University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Doctor of Philosophy

of

MICHAEL OPTIS

MASc (University of Victoria, 2008)
BSc (University of Waterloo, 2005)

"The Modelling of the Wind Profile Under Stable Stratification at Heights Relevant To Wind Power: A Comparison of Models of Varying Complexity"

School of Earth and Ocean Sciences

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1:00PM
Bob Wright Centre
Room A319

Supervisory Committee:
Dr. Adam Monahan, School of Earth and Ocean Sciences, University of Victoria (Supervisor)
Dr. Jody Klymak, School of Earth and Ocean Sciences, UVic (Member)
Dr. Norm McFarlane, School of Earth and Ocean Sciences, UVic (Member)
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Dr. Larry Berg, Pacific Northwest National Laboratory

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Dr. Malcolm Rutherford, Department of Economics, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

The accurate modelling of the wind speed profile at altitudes relevant to wind energy (i.e. up to 200 m) is important for preliminary wind resource assessments, forecasting of the wind resource, and estimating shear loads on turbine blades. Modelling of the wind profile at these altitudes is particularly challenging in stable stratification due to weak turbulence and the influence of a broad range of additional processes. Models used to simulate the wind profile range from equilibrium-based 1D analytic extrapolation models to time-evolving 3D atmospheric models. Extrapolation models are advantageous due to their low computational requirements but provide a very limited account of atmospheric physics. Conversely, 3D models are more physically comprehensive but have considerably higher computational cost and data requirements. The middle ground between these two approaches has been largely unexplored.

The intent of this research is to compare the ability of a range of models of varying complexity to model the wind speed profile up to 200 m under stable stratification. I focus in particular on models that are more physically robust than conventional extrapolation models but less computationally expensive than a 3D model. Observational data taken from the 213-m Cabauw meteorological tower in the Netherlands provide a basis for much of this analysis.

I begin with a detailed demonstration of the limitations and breakdown in stable stratification of Monin-Obukhov similarity theory (MOST), the theoretical basis for the logarithmic wind speed profile model. I show that MOST (and its various modifications) are reasonably accurate up to 200 m for stratification no stronger than weakly stable. At higher stratifications, the underlying assumptions of MOST break down and large errors in the modelled wind profiles are found. I then consider the performance of a two-layer MOST-Ekman layer model, which provides a more physically-comprehensive description of turbulence compared to MOST-based models and accounts for the Coriolis force and large-scale wind forcing (i.e. geostrophic wind). I demonstrate considerable improvements in wind profile accuracy up to 200 m compared to MOST-based approaches.

Next, I contrast the performance of a two-layer model with a more physically- comprehensive equilibrium-based single-column model (SCM) approach. I demonstrate several limitations of the equilibrium SCM approach - including frequent model breakdown - that limit its usefulness. I also demonstrate no clear association between the accuracy of the wind profile and the order of turbulence closure used in the SCM. Furthermore, baroclinic influences due to the land-sea temperature gradient are shown to have only modest influence on the SCM wind speed profile in stable conditions. Overall, the equilibrium SCM (when it does not break down) is found to generally outperform the two-layer model.

Finally, I contrast the performance of the equilibrium SCM with a time-evolving SCM and a time-evolving 3D mesoscale model using a composite set of low-level jet (LLJ) case studies as well as a 10-year dataset at Cabauw. For the LLJ case studies, the time-evolving SCM and 3D model are found to accurately simulate the evolving stratification, the inertial oscillation, and the LLJ. The equilibrium SCM is shown to have comparatively less skill. Over the full 10-year data set, the sensitivity of the time-evolving SCM to horizontally-driven temperature changes in the ABL is found to be a considerable limitation. Despite its various limitations and simplified physics, the time-evolving SCM is generally found to be equally as accurate as the mesoscale model while using a fraction of the computational cost and requiring only a minimal amount of easily attainable local observations.

Overall, the time-evolving SCM model is found to perform the best (considering both accuracy and robustness) compared to a range of equilibrium approaches as well as a time-evolving 3D model, while offering the best balance of observational data requirements, physical applicability, and computational requirements. This thesis presents a compelling case for the use of SCMs in the field of wind energy meteorology.