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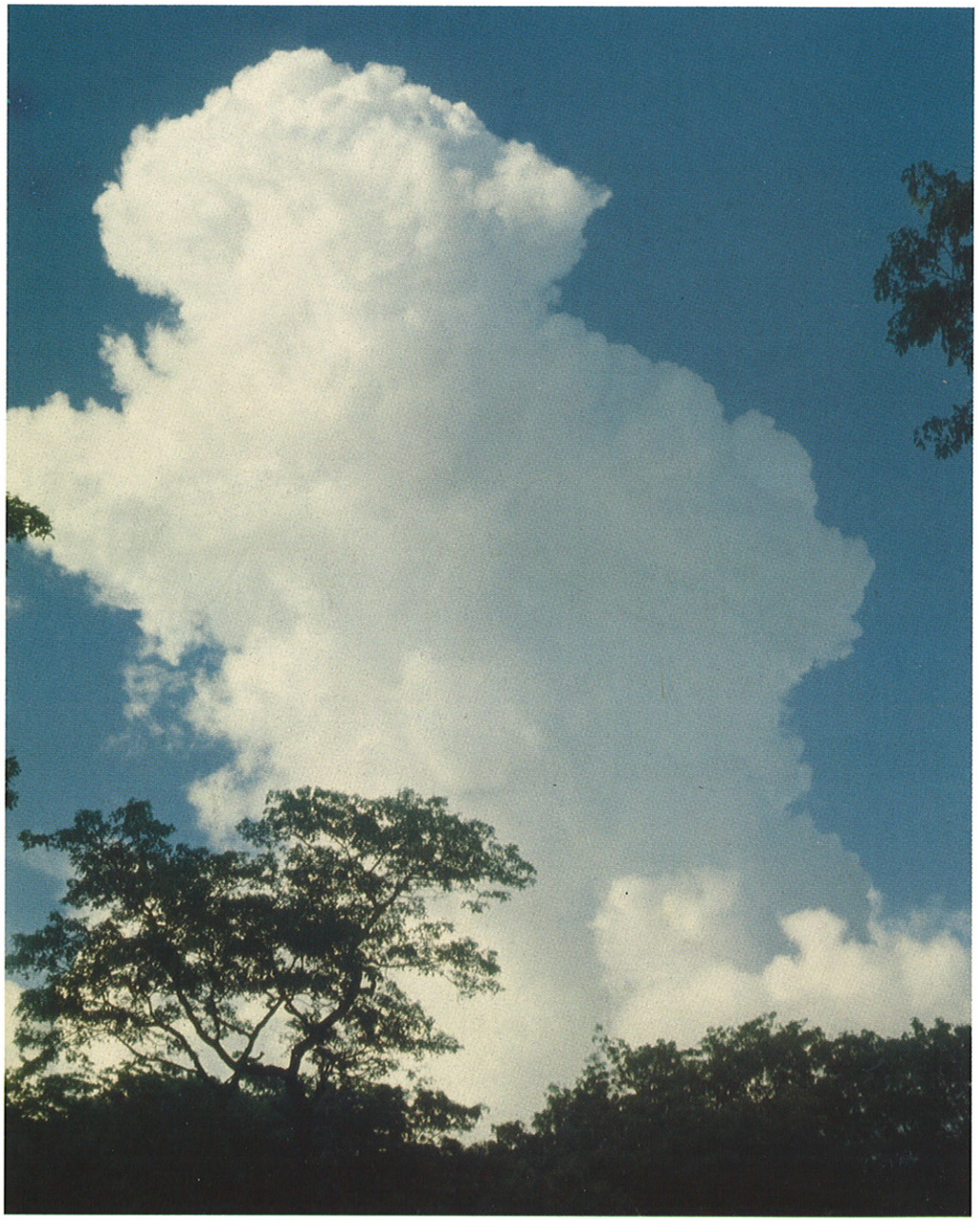

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TITLE

## EXTREME WIND ANALYSIS AT SMØLA AND HITRA

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SUMMARY

This work is made for Kjeller Vindteknikk, using the data collected from October 1998 to the end of December / the beginning of January 1999.

50 year values of mean wind speed and wind gusts are given 50 m above ground, 20 m above sea level at 3 sites at the island Smøla, and 300 m above sea level at 3 sites at Eldsfjellet, Hitra.



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# Extreme wind analysis at Smøla and Hitra

## Summary

Data from 36 years at Ona lighthouse are analysed by the Gumbel extreme value method. From this analysis the 50 year 10 min extreme wind speed is calculated to 40 m/s. The sector coefficients show a rather strong variation, from 0.50 at south-east and 0.97 at south-west, giving sectorial 50 year wind speeds from 20 to 39 m/s.

There are established coefficients from Ona lighthouse to the anemometer in the top of each of 6 project masts. From this comparison and the extreme values of Ona, the 50 - year values of wind speed of the project stations are established. The tables show the extreme values of the 10 min mean wind speed, u, and the corresponding values of the 2 sec. wind gusts at Smøla (stn. 121-123) and Hitra (stn. 124-126). The 50 - year values of the wind gusts vary from 47 to 52 m/s at the flat region (Smøla), and 53 - 55 m/s on the hilly mountain plain at Hitra. Typically, the extremes of the 10 min wind speed 50 m above ground at Smøla are slightly lower than 10 m above ground at Ona, while they are slightly higher at Eldsfjellet.

| U | U | U | U | U | U | U | Ug | Ug | Ug | Ug | Ug | Ug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ona | 121 | 122 | 123 | 124 | 125 | 126 | 121 | 122 | 123 | 124 | 125 | 126 |
| 40.1 | 40.6 | 36.5 | 36.9 | 42.4 | 40.6 | 42.2 | 52.2 | 46.5 | 48.0 | 54.6 | 52.8 | 55.3 |

# 1. Introduction

There have been carried out wind measurements at the western part of the island Smøla at northern Nordmøre and the central part of the island Hitra at the south-western Sør-Trøndelag since October 1998. The aim is to describe the wind climate at those areas and to find out the possible wind energy production. The measurements are carried out 50 m above ground. At Smøla the area is rather flat, and the wind masts are situated at small hills 20 - 40 masl. At Hitra, the stations are situated at Eldsfjellet, a rather gentle hilly mountain plain some 300 masl.

Kjeller Vindteknikk have carried out the measurements for Statkraft SF. Site and topography, sensors and sensor masts are described in the report «Description of wind monitoring program at Smøla» (1) and «Description of wind monitoring program at Eldsfjellet Hitra» (2).

The collected data clearly suggest that wind mills in this area have to deal with rather large wind loads. However, more exact knowledge of the return periods of extreme wind is essential to choose the optimal strength of the constructions.

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# 2. Data procession and data quality

The received data from Kjeller Vindteknikk include 3 stations at Smøla (1) and 3 stations at Hitra (2). The quality of the data was first inspected. The wind directions and wind speeds from the two measuring levels in each mast were cross - checked, and all speeds from all top levels were compared. The gust factors from each top level were verified. The gust factor is defined by the maximum wind gust from a 10 min period divided to the mean value of this period.

For mean winds above 15 m/s, all those controls were made. Some gust factors, $gf < 1.00$ due to errors, and such data were removed. Besides, $gf > 2.0$ suggests questionable data except at high turbulent sites. Such data were inspected and obvious errors removed. Besides, all storm values used in the extreme value statistics were carefully controlled.

## 3. Reference stations

Ona lighthouse is situated some 100 km Southwest of Smøla and 150 km Southwest of Eldsfjellet, Hitra. (Fig. 1).


**Figure 1.**
*Map of the coastal area showing Smøla, Hitra and Ona lighthouse.*

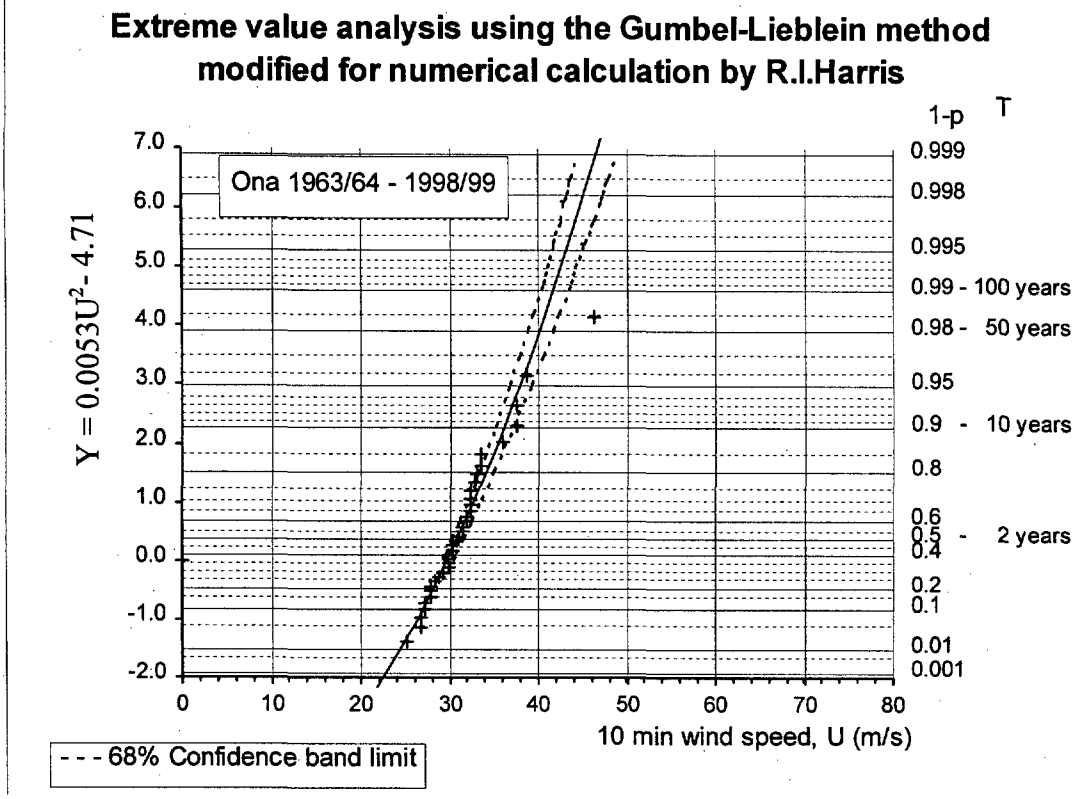
By inspecting the storm episodes during the autumn 1998, and also the storms at the weather stations in a longer data series, it is clearly that the extremes belong to the sectors SW and W. As seen on the map, Ona lighthouse is exposed to these wind directions, and so are the project areas. Since there is nothing in the local topography at the project stations, neither at Ona, which should modify the regional wind directions, and data clearly give the same impression, Ona is chosen as reference station. At Ona, a homogenous data record length from 1963/64 exist. Data stored electronically are 10 mean wind speed, and wind direction, measured at 06, 12, and 18 GMT. Also the maximum values of the 10 min wind speed since last observation are stored. Continuous registrations exist, but at paper strips.

The maximum wind speed of each of the 8 wind directions is earlier read by students and exist as a part of an extreme value data basis.

## 4. Methods and results

### *4.1 Extreme value analysis of the Ona data*

Data from 36 years at Ona lighthouse (1963/64 - 1998/99) are analysed by the Gumbel extreme wind method. The results is given in Figure 2. The analysis is made using $U^2$ as free variable. The parent data at Ona are Rayleigh - distributed (Weibul - distribution with the form parameter of 2), and then $U^2$ have a better convergence than U (3). As seen, the fit to the data is rather good, except from the data point of 46 m/s, representing the hurricane of 1.1.92. This storm value is objectively plotted as an outlier. An up to day analysis using an automatic method suggested by R. Harris (4) to determine the Gumbel parameters by the Lieblein technique is used. This method gives less weight to the highest and lowest yearly extremes.




| p | 0.5 | 0.2 | 0.1 | 0.05 | 0.04 | 0.02 | 0.01 | |
|---|---|---|---|---|---|---|---|---|
| T | 2 | 5 | 10 | 20 | 25 | 50 | 100 | years |
| U | 30.8 | 34.1 | 36.1 | 37.9 | 38.5 | 40.1 | 41.7 | m/s |

**Table 1**

*Sectorial transfer coefficients and 50 - year extreme values of 10 minute wind speed at Ona*

| | N | NE | E | SE | S | SW | W | NW | All |
|---|---|---|---|---|---|---|---|---|---|
| Tr.coeff. | 0.66 | 0.64 | 0.56 | 0.50 | 0.70 | 0.97 | 0.92 | 0.76 | 1.00 |
| 50 yr.w. | 26.5 | 25.7 | 22.5 | 20.1 | 28.1 | 38.9 | 36.9 | 30.5 | 40.1 |

### *4.2 Transfer coefficients and extreme values at the project stations*

During the autumn 1998, the episodes of strong wind in the area are inspected. The strongest 10 min wind speed, $U_{max,10}$ and the strongest wind gust, $U_{max,g}$ of each episode is noted. All episodes with $U_{max,10} \geq 19$ m/s at one of the stations were chosen, and the episodes should be separated by at least 24 hours. This gives us 10 episodes, and 9 of these are within the direction 220 - 260°, which is well included in the SW to W sector. Some of the project stations may have data from only 9 episodes due to shorter registration period or missing data. However, none of the 5 strongest episodes seems to be missing at any station.

**Table 2**

*Chronological storm data, U ($U_{max,10}$), and $U_g$ ($U_{max,g}$) at Ona and the project stations.*

| Episode | | | DD | U Ona | U 121 | U 122 | U 123 | U 124 | U 125 | U 126 | Ug 121 | Ug 122 | Ug 123 | Ug 124 | Ug 125 | Ug 126 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 10 | 16 | W-SW | 19.5 | 21.0 | 21.5 | x | 24.0 | 24.3 | 23.3 | 27.4 | 27.4 | x | 31.2 | 30.4 | 30.3 |
| 1998 | 10 | 24 | W-SW | 26.2 | 27.9 | 24 | 22.2 | 25.4 | 24.7 | 24.4 | 35.4 | 31.4 | 33.4 | 34.2 | 34.4 | 33.3 |
| 1998 | 11 | 21 | W-SW | 20.6 | 18.3 | 15.9 | 16.5 | 18.1 | 17.2 | 19.0 | 23.4 | 20.4 | 21.4 | 22.3 | 21.4 | 24.3 |
| 1998 | 12 | 2 | W-SW | 23.2 | 24.4 | 21.8 | 24 | 29.5 | 27.2 | 30.3 | 31.4 | 28.4 | 29.4 | 37.2 | 35.4 | 37.3 |
| 1998 | 12 | 13 | W-SW | 15.9 | x | 17.9 | 19.4 | 19.3 | 16 | 18.9 | x | 27.4 | 24.4 | 23.3 | 21.4 | 23.3 |
| 1998 | 12 | 15 | W-SW | 33.4 | 34.5 | 31.4 | 31.3 | 33.9 | 33.3 | 33.7 | 43.4 | 39.4 | 39.4 | 44.1 | 41.4 | 46.3 |
| 1998 | 12 | 17 | W-SW | 25.2 | 25.8 | 23 | 23.6 | 28.2 | 25.8 | 28.6 | 34.4 | 28.4 | 30.4 | 35.2 | 34.4 | 36.3 |
| 1998 | 12 | 18 | W-SW | 25.7 | 22.8 | 21.5 | 21.4 | 21.1 | 19.5 | 23.3 | 27.4 | 25.4 | 26.4 | 27.2 | 27.4 | 27.3 |
| 1998 | 12 | 20 | NW-N | 19.5 | 22.2 | 21.1 | 21.9 | 24.4 | 23.2 | 23.8 | 28.4 | 26.4 | 27.4 | 31.2 | 29.4 | 31.3 |
| 1998 | 12 | 25 | W-SW | 20.6 | 20.6 | 19.6 | 19.9 | x | 18.7 | x | 29.4 | 26.4 | 26.4 | x | 25.4 | x |

**Table 3**

*Individual sorted storm data, U ($U_{max,10}$), and $U_g$ ($U_{max,g}$) at the stations. Transfer coefficients from Ona to the project stations, and calculated extreme values at all stations.*

| Episode | U Ona | U 121 | U 122 | U 123 | U 124 | U 125 | U 126 | Ug 121 | Ug 122 | Ug 123 | Ug 124 | Ug 125 | Ug 126 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 33.4 | 34.5 | 31.4 | 31.3 | 33.9 | 33.3 | 33.7 | 43.4 | 39.4 | 39.4 | 44.1 | 41.4 | 46.3 |
| 2 | 26.2 | 27.9 | 24.0 | 24.0 | 29.5 | 27.2 | 30.3 | 35.4 | 31.4 | 33.4 | 37.2 | 35.4 | 37.3 |
| 3 | 25.7 | 25.8 | 23.0 | 23.6 | 28.2 | 25.8 | 28.6 | 34.4 | 28.4 | 30.4 | 35.2 | 34.4 | 36.3 |
| 4 | 25.2 | 24.4 | 21.8 | 22.2 | 25.4 | 24.7 | 24.4 | 31.4 | 28.4 | 29.4 | 34.2 | 34.4 | 33.3 |
| 5 | 23.2 | 22.8 | 21.5 | 21.9 | 24.4 | 24.3 | 23.8 | 29.4 | 27.4 | 27.4 | 31.2 | 30.4 | 31.3 |
| 6 | 20.6 | 22.2 | 21.5 | 21.4 | 24.0 | 23.2 | 23.3 | 28.4 | 27.4 | 26.4 | 31.2 | 29.4 | 30.3 |
| 7 | 20.6 | 21.0 | 21.1 | 19.9 | 21.1 | 19.5 | 23.3 | 27.4 | 26.4 | 26.4 | 27.2 | 27.4 | 27.3 |
| 8 | 19.5 | 20.6 | 19.6 | 19.4 | 19.3 | 18.7 | 19.0 | 27.4 | 26.4 | 24.4 | 23.3 | 25.4 | 24.3 |
| 9 | 19.5 | 18.3 | 17.9 | 16.5 | 18.1 | 17.2 | 18.9 | 23.4 | 25.4 | 21.4 | 22.3 | 21.4 | 23.3 |
| 10 | 15.9 | x | 15.9 | x | x | 16.0 | x | x | 20.4 | x | x | 21.4 | x |
| Mean of 5 upper | 26.7 | 27.1 | 24.3 | 24.6 | 28.3 | 27.1 | 28.2 | 34.8 | 31.0 | 32.0 | 36.4 | 35.2 | 36.9 |
| Ux/Um(Ona) | 1.00 | 1.01 | 0.91 | 0.92 | 1.06 | 1.01 | 1.05 | 1.30 | 1.16 | 1.20 | 1.36 | 1.32 | 1.38 |
| 10 yrs | 36.0 | 36.5 | 32.8 | 33.1 | 38.1 | 36.4 | 37.9 | 46.9 | 41.7 | 43.1 | 49.0 | 47.4 | 49.7 |
| 50 yrs | 40.1 | 40.6 | 36.5 | 36.9 | 42.4 | 40.6 | 42.2 | 52.2 | 46.5 | 48.0 | 54.6 | 52.8 | 55.3 |
| 100 yrs | 41.7 | 42.2 | 38.0 | 38.4 | 44.1 | 42.2 | 43.9 | 54.3 | 48.3 | 49.9 | 56.7 | 54.9 | 57.5 |

Table 3 show the extreme values of the 10 min mean wind speed, u, and the corresponding values of the 2 sec. wind gusts at Smøla (stn. 121-123) and Hitra (stn. 124-126). The 50 - year values of the wind gusts vary from 47 to 52 m/s at the flat region (Smøla), and 53 - 55 m/s on the hilly mountain plain at Hitra. Typically, the extremes of the 10 min wind speed 50 m above ground at Smøla are slightly lower than 10 m above ground at Ona, while they are slightly higher at Eldsfjellet.

Smøla is a rather flat area, and with no tall vegetation in the western part. So the project area there should be close to the reference terrain in the national standard (NS3479, (5)). The curve

E is recommended east of 8°, and the curve F west of 8°. The corresponding 50 year gust values 50 m above ground can be read to 54 and 60 m/s, which are somewhat higher than the results from this study (47 - 52 m/s). Now, the curves E, and F in NS3479 were given as a first attempt of mapping the high wind loads in outer coastal districts (see (6)). NS3479 will within short time be replaced by a new national standard based on the 50 year extreme values of the 10 min wind speed 10 m above a flat open country (like Smøla). The Smøla values are proposed to 30 m/s east of 8° E, and 32 m/s west of 8° E. The curve is modified with $\ln(z_2/0.05/\ln(z_1/0.05)$ for different heights above ground level, which gives us 39.1 and 41.7 m/s at 50 m height. Those values are closer to the measurements at Smøla than the old gust values. However, the values suggest that 30 m/s also could be used west to 7 °55'N.

The values at Hitra are some higher than at Smøla, the 10 min values being 41 - 42 m/s. If the terrain were flat, the opposite should occur, so there obviously is a speed - up factor of 1.1 - 1.2 at 50 m level at Eldsfjellet.

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