Exchanges in Surface and Boundary Layer Reconsidered: Introducing FaNTASTIC-1

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Abstract

Monin-Obukhov Similarity Theory (MOST) has known failures in describing fluxes and microclimate profiles away from the surface, in both stable and unstable boundary layers. We have launched a project entitled Forced and Natural Turbulence Allowing Studies of Turbulent anisotropic Conditions (FaNTASTIC-1) to provide high-resolution turbulences measurements, with a goal to develop a physically-based alternative approach constrained by energy conservation to deal with large turbulent eddies away from the surface. We use locations inside and outside a large wind farm to concurrently observe, respectively, forced and natural turbulence to gain a better understanding of coherent eddies and budgets of turbulence potential energy and turbulence kinetic energy as a basis for achieving this goal.

Keywords: *Tall tower measurements, Turbulence intermittency, Coherent eddies, Energy budget conservation*

Introduction

Nocturnal surface cooling introduces rapid transitions between the stable and neutral atmospheric boundary layers that are not represented well by current ABL schemes of mesoscale models. The problems of transition instabilities in numerical models and poor agreement with observed low-level wind shear and surface microclimate are well known [1,2,3]. Jahn [4] found that WRF simulations of higher-than-observed nighttime winds at 100 m could be traced to the collapse of the mixing length scale. Models using local shear restrict influences of large-scale forcing on eddy size growth under these conditions. Recent analysis from the 1999 Cooperative Atmospheric Surface Exchange Study (CASES-99) highlights the importance of large coherent eddies, which do not follow MOST scaling, in describing three turbulence regimes [5,6]. Inclusion of the turbulence potential energy (TPE) in the total turbulence energy budget (also including turbulent kinetic energy (TKE)) describes the mechanism for energy transfer between TPE and TKE in sustaining low turbulence [7,8]. Understanding the role of large coherent eddies in the convective atmospheric boundary layer [9] and energy conservation in determination of turbulence intensity to replace the statistical parameterizations of MOST in numerical models are important steps toward improving model physics and performance.

We have launched high-resolution measurements of the characteristics of large coherent eddies to provide a physical basis for improving on MOST, which in turn will improve the skill of weather forecast and global climate models. We use a "natural experiment" to examine the effects of different scales of turbulence on near-surface fluxes. Utility-scale wind farms create turbulence ("forced turbulence") having a unique spectral signature. FaNTASTIC uses concurrent measurements of turbulence variances and covariances produced by natural and "forced" turbulence to develop a physically based alternative to MOST for describing surface fluxes and microclimate.

Methods

Our field site is in flat agricultural land in central Iowa that includes a 300 MW (200 turbine) utility-scale wind farm. We have erected a 120-m tower (denoted A1) near the middle of this wind farm instrumented at six levels with 1-Hz measurements temperature, wind speed and direction, and humidity at all levels and barometric pressure at 10 m and 80 m. We also have sonic anemometers measuring turbulence at 10-m, 80-m, and 120 m. An identical tower (denoted A2) is located a few km to the northwest of the wind farm and allows measurement of natural (unaffected by the wind farm) boundary - layer conditions. The 1-Hz measurements on this tower are identical with those at A1. In addition we have deployed supplemental instruments as shown in Fig. 1. Nearby the A2 tower we are erecting a 10-m tower (denoted B-tower) to provide high-resolution refinement of heat and momentum exchanges near the soil or plant canopy surface. Measurements of soil moisture, temperature and heat flux will be co-located with the turbulence instrumentation on the B-tower (Fig. 2b). A sodar near the A2 tower will report boundary-layer flow characteristics up to 200 m. Characteristics of coherent eddies and TPE/TKE ratios over a wide range of scales at the A2 site will be documented. Mesoscale (non-local) sources of turbulence generation will be identified using a combination of spectral, wavelet, and multi-resolution decomposition techniques. Measurements at the A1 tower will provide mean and turbulence characteristics of forced turbulence that govern microclimate of the wind farm boundary layer. These measurements will expand on observations from CASES-99 and will allow development of physically based alternatives to MOST.

(a) **(b)**

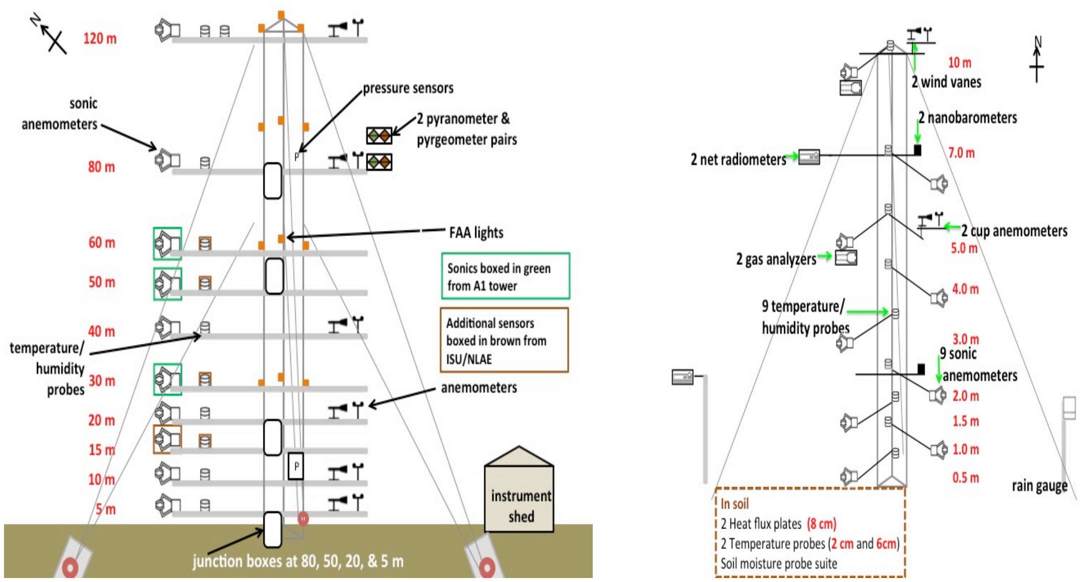

Fig. (a) A-tower instrument configuration for FaNTASTIC; (b) B-tower instrumentation

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References

1. Storm, B., and S. Basu, 2010: The WRF model forecast-derived low-level wind shear climatology over the United States Great Plains. Energies, 3 , 258-276. DOI:10.3390/en3020258
2. Hu, X.M., Klein, P.M. and Xue, M., 2013: Evaluation of the updated YSU planetary boundary layer scheme within WRF for wind resource and air quality assessments. Journal of Geophysical Research: Atmospheres, 118(18).
3. Zhang, H., Z. Pu, and X. Zhang, 2013: Examination of errors in near-surface temperature and wind from WRF numerical simulation in regions of complex terrain. Wea. Forecasting , 28 ,
893-914, DOI:10.1175/WAF-D-12-00109.1.
4. Jahn, D.E., Takle, E.S. and Gallus, W.A., 2017: Improving Wind-Ramp Forecasts in the Stable Boundary Layer. Boundary-Layer Meteorology, 163(3), 423-446.
5. Sun, J., Mahrt, L., Banta, R.M. and Pichugina, Y.L., 2012: Turbulence regimes and turbulence intermittency in the stable boundary layer during CASES-99. Journal of the Atmospheric Sciences, 69(1), 338-351.
6. Sun, J., Lenschow, D.H., LeMone, M.A. and Mahrt, L., 2016: The role of large-coherent-eddy transport in the atmospheric surface layer based on CASES-99 observations. Boundary-Layer Meteorology, 160(1), 83-111.
7. Zilitinkevich, S.S., Elperin, T., Kleeorin, N. and Rogachevskii, I., 2007: Energy-and flux-budget (EFB) turbulence closure model for stably stratified flows. Part I: steady-state, homogeneous regimes. Boundary-Layer Meteorology, 125(2), 167-191.
8. Zilitinkevich, S.S., Elperin, T., Kleeorin, N., Rogachevskii, I. and Esau, I., 2013: A hierarchy of energy-and flux-budget (EFB) turbulence closure models for stably-stratified geophysical flows. Boundary-Layer Meteorology, 1-33.
9. Zilitinkevich, S.S., Hunt, J.C.R., Grachev, A.A., Esau, I.N., Lalas, D.P., Akylas, E., Tombrou, M., Fairall, C.W., Fernando, H.J.S., Baklanov, and A., Joffre, S.M., 2006: The influence of large convective eddies on the surface layer turbulence. *Quart. J. Roy. Met. Soc*. **132**, 1423-1456.