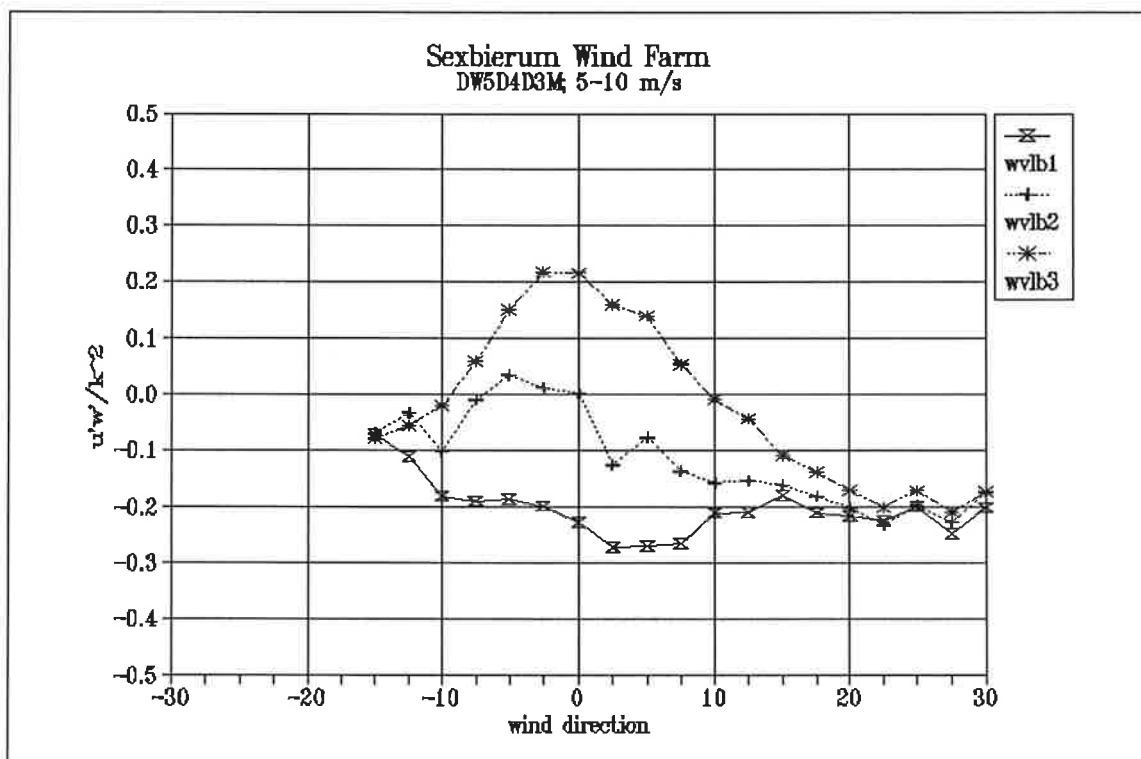


Figure 13 Non-dimensionalized shear stresses $u'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

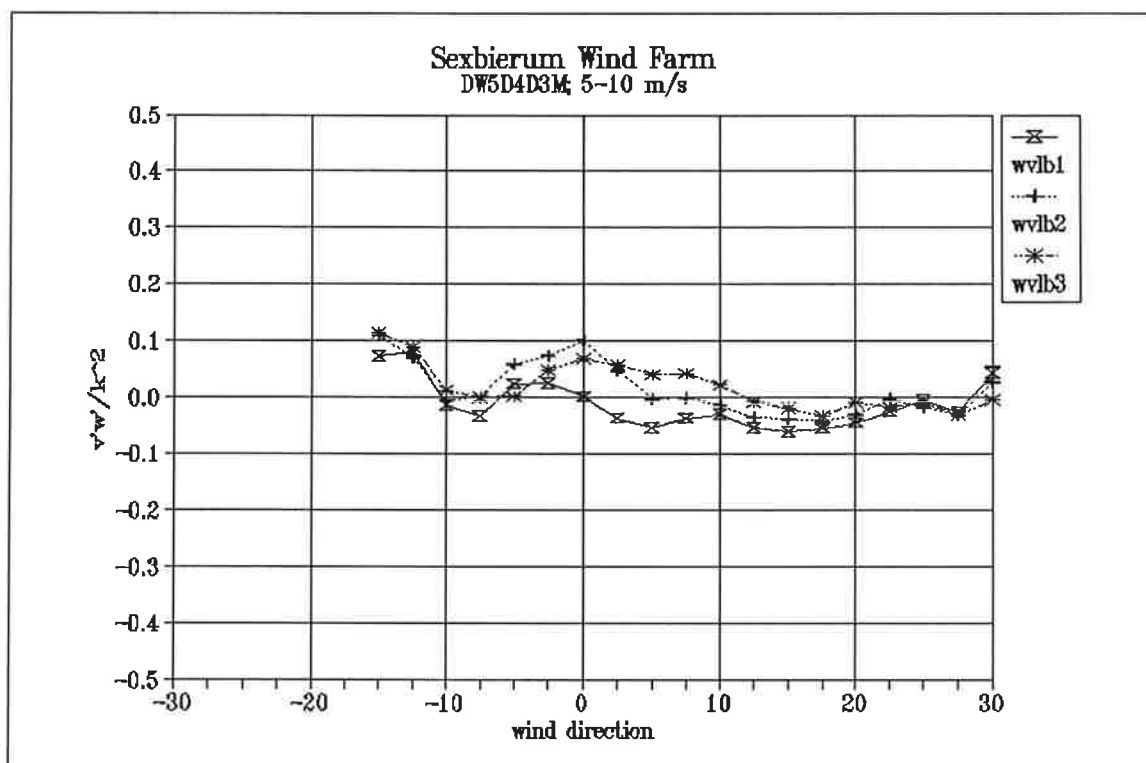


Figure 14 Non-dimensionalized shear stresses $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

Results of Sexbierum Wind Farm; double wake measurements
– Revised –

A4.9 Horizontal profiles

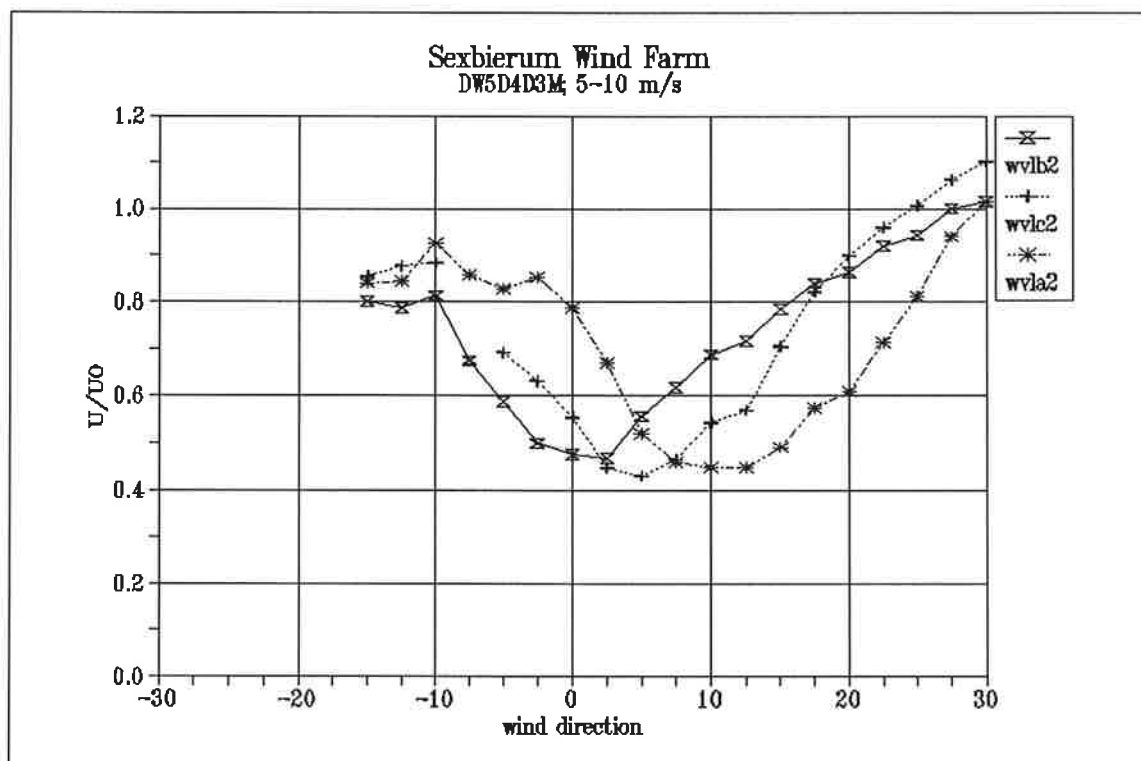


Figure 1 Wake deficit U/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

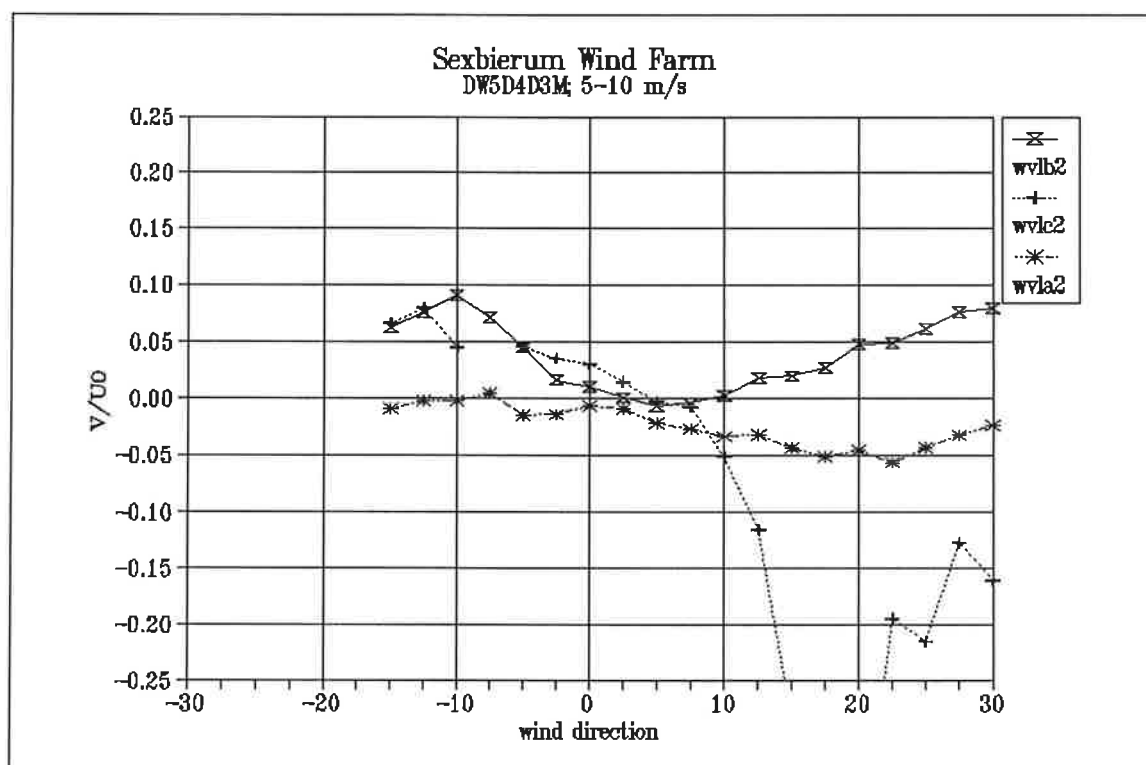


Figure 2 Lateral wind speed V/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

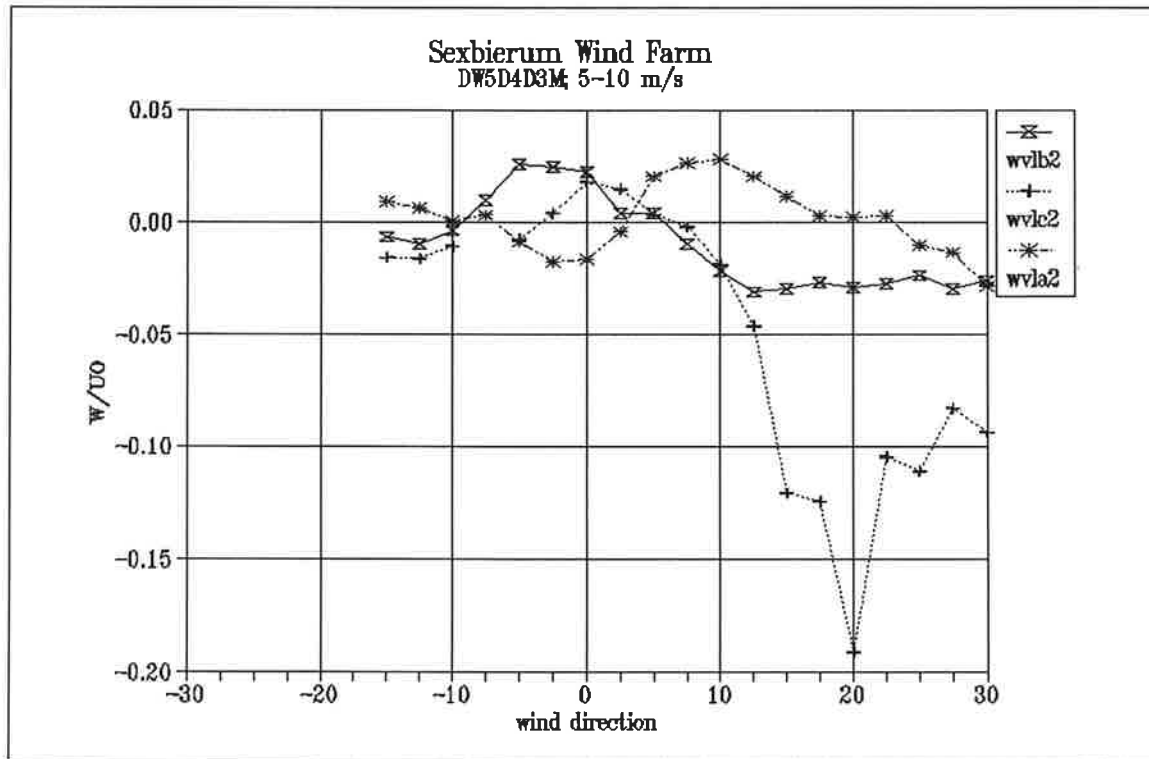


Figure 3 Vertical wind speed W/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

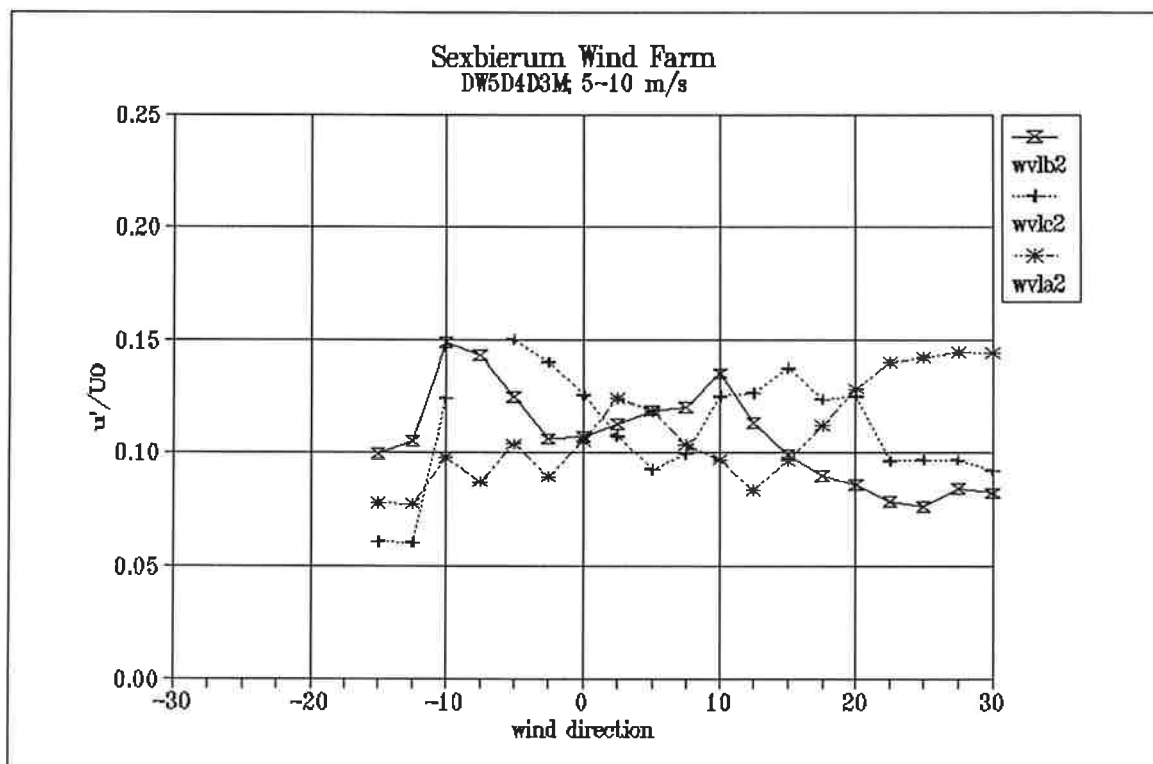


Figure 4 Non-dimensionalized longitudinal turbulent fluctuations u'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

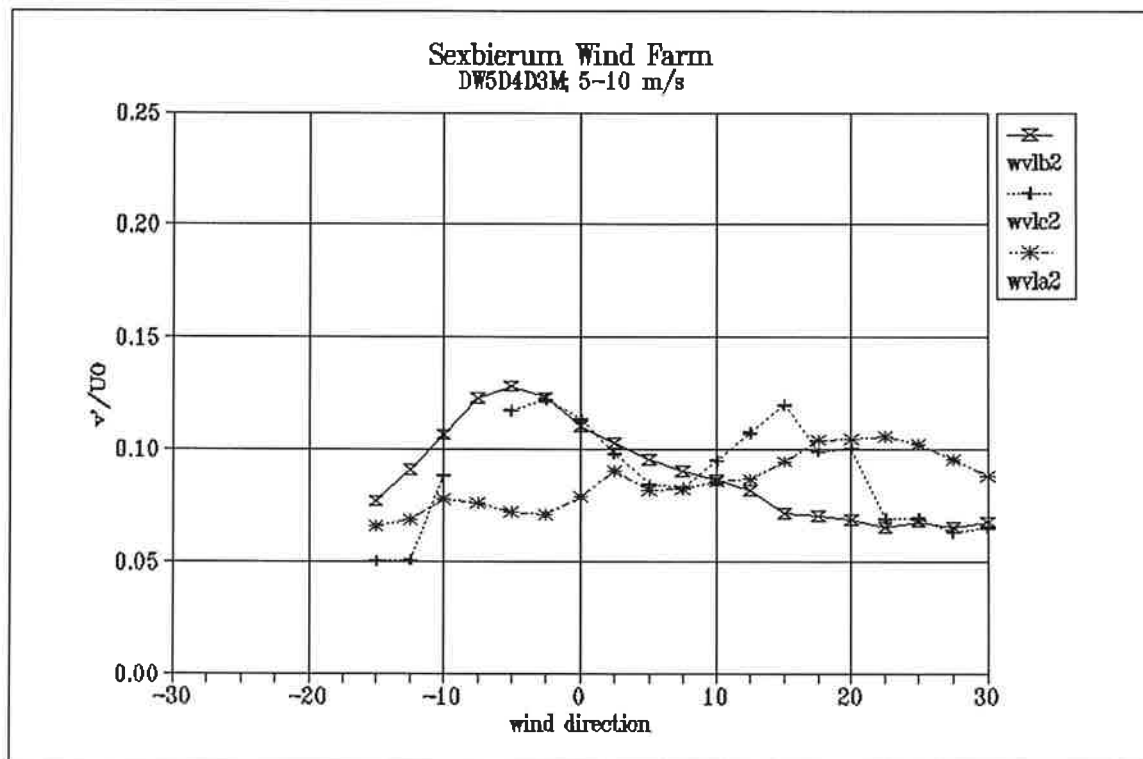


Figure 5 Non-dimensionalized lateral turbulent fluctuations v'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

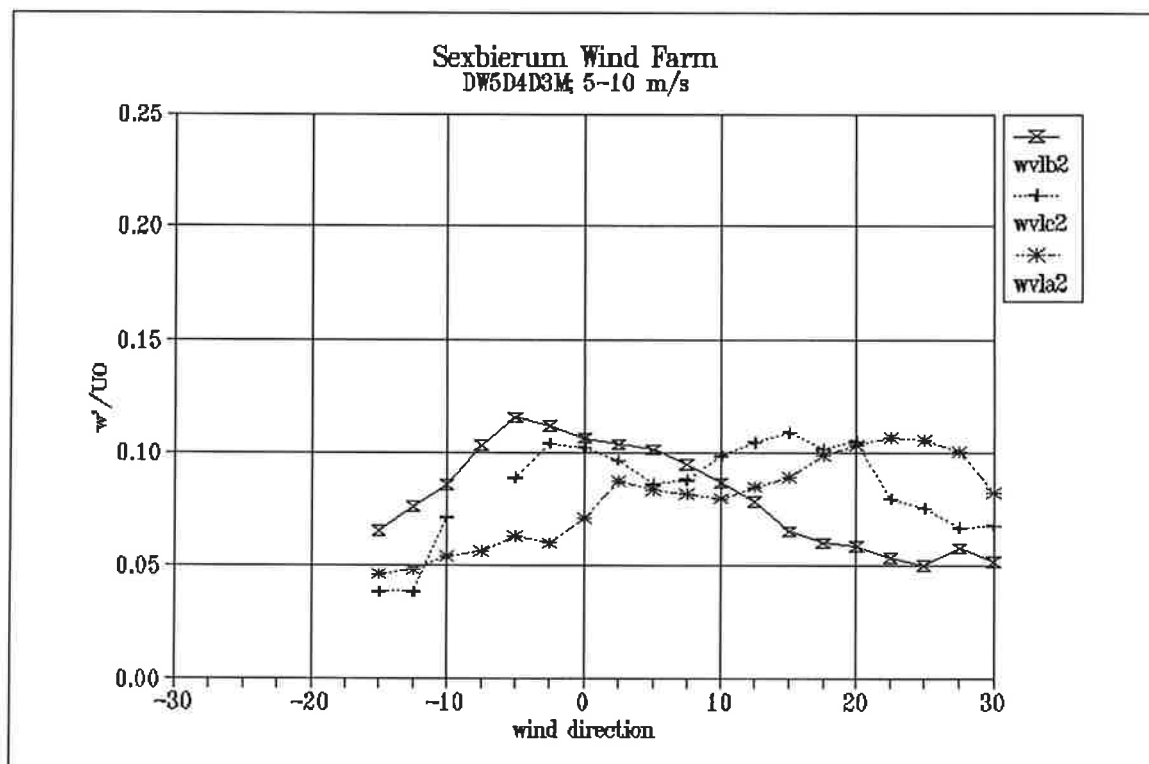


Figure 6 Non-dimensionalized vertical turbulent fluctuations w'/U_0 as a function of wind direction in the wind speed bin 5-10 m/s

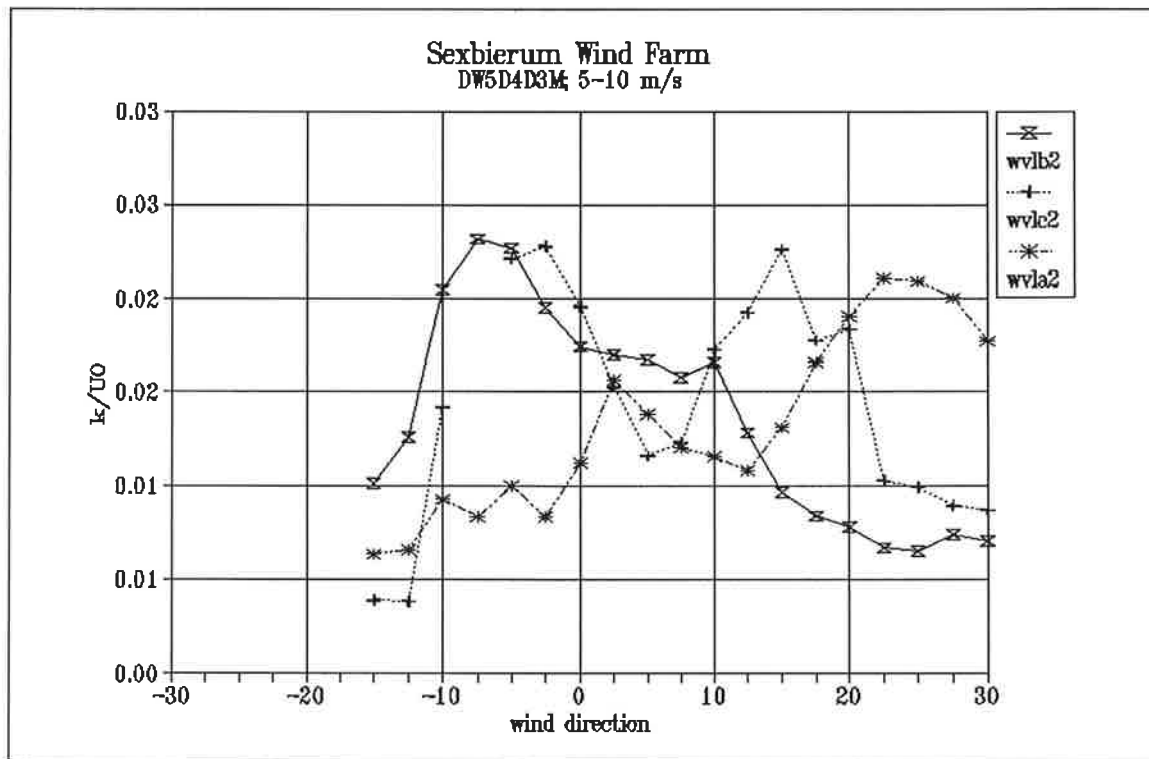


Figure 7 Non-dimensionalized turbulent kinetic energy k/U_0^2 as a function of wind direction in the wind speed bin 5-10 m/s

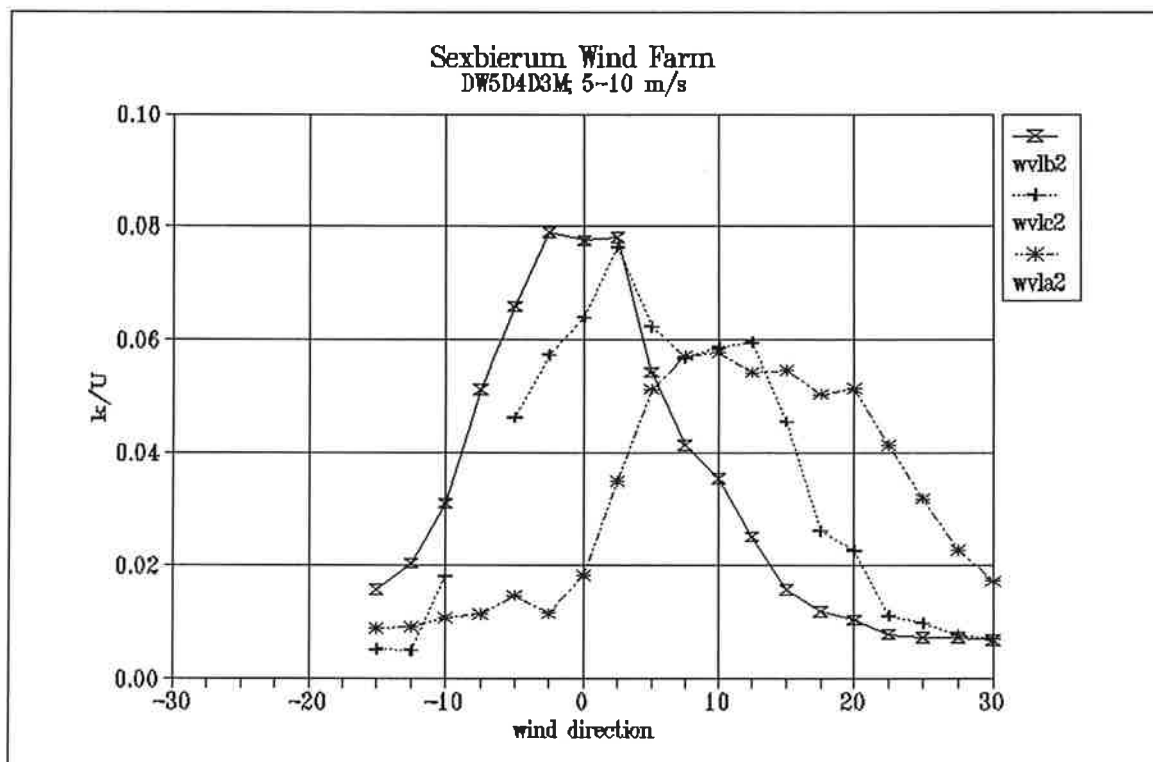


Figure 8 Non-dimensionalized turbulent kinetic energy k/U^2 as a function of wind direction in the wind speed bin 5-10 m/s

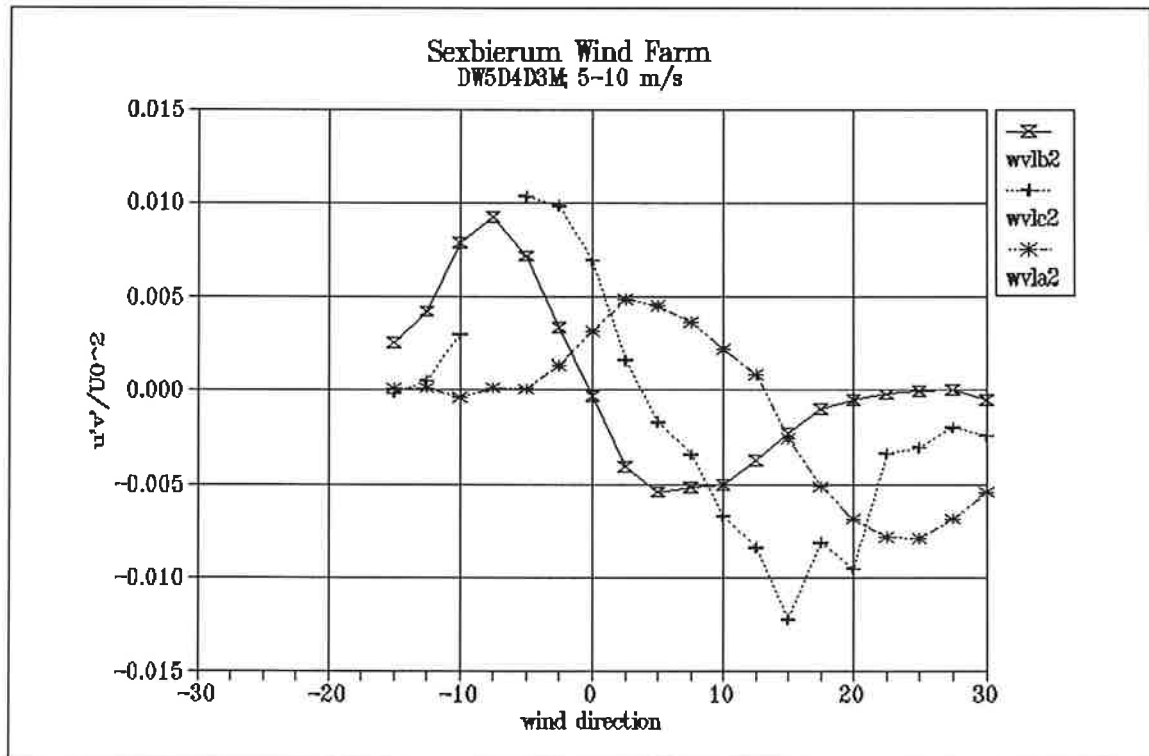


Figure 9 Non-dimensionalized shear stresses $u'v'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

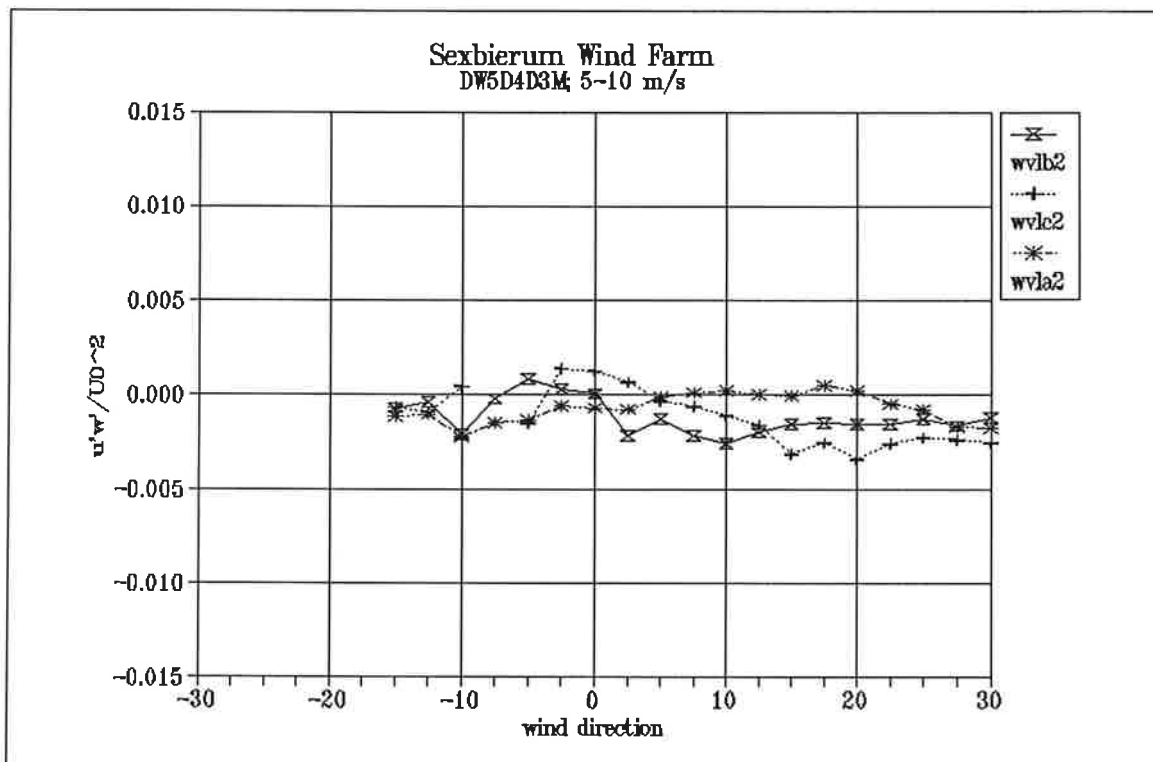


Figure 10 Non-dimensionalized shear stresses $u'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

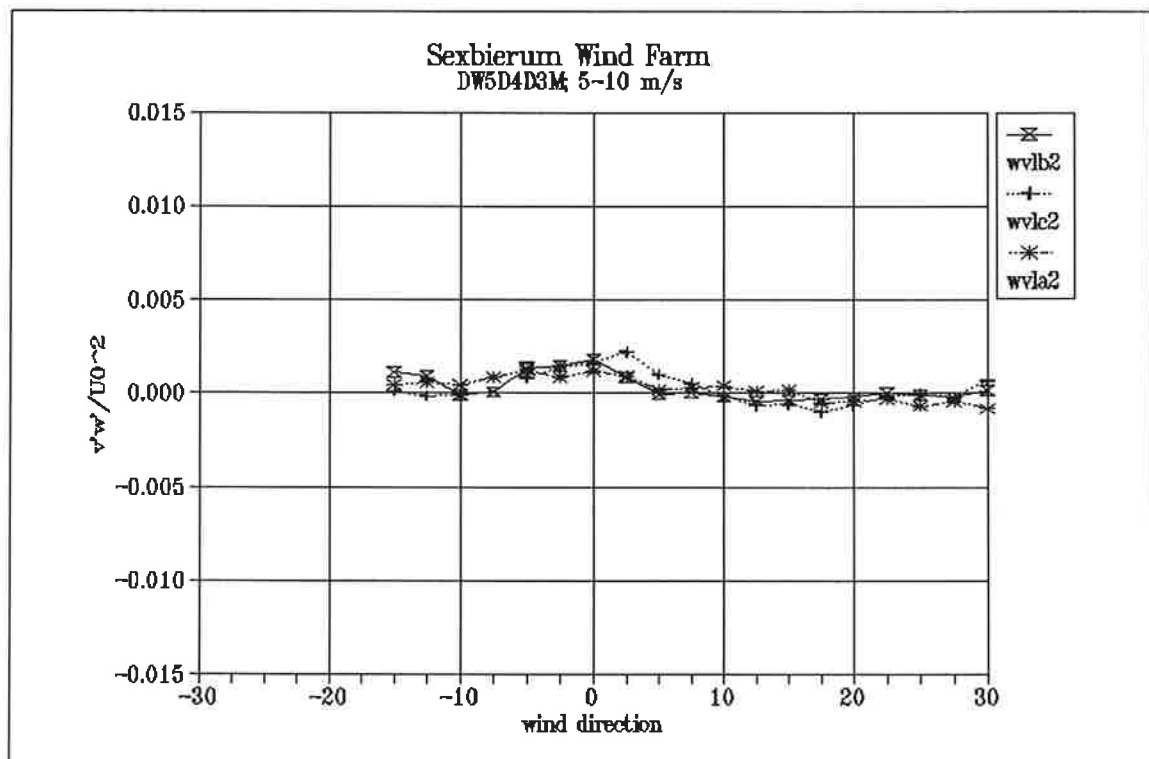


Figure 11 Non-dimensionalized shear stresses $v'w'/U_0^2$ as a function of wind direction in the wind speed bin 5-10 m/s

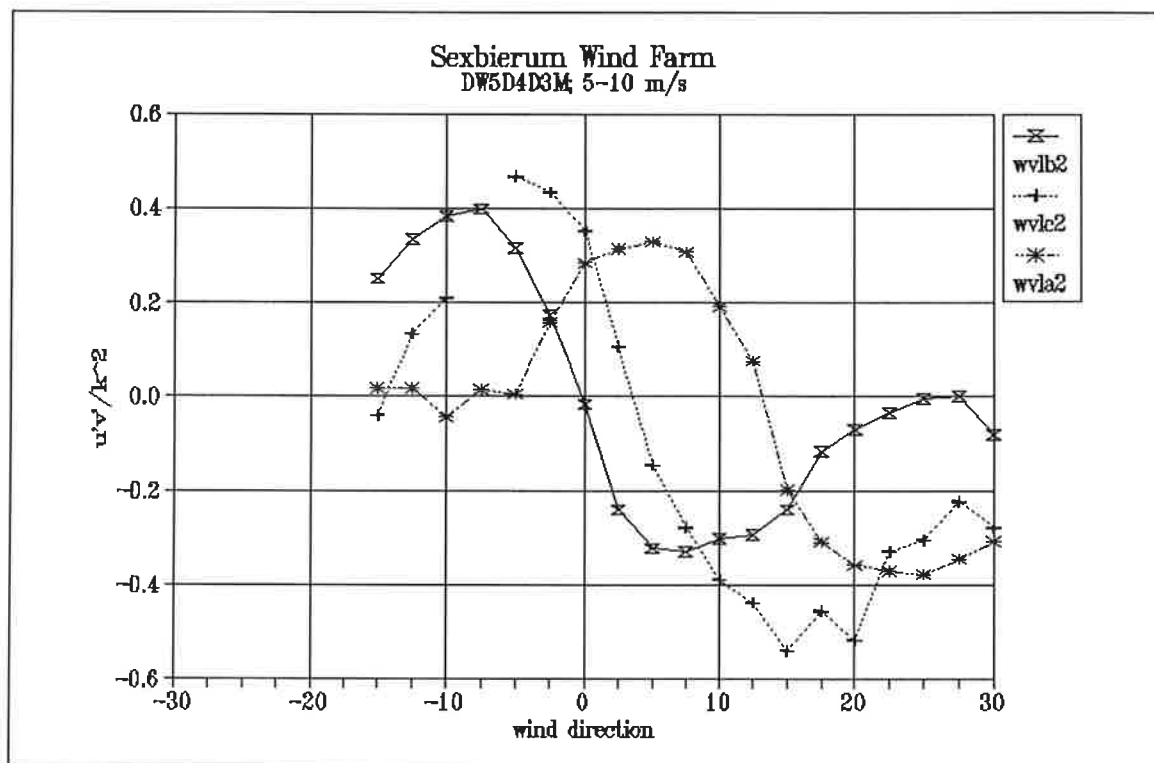


Figure 12 Non-dimensionalized shear stresses $u'v'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

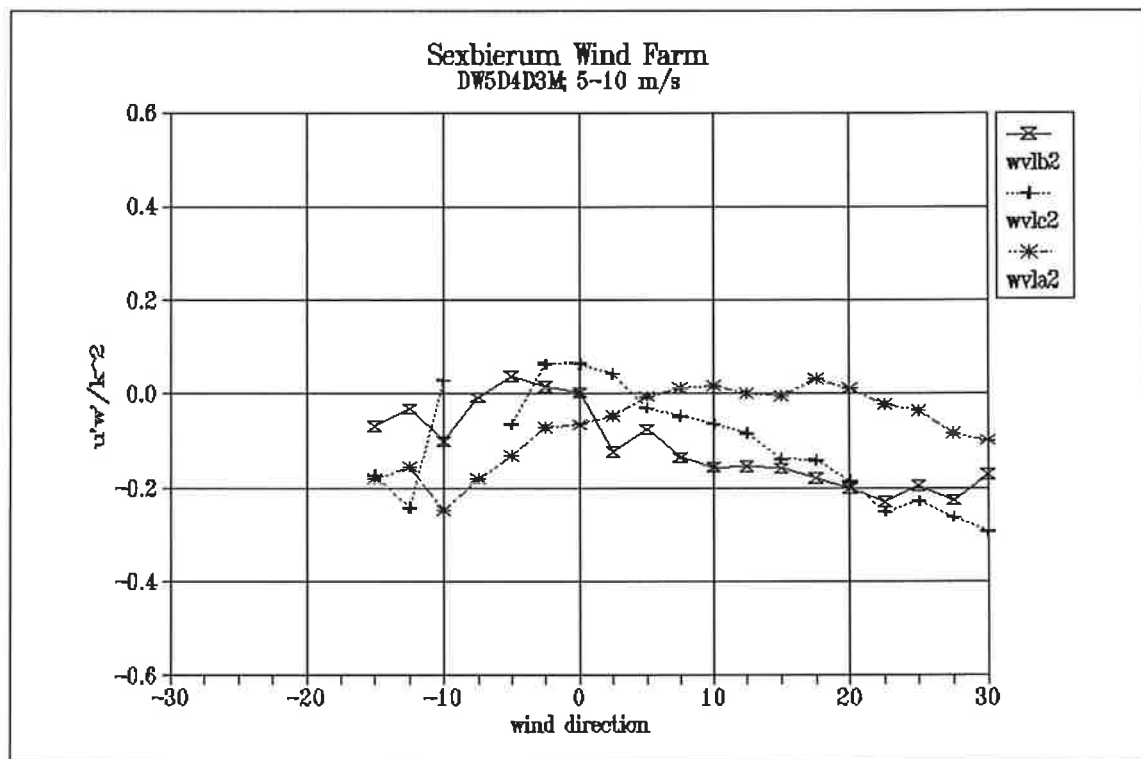


Figure 13 Non-dimensionalized shear stresses $u'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s

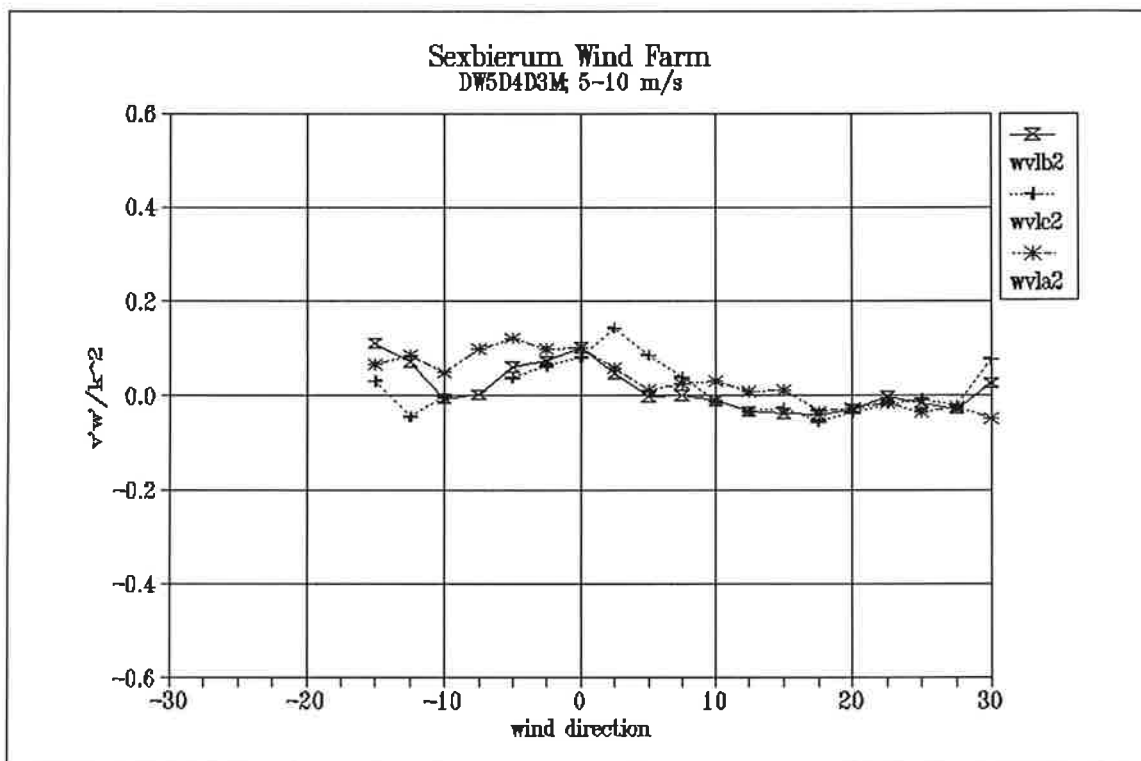


Figure 14 Non-dimensionalized shear stresses $v'w'/k$ as a function of wind direction in the wind speed bin 5-10 m/s