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Towards consistent two-equation closure modelling of atmospheric flows, suitable for wind energy applications

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When modelling atmospheric flows with Reynolds-averaged Navier-Stokes equations, two-equation closure is a pragmatic compromise between simple first-order closure and more complex higher-order closure schemes. The problem of treating vegetative canopy and/or buoyancy effects has seriously limited the use of such closure in many practical applications. We develop a consistent closure implementing these effects, through consideration of the behaviour of the supplementary equation for the length-scale-determining variable in different turbulent flows. Being consistent with the canonical flow regimes of grid turbulence and wall-bounded flow, the suggested closure is also valid for homogeneous shear flows commonly observed inside tall vegetative canopies and in non-neutral atmospheric conditions. We apply Monin-Obukhov stability theory to assess the closure implemented within the most popular two-equation schemes, namely $E - \varepsilon$ and $E - \omega$ (where ε is the dissipation rate of turbulent kinetic energy, E, and $\omega = \varepsilon/E$ is the specific dissipation), for buoyancy-affected conditions occurring during a typical diurnal cycle over bare land.

As a practical application here we explore wind speed, direction, and wind-speed shear through and above the surface layer (40–130 m), where physical measurements are not trivial and still relatively rare. Model experiments show that stably-stratified airflow in night time and early morning demands special attention. Along with the increase in wind speed and decrease in turbulence intensity (both factors are favourable for wind power production) associated with these conditions, wind-speed and directional shear across the heights spanned by typical wind turbine rotors create large amounts of stress on the turbines (especially at dawn when turbulence starts to develop), causing difficulties in their operation and fatigue issues over time. Coupling of the airflow model and an aeroelastic model will allow quantitative prediction of the consequences for power production and dynamic loads on wind turbines.