



A global investigation of atmospheric circulation regimes driving wind power generation and its extremes at country and continent scales

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Large-scale wind power installations are expanding across the world as part of electricity decarbonization efforts. Extreme wind energy events including wind droughts can pose major challenges for decarbonizing electricity grids that increasingly depend on renewable, including wind, power generation. In the context of conversions of available potential to horizontal kinetic energy predominantly over oceanic regions that are often remote from wind farms as well as load centers, we simulate country and continental scale wind power generation across the world and examine factors driving wind droughts. We use ERA-5 reanalysis wind speed and a wind turbine power curve to estimate daily wind generation at existing sites across the world. Site-level generation is aggregated to estimate daily generation patterns at country and continental scales. We estimate wind drought patterns in absolute terms and with respect to anomalies in relation to daily climatology and examine associations between wind droughts and characteristics of the large-scale atmospheric circulation.

Long-range advection of horizontal kinetic energy can also play an important role in maintaining wind power, and we systematically explore and distinguish the roles of local and remote factors in driving wind power variability at three types of scales: site-level, country-scale, continental-scale. This study offers a systematic approach to comprehending interactions between the large-scale kinetic energy budget and wind power variability across scales. We investigate the following questions: What background conditions over open oceanic regions facilitate long-range advection of wind energy, and how critical is advection for wind power variability? What specific circulation regimes are more instrumental in driving overall variability? The results offer insights for understanding controls from the mechanical energy budget on decarbonizing energy systems, and factors driving their variability across timescales.