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THE SIMILARITY PRINCIPLE – ON USING MODELS CORRECTLY

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SUMMARY
This paper will present some guiding principles on the most accurate use of the WAsP program in particular, but the principle can be applied to the use of any linear model which predicts some quantity at one location based on another. We have felt a need to lay out these principles out explicitly, due to the many, many users and the uses (and misuses) of the WAsP program. Put simply, the *similarity principle* states that one should chose a predictor site which – in as many ways as possible – is similar to the predicted site.
Keywords: wind modeling, errors, WAsP, wind atlas methodology, similarity principle

INTRODUCTION

This paper will develop a general modeling principle: the similarity principle and apply it to wind resource estimation and siting of wind turbines. The aim of the paper is to avoid that models – like Risø's WAsP [1] – are being misused only because the basic ideas and concepts are violated and/or misunderstood. Misusing models may have significant consequences for the economy of a wind power project, and hence improving the understanding of the general use of models will contribute to the profitability of the wind energy industry as a whole.

The similarity principle says – in short – that if one wants to model the wind climate at a location using data from another location, then – in order to minimise the errors – the two locations should be as similar in as many respects as possible. In wind energy terms these respects are e.g. overall regional wind climate (on the meso- and synoptic-scale), general forcing effects (as e.g. sea/land breezes), atmospheric stability, and also topographical setting such as complexity of the terrain, elevation, exposure, roughness and distance to significant roughness changes.

When applying the similarity principle the idea is to select pairs of sites – i.e. a met. station as the predictor site and a turbine site as the predicted site – that fulfill as many of the aspects on this long list of requirements. Furthermore, the lack of similarity is an indicator of the likely error that will be made. The paper will describe the principle and give examples of its use in the context of the wind atlas methodology as implemented in WAsP.

THEORETICAL CONSIDERATIONS

The underlying assumption behind the similarity principle is that no matter how advanced a model is, it will always produce errors. Further, if the model is linear in some sense, it can be expected that the error also will behave linearly, i.e. a large forcing of some kind (in a WAsP context think of a steep hill), will result in larger errors, as compared to a smaller forcing.

Furthermore, the errors of a model which is applied at one location and then reapplied in another will have a tendency to cancel out. In pseudo-mathematical formulation the wind speed at a site, u_s, as modeled by WAsP can be written

$$u_s = u_o \frac{\sum_i (1 + f_i^d + e_i^d)}{\sum_i (1 + f_i^u + e_i^u)}, \quad i \in \{oro, rou, obs\}$$

where u_o is the observed wind speed, superscript d refers the application (down) part of the wind atlas method (see [2] for details), superscript u the analysis (up) part. The application and analysis parts are procedures by which the terrain around the predicted and the predictor site, respectively, are taken into account.

As can be seen from the equation, if a self-prediction (i.e. using the same site as the predictor and the predicted site) is carried out, it can be seen that the two errors e_i^d and e_i^u are identical, and as a result they will cancel out, leaving a near-perfect self-prediction. Taking this reasoning a bit further and assuming a linear response in the error (due to the linearity of the model), one can see that small differences in forcing will also lead to small errors, and hence the similarity principle follows.

WIND ATLAS METHODOLOGY

The wind atlas methodology, which consists of a comprehensive set of models for the horizontal and vertical extrapolation of meteorological data and the estimation of wind resources – was developed for the analysis presented in the European Wind Atlas [2]. The actual implementation of the models is now known as the Wind Atlas Analysis and Application Program – or WAsP for short [3].

The models are based on the physical principles of flows in the atmospheric boundary layer and they take into account the effect of different terrain surface conditions, sheltering effects due to buildings and other obstacles, and the modification of the wind imposed by the specific variations of the height of ground around the meteorological station in question. Figure 1 illustrates the use of these models on measured wind data to calculate a regional wind climatology.

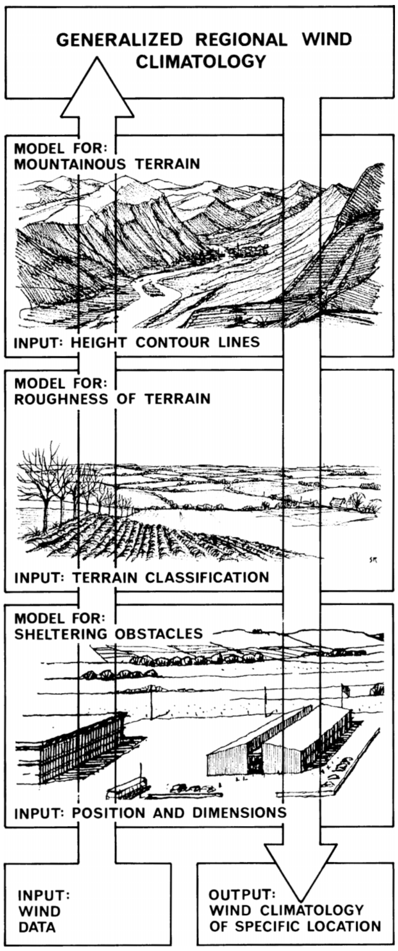

Figure 1. The wind atlas methodology of WAsP. Meteorological models are used to calculate the regional wind climate from the observed wind climate (raw data); this is referred to as the analysis part. In the reverse process – the application of wind atlas data – the predicted wind climate at any specific site and height may be calculated from the regional climatology [2].

The figure also illustrates the so-called application part of the methodology, following a procedure in which the regional wind climate is used as input to the same models to produce site-specific wind climatologies and, given the power curve of a wind turbine, power production estimates. For more detailed information on the wind atlas models and the WAsP-program, the reader is referred to the European Wind Atlas [2] and the WAsP User's Guide [3], respectively.

PRACTICAL GUIDELINES

In this section we will list some of the more typical conditions, but the list is far from being exhaustive – in each case the user must try to determine which conditions are the important ones.

Regional wind climate	• Similar regional wind climates (the number one criteria when using WAsP!) • General atmospheric forcing effects • Atmospheric stability
Orography	• Difference in RIX less than 10 (the number one criteria in complex terrain) • Similar slopes, exposure and orientation of main topographical features • Similar site elevation above sea level
Roughness	• Similar background roughness • Equal orientation and distance of major roughness changes (e.g. coast-lines)
Obstacles	• Same degree of "three-dimensionality" • Orientation
Other site characteristics	• Similar height above ground level of predictor (anemometer) and predicted site (wind turbine hub)

RIX is the so-called ruggedness index, which was proposed [4] as a coarse measure of flow separation. The ruggedness index has further been used to develop an orographic performance indicator, ΔRIX, which can predict the sign and approximate magnitude of the prediction error when applying linear flow models like WAsP in complex terrain [4, 5].

Note, that the horizontal distance between the predictor and the predicted sites does not appear on the list above; one should much rather use similarity in regional wind climate.

SUMMARY

This paper has given a brief outline of the similarity principle, both from a (pseudo-) theoretical and a practical angle. More research is needed to quantify and exemplify the effect of the principle, but it has great practical use as a guiding principle.

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