Representivity of wind measurements for design wind speed estimations

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Abstract

The siting of wind measurement infrastructure has implications on the development of wind speed statistics for the design of the built environment. The South African Weather Service (SAWS) wind measurement network is considered to be typical of instrumentation sited according to World Meteorological Organization (WMO) requirements. With the advent of automatic weather station technology several decades ago, wind measurements have become much more cost-effective. While previously wind measurements were mostly restricted to airports with inherent good exposure, this is no longer the case. The impact of the positioning of anemometers on the representivity of the recorded data is demonstrated, motivating additional guidelines for the placement of wind recording infrastructure.

1 Introduction

It can be argued that the adequate description of the strong wind climate forms the most important input aspect of the wind loading design chain. The wind design input can be considered in terms of the probability of occurrence of the critical wind speed and its directional prevalence, which are both site specific. Therefore, positioning and spatial distribution of wind observation stations are critical for achieving regional representivity, which impact on the levels of reliability in structural design. The current paper discusses considerations regarding the representivity of wind recording observations and their implications on the development of wind statistics for the design of the built environment, based on the SAWS wind measurement network.

2 WMO requirements

National Meteorological and Hydrological Services are guided by WMO requirements for the exposure of surface observation infrastructure. This is also the case for SAWS, which has most of its wind recording infrastructure positioned accordingly. The requirements essentially stipulate the avoidance of local obstructions approximately ten times the height of the measurements (i.e. 100m from a 10m wind mast), and the preference for flat open terrain (WMO, 1996). However, even strict adherence to these guidelines will not necessarily ensure the regional representivity of the measurements.

3 SAWS wind measurement network

3.1 Spatial distribution

In 1987, data from 14 stations formed the basis for the development of the set of design wind speed maps (Milford, 1987). When an updated assessment commenced in 2007, the number had increased to almost 200, as presented in Figure1.

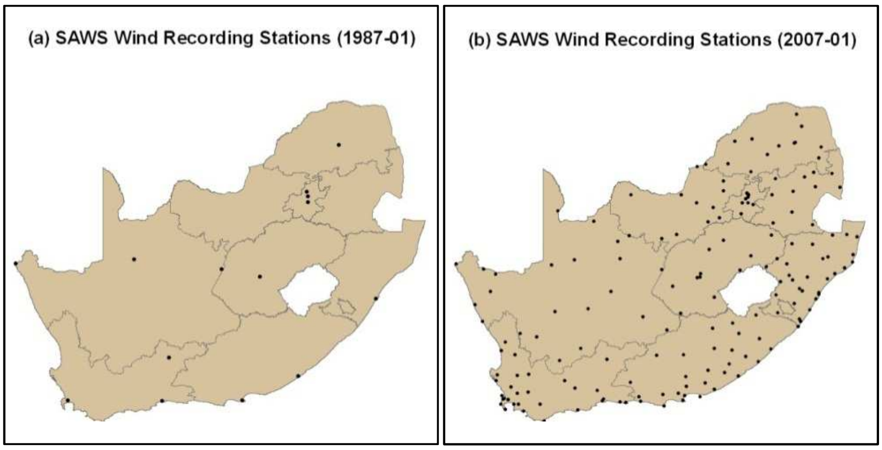

Figure 1: Spatial distribution of SAWS weather station network in a)1987 and b) 2007

3.2 *Limitations and deficiencies*

The positioning of the AWS's is often governed by 'practical' circumstances e.g. accessibility of power supply, logistics of supervision, maintenance and security against vandalism. Therefore, the positioning of weather stations is not always suitable/optimal from a strong wind climatology point of view, where the measurement forms the input for the development of design wind speed statistics, as well as the verification of extreme wind related disasters.

Despite of its non-disputed benefits in relation to all climatic observations (e.g. temperature or precipitation) the expansion programme introduced a considerable amount of deficiencies regarding the integrity of the wind climatic data concerning the scientific and engineering professions. Three generic exposure problems were identified as:

- inadequate approach terrain type (i.e. roughness),
- influences of prominent topography, and
- positioning of the wind meters within close proximity of other structures.

3.3 *Preliminary categorisation*

A joint project involving SAWS, CSIR and Stellenbosch University (Kruger, 2010) was undertaken in which the implications of the inadequacies summarised in Section 3.2 were analysed and estimated. For various reasons the information regarding only 91 weather stations was considered and collected. This included their geographical coordinates, altitude above sea level, topographical features of locations, their surroundings and the distances and geometry of close-by obstructions (if any). The information was extracted from weather station inspection files and Google Earth maps.

The data which was obtained was then scrutinised in terms of the following basic criteria: anemometer at 10 m elevation, open terrain with no built-up areas for at least 2km, no obstruction within 100m, and no prominent topography within 3km. All stations were then categorised in terms of categories:
1: adequate positioning
2: inadequate surface roughness
3: influence of nearby obstructions
4: topographical influences.

40 weather stations (i.e. 43% of the sample) were considered as acceptable. The exposure of additional 9% of the stations will likely lead to some overestimation of the wind speeds (mainly due to proximity of large water bodies or barren land) and was also accepted as adequate. Therefore, in total 52% of the stations were categorised as category 1.

39 weather stations are located close, or even within, built-up areas, while 21 of the stations are influenced by nearby prominent obstructions. In most cases these would lead to the underestimation of wind speeds. In several cases, weather stations are located or surrounded by significant topographical features which could either lead to underestimation or overestimation of the recorded wind speeds.

3.4 Correction factors

An initial assessment of the situation indicated that for several of the weather stations it is not feasible to determine and calculate the magnitude of localised influences and to introduce any adjustments to the measured data. This refers mainly to situations in which large obstacles are present within close vicinity of the wind anemometers or anemometers are located close to or on top of prominent topographical features. This data was thus deemed not usable for extreme value estimates of wind speeds.

For about 80% of the weather stations the possible deviations were predominantly caused by inappropriate surface roughness and attempts were, therefore, made to correct for these based on initial approximations. A process was undertaken in which for each station and range of wind azimuths under consideration, the relevant surface roughness was estimated visually on the basis of aerial information (Barthelmie et al 1993), using the principles of terrain roughness descriptors proposed by Davenport (1960) and updated by Wieringa et al (2001). Davenport et al (2000) noted that when such a judgement is supported by a clearly worded classification, the error of this procedure will not be more than a single roughness width and Wieringa (1992) referred to potential errors in estimation of less than 6%. A typical Google Earth image of the surroundings of Grahamstown weather station is presented in Figure 2.

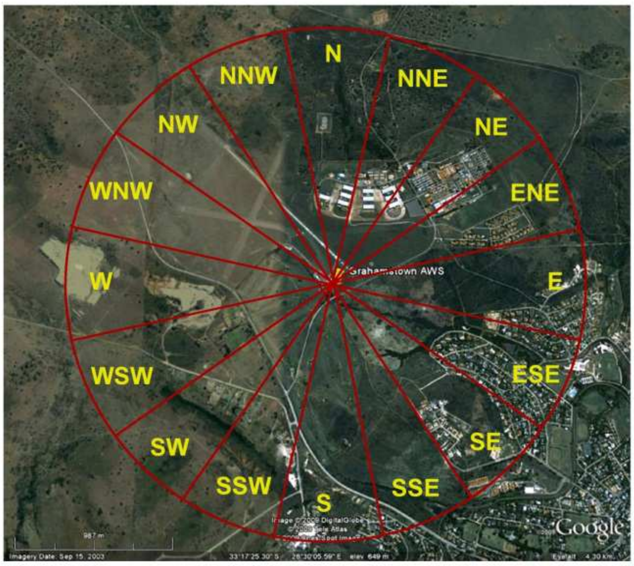

Figure 2: Aerial image of weather station in Grahamstown with 16 sectors superimposed

The magnitude of the correction factors differed substantially between values marginally smaller than unity, corresponding to influences of the open sea terrain, to values substantially larger than unity, due to the influences of built-up areas. The effects of the application of correction factors to the wind speed data were substantial, with increases of around 20% in the subsequent estimated design wind speed values.

From Wieringa (1986), and applied by Wever and Groen (2009) and others, when the local roughness length is known, the Exposure Correction Factor (ECF) due to improper terrain category could be calculated. These correction factors were then applied to the measured wind speeds, except for gust values where the directives from ISO 4354: 2009 were followed. In the case where the gusts were from synoptic origin, the corrections were applied according to Table 1.

Table 1. Correction factors for the 3 s wind gusts deduced from ISO 4354: 2009, at a height of 10 m for the different terrain categories.

Terrain roughness category	**Roughness length (m)**	**Correction factor**
I. Open sea/flat surface	z_0 = 0,003	0,90
II. Open country	z_0 = 0,03	1,00
III. Suburban	z_0 = 0,3	1,19

As an example, Figure 3 compares two hourly wind speed distributions for Grahamstown. Sixteen annual maximum hourly values were used in this comparison. The *ECF* was applied to three measurements; for those winds forthcoming from directions where the terrain was not regarded as open and flat. Even with only this small number of corrections the estimated 1:50 year wind speed increased from 17.1 m/s to 18.1 m/s after application of the *ECF* to the relevant wind speeds.

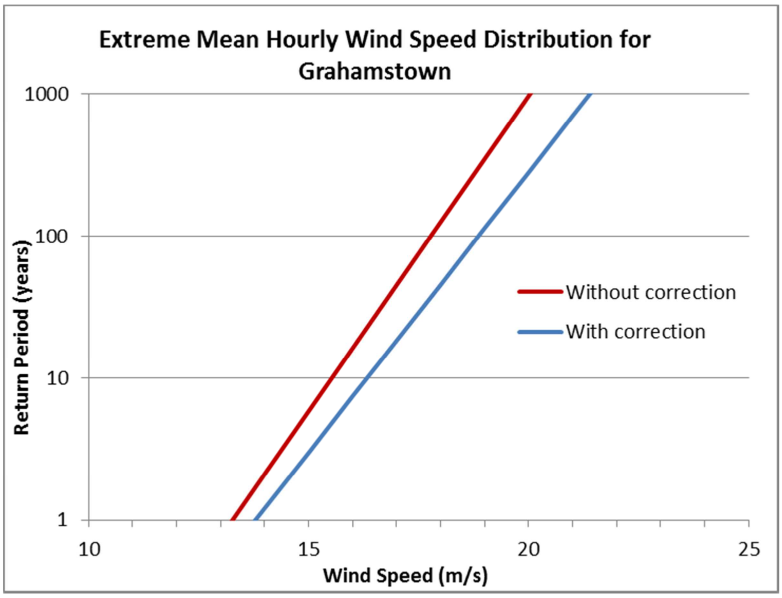

Figure 3. Hourly wind speed distribution for Grahamstown before and after application of the *ECF*.

4 Conclusions and recommendations

This paper summarises an investigation into the importance of the exposure of wind speed anemometers, based on the current network of South African Weather Service anemometers. The exposure of a large number of stations leads to distortions of the recorded wind speed data. The process of developing the correction factors, which was carried out, enabled to generate the initial estimates offering more realistic output data than that which ignores the effects of inappropriate terrain roughness. These results could be refined further by using one of the comprehensive methodologies incorporated in WAsP or ESDU 01008.

On the other hand, the application of correction factors cannot be considered to be a substitute for the sub-optimal placement of anemometers. In light of the above it was recommended that additional specific exposure requirements for wind measurement equipment be developed in the South African Weather Service. These specifically took into account the proximity of complicated topographical features and extensive areas with surface roughness higher than 0.05m.

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