ON THE DIRECTIONAL UNCERTAINTY OF STRONG WIND GUSTS

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Introduction

Recently there has been an increasing requirement for estimates of extreme winds for building design to be provided by direction sector, and efforts have been made to provide such data. However, the estimates made have had to depend on wind records kept over past years. Most such records have been made with autographic instruments which, as their chart speed was slow compared to the turbulent fluctuations of wind direction, have left a direction trace consisting of a broad band. The width of this band represents an uncertainty as to the precise direction of a recorded strong gust. The magnitude of the uncertainty has been discussed briefly for a particular observing site (East Sale) in a previous paper (1). In the present paper it is proposed to consider more fully the results from East Sale, to discuss some implications of the uncertainty when the data are used for estimating long term extreme gusts, and to suggest an approach to overcoming the associated problems.

Directional Uncertainties of Maximum Gusts at East Sale

Table 1 sets out the distribution of direction trace widths corresponding to strong gusts at East Sale in each of 8 direction sectors over the thirty years 1952-81. The gusts were allocated to the sectors corresponding to the centre of the direction trace. For the most part these statistics relate to daily maximum gusts of 15 m/s and over, but for some sectors (especially north and northeast) there were some years with no such gusts, and then daily maxima over 10 m/s were included. The statistics do not include all gusts over a particular strength, and the gusts strengths that were included varied from one day to another. However, it seems likely that the sample is sufficiently large and varied to give a good representation of the direction trace widths of the stronger gusts at East Sale.

The typical (modal) width of the direction trace was found not to vary much from one direction sector to another. In all sectors it was only slightly less than the width of the direction sector itself (45°). Thus the uncertainty associated with the direction allocated to a particular maximum gust would in the great majority of cases allow the possibility that the gust should have been allocated to a neighbouring sector. Such uncertainties might in turn cast considerable doubt on the estimated long term extreme gusts for the various sectors.

Factors Affecting the Uncertainty of Gust Direction

The spread of the direction trace into a band of variable width is due to the rapid variations of wind direction associated with turbulence. In the past it has been customary to attribute the gust to the direction corresponding to the centre of the direction trace, but this may not be justifiable.

If a maximum gust of a given strength embedded in a wind from a particular direction is regarded as one member of a large ensemble of such gusts, it might be expected that the directions of the gusts in the ensemble would have a statistical distribution across the recorded direction trace. If this distribution were to have a maximum near the centre of the trace, taking the

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Table 1. Frequency (%) of direction trace widths for the stronger daily maximum gusts at East Sale in the years 1952-81. Daily maximum gusts stronger than 15 m/s are included, and, when there were no such gusts in a sector for a year, daily maxima stronger than 10 m/s. The mode for each sector was estimated graphically from the data in the table.

Width of dirn. trace (in°)	Direction Sector N	NE	E	SE	S	SW	W	NW	All
0 - 15	12.1	2.1	1.7	0.7	0.0	0.5	0.0	0.1	0.7
15 - 25	15.3	12.8	8.2	2.8	6.7	1.7	1.2	1.2	2.7
25 - 35	21.8	19.1	29.3	14.7	15.6	9.8	10.9	9.7	12.4
35 - 45	27.4	37.6	33.6	32.9	37.0	38.3	34.7	37.7	35.4
45 - 55	9.7	22.7	16.4	21.0	17.0	27.7	27.4	28.1	25.5
55 - 65	9.7	2.8	9.5	21.7	11.1	13.3	18.8	17.4	16.3
65 - 75	1.6	1.4	0.9	3.5	4.4	4.2	5.2	3.2	4.1
75 - 85	2.4	0.0	0.4	2.1	5.2	2.4	1.7	1.6	1.8
85 - 95	0.0	0.0	0.0	0.0	1.5	1.2	0.2	0.5	0.4
> 95	0.0	0.7	0.0	0.7	1.4	0.9	0.5	0.4	0.4
Mode of trace width (in°)	38	41	38	43	40	43	43	42	42
No. of cases	124	141	232	143	135	592	1981	741	4089

centre as giving the gust direction would seem an appropriate procedure for many purposes - though when using the gust observations for estimating directional extreme gusts it would still be necessary to keep in mind the finite probability that the gust was allocated to a wrong sector. In general, however, the distribution is not known. For the case of maximum gusts in strong general wind streams, the gusts would be due to downward turbulent transport of momentum from a layer where the mean wind is more nearly parallel to the isobars, so that in the southern hemisphere the distribution would probably be skewed towards the bottom (low azimuth angle) side of the direction trace. For thunderstorm gusts it is not clear what to expect, but the variations of direction over short distances found by Fujita (2) suggest that a given gust might easily correspond to any part of the recorded direction trace.

At times, of course, the wind direction swings appreciably during the course of a gust. Such a gust would need to be attributed to all directions within the ambit of the swing. However, the swing would seldom cover the full width of the direction trace, and Davenport (personal communication) has noted that the swing is small for the strong gusts which are of concern in the present context. This is not, then, likely to be an important consideration.

When observed maximum gusts are used to estimate long term extreme values, the results are in practice applied not just to the observing site but to a considerable surrounding area. This introduces uncertainties about the results in addition to those arising from the width of the direction trace. Wieringa (3) has remarked that station measured gusts are not regionally representative, and this applies to the measured direction as well as the speed. Local topography and roughness elements near the observing site are likely to influence not just the width of the direction trace, but also the distribution of strong gust directions across the trace and even the direction of the mean wind. For

maximum gusts which are embedded in a strong mean wind, then, if the gusts are to be treated as representative of an area surrouding the observing site, the directional uncertainty is likely to extend beyond the width of the direction trace. With thunderstorm gusts the situation is even worse. Examples given by Fujita (2) suggest that damaging winds associated with thunderstorm outflows "fan" out, and on occasion exhibit differences in direction over a few kilometres of 90° or more, and of 45° fairly commonly. The direction of the gust at the observing site might coincide with one edge of the "fan", so this implies extension of the gust direction uncertainty considerably beyond the width of the direction trace.

Allowing for the Uncertainty of Gust Direction

Initially the directional maximum gust data at East Sale were extracted using the centre of the trace to indicate direction. The annual maximum gusts for each sector were then used to estimate the expected extreme gusts with various return periods, using the Gumbel technique (4). The results for 20 and 1000 year return periods are shown in Fig. 1.

It may be seen that there was a somewhat erratic variation indicated from sector to sector. This was surprising in view of the topographical surroundings of the East Sale observing site - in the immediate vicinity there are the mostly low buildings of the Air Force Base, and beyond them uniform flat open country with only isolated farm buildings and trees, extending for considerable distances in all directions. Allocation of some gusts to the wrong sector seemed a likely cause of the irregularity, so that an attempt to allow for the uncertainty of gust direction by some kind of smoothing over the sectors was indicated.

A possible approach would be to allocate particular gusts to all sectors into which the direction trace overlapped. Each sector would then have all the strong gusts to which it was "entitled" though it would also have some which actually occurred in neighbouring sectors. However, the considerations of the preceding section suggest allocating gusts to an even wider range of directions. With the East Sale data, the expected extreme gusts for each direction sector were re-calculated using for each 45° sector the largest gust recorded each year in the sector itself or in either of the neighbouring sectors i.e. a system of overlapping 135° sectors was used, spaced at 45°. Some of the results are shown in Fig. 1. It may be seen that the sector-to-sector variations found were much smoother. The results may reflect too much smoothing, but at least they should be conservative.

Conclusions

The width of the direction trace produced by an anemograph gives rise to considerable uncertainty as to the appropriate direction for given large gusts, and a consequent uncertainty about the expected extreme gusts calculated for particular sectors. Further uncertainty is added when the calculated expected extreme gusts are applied to a fairly wide area around the observing site. At East Sale the directional extreme gusts calculated without allowing for the directional uncertainty showed irregular sector-to-sector variations, but when the data were smoothed by using overlapping direction sectors the irregularities were greatly reduced.

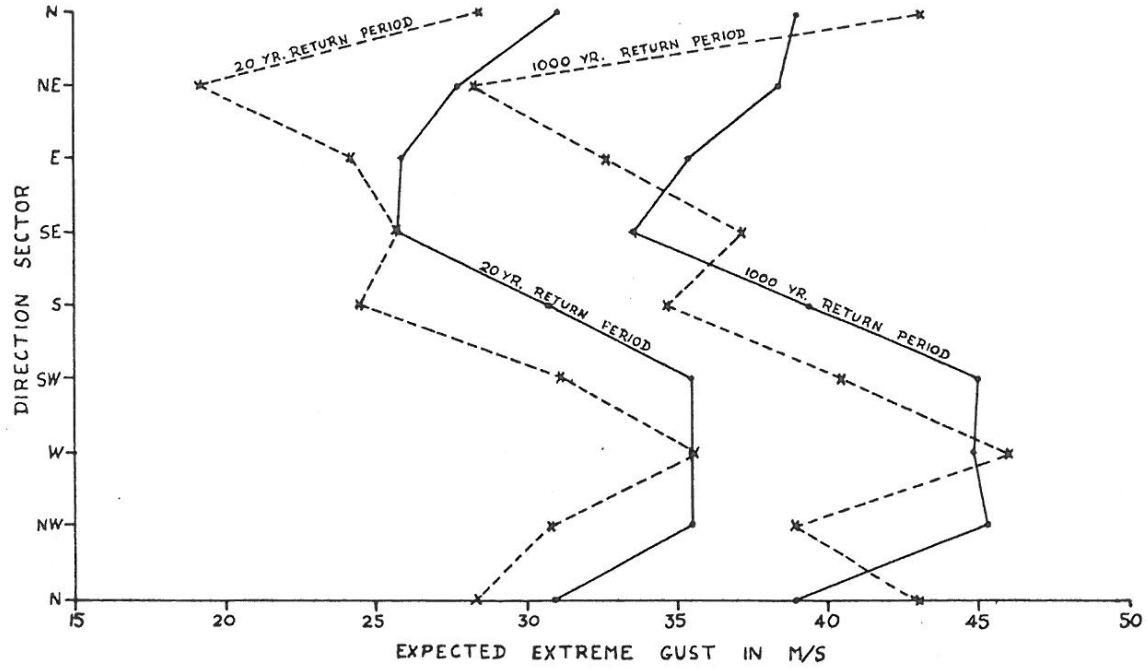
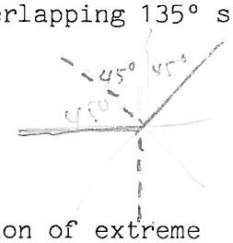


Figure 1. Variation by direction sector of expected extreme gusts for return periods of 20 years and 1000 years at East Sale. Values calculated for each sector using only the observed annual maximum gusts in the sector concerned (i.e. for which the centre of the direction trace fell within that sector) are shown -x---------x- and values calculated using the annual maxima of gusts which occurred in the sector concerned or in either of the neighbouring sectors (i.e. using overlapping 135° sectors) are shown —•————•—.



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