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The wind energy potential of Iceland

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ABSTRACT

Downscaling simulations performed with the Weather Research and Forecasting (WRF) model were used to determine the large-scale wind energy potential of Iceland. Local wind speed distributions are represented by Weibull statistics. The shape parameter across Iceland varies between 1.2 and 3.6, with the lowest values indicative of near-exponential distributions at sheltered locations, and the highest values indicative of normal distributions at exposed locations in winter. Compared with summer, average power density in winter is increased throughout Iceland by a factor of 2.0–5.5. In any season, there are also considerable spatial differences in average wind power density. Relative to the average value within 10 km of the coast, power density across Iceland varies between 50 and 250%, excluding glaciers, or between 300 and 1500 W m^{-2} at 50 m above ground level in winter. At intermediate elevations of 500–1000 m above mean sea level, power density is independent of the distance to the coast. In addition to seasonal and spatial variability, differences in average wind speed and power density also exist for different wind directions. Along the coast in winter, power density of onshore winds is higher by 100–700 W m^{-2} than that of offshore winds. Based on these results, 14 test sites were selected for more detailed analyses using the Wind Atlas Analysis and Application Program (WAsP).

1. Introduction

In Iceland, more than 80% of the primary energy supply derives from geothermal and hydropower. Almost all electricity produced in Iceland derives from renewable sources, with 73% from hydropower plants, and 27% from geothermal plants [1]. One aspect of hydropower in Iceland is that the streamflow in rivers tends to exhibit a large annual variation, with larger flow during summer than in winter. Since the annual cycle of wind in Iceland has the opposite phase, with stronger winds in winter than in summer, wind power can potentially be used effectively in combination with hydropower.

In coming decades it is expected that glacier melt will increase the hydropower potential in Iceland [2], with the increase in runoff peaking in the latter half of this century [3]. Analysis of likely changes in wind climate [4,5] does not reveal such large scale changes for the wind, and thus wind energy production may in the longer term prove to be more sustainable.

The use of wind power for electricity generation in Iceland has hitherto been limited to small wind turbines for off-grid use, and until recently there were no large wind turbines in operation in Iceland. Despite Iceland having a favourable climate for wind power [6], detailed research into the wind power potential in Iceland is quite recent.

The goal of this study therefore is to develop a wind atlas for Iceland, to provide the first overview across the entire island of the statistics relevant to wind energy assessments. Based on model data that has been corrected using surface station wind measurements, we estimate the statistical parameters describing local wind speed distributions across Iceland. This allows us to make a regional comparison of wind energy potential within Iceland and also to identify possible sites for wind farms. This study is part of the Nordic IceWind project, which focuses on wind engineering in cold climates and aims to improve forecast of wind, waves, and icing.

The structure of the paper is as follows: In Section 2 we describe the data used and methodology. In Section 3 we provide an overview of wind power potential across Iceland. In Section 4 we discuss the results of a more detailed assessment of 14 test sites, followed by our conclusions.

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2. Methodology

2.1. Wind modelling

The Icelandic network of weather stations is sufficient to provide a good overview of the surface wind conditions over the low-lying parts of the country. However, it leaves several regions unobserved, which may be suitable for the installation of wind farms. It is therefore important to augment the observational data with results from numerical simulations, which provide regularly gridded fields of atmospheric variables at different heights above the ground.

The simulated data used for this study was obtained from the Institute for Meteorological Research in Iceland. The numerical model data was produced with the mesoscale Weather Research and Forecasting (WRF) Model (Version 3.1.1; see Skamarock et al. [7] for details). Simulations were performed in three nested horizontal domains, all approximately centred around Iceland: the outer domain with 43 × 42 grid points spaced at 27 km, the intermediate domain with 95 × 90 grid points spaced at 9 km, and the inner domain with 196 × 148 grid points spaced at 3 km. As shown in Fig. 2, the northwest corner of the outer domain covers a part of the southeast coastal region of Greenland. However, the main landmass included in the model domain is Iceland. The data used here is that of the inner domain. The initial and boundary conditions for the model simulations were determined by 6-hourly operational analyses obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) [8,9], valid at 00, 06, 12, and 18 UTC. After initialisation of the model run, this data is only applied at the outer boundaries. WRF model output fields were produced every 3 h in one continuous simulation, with a 15-day spin-up period. Data is available for the period 1 Sep 1994–2 Nov 2009. However, to include only years with complete data records, the main analysis here is limited to the 1995–2008 period.

With a grid-point spacing of 3 km, the WRF model results are too coarse for a precise assessment of the wind conditions within a limited region, such as an individual valley or ridge, that may be appropriate for wind energy production. For this, a spatial resolution of 100 m or higher is required, a resolution that is not practical to use with a prognostic numerical model. Here, instead the Wind Atlas Analysis and Application Program (WAsP), developed by the Wind Energy and Atmospheric Physics Department at Risø National Laboratory (now the Department of Wind Energy at the Technical University of Denmark), was used for more detailed analyses of the wind energy potential of selected sites. WAsP employs parameterised boundary-layer modelling within a geographically consistent or contained region [10,11]. The input data can be either measured or simulated wind speed and direction time-series at one location somewhere within the domain, but ideally at a

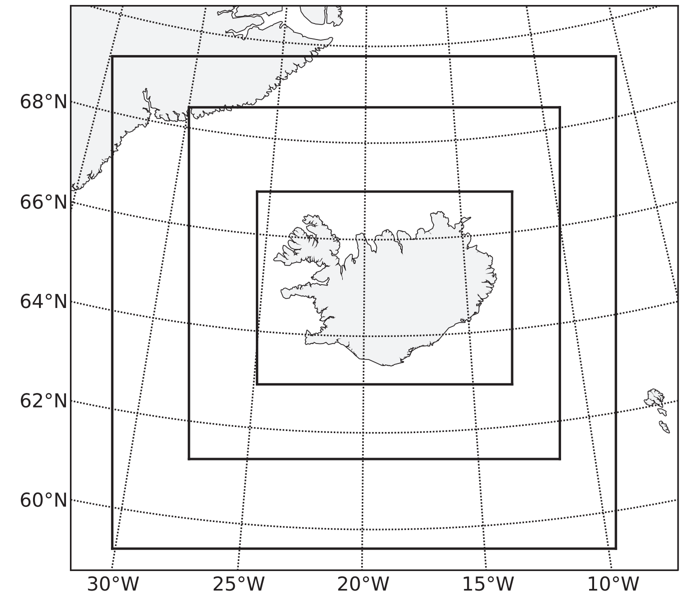

Fig. 2. Boundaries of the three nested WRF model domains.

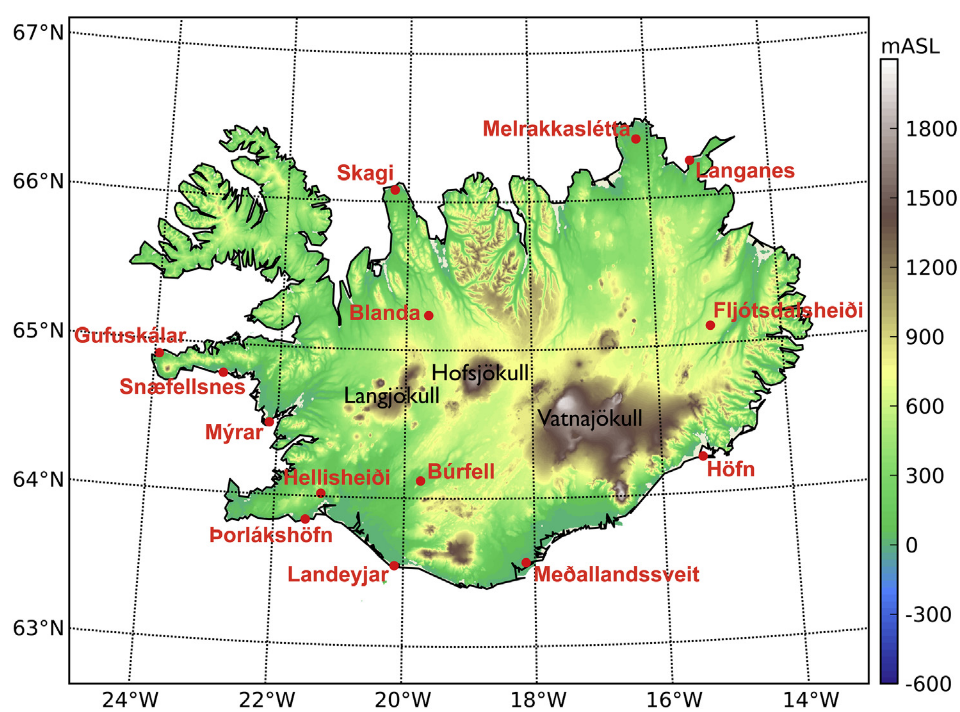

Fig. 1. Topographic map of Iceland, with the locations of sites, for which detailed analyses were performed, shown in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)