NOCTURNAL OBSERVATIONS OF THERMODYNAMIC AND KINEMATIC PROPERTIES IN A WIND TURBINE ARRAY BOUNDARY LAYER USING AN INSTRUMENTED UNMANNED AERIAL SYSTEM

Christopher J. Swinford, Nikolaus Rentzke, and Kevin A. Adkins, Ph.D. *(faculty mentor)*

Embry-Riddle Aeronautical University, Daytona Beach, FL

BACKGROUND

The atmospheric boundary layer (ABL) is the lowest layer of the atmosphere adjacent to the Earth's surface. As a result, it is a region highly influenced by the Earth's surface. The Earth's surface influences the atmosphere in three main ways[1]:

- Sensible heat flux
- Moisture flux
- Radiation

There are three main ways that air can be moved in the atmosphere[2]:

- Mean wind
- Waves
- Turbulence

Turbulence is another hallmark of the ABL and can be used to differentiate the ABL from the free atmosphere that resides above. In the ABL, the transport of moisture, heat and momentum are dominated by the mean wind in the horizontal direction and by turbulence in the vertical direction[1].

An observed atmospheric parameter can be broken down into a mean and fluxuating component[2]. Consequently, the wind can be analyzed in this manner as:

$$\boldsymbol{U} = \boldsymbol{\bar{U}} + \boldsymbol{u'}$$

where the instantaneous wind, U, is the sum of the mean wind, $\bar{U}$, and the fluxuating component, u'. The high frequency fluxuating component represents turbulence.

A flux is the transfer of a variable per unit area per unit time. Because of the influence of the Earth's surface in the ABL, two fluxes of primary interest are: 1) Kinematic heat flux; 2) Kinematic moisture flux. After simplification, these vertical fluxes are defined as[2]:

- Kinematic heat flux = $\overline{\boldsymbol{w'\theta'}}$
- Kinematic moisture flux = $\overline{\boldsymbol{w'q'}}$

where the prime indicates the fluxuating component of vertical velocity, w, potential temperature, θ, and specific humidity, q.

OBJECTIVE

Substantiate numerical simulation results for surface sensible heat and moisture flux in the near-wake of a single upstream wind turbine with empirical measurements using a meteorologically-instrumented unmanned aerial system

RESULTS

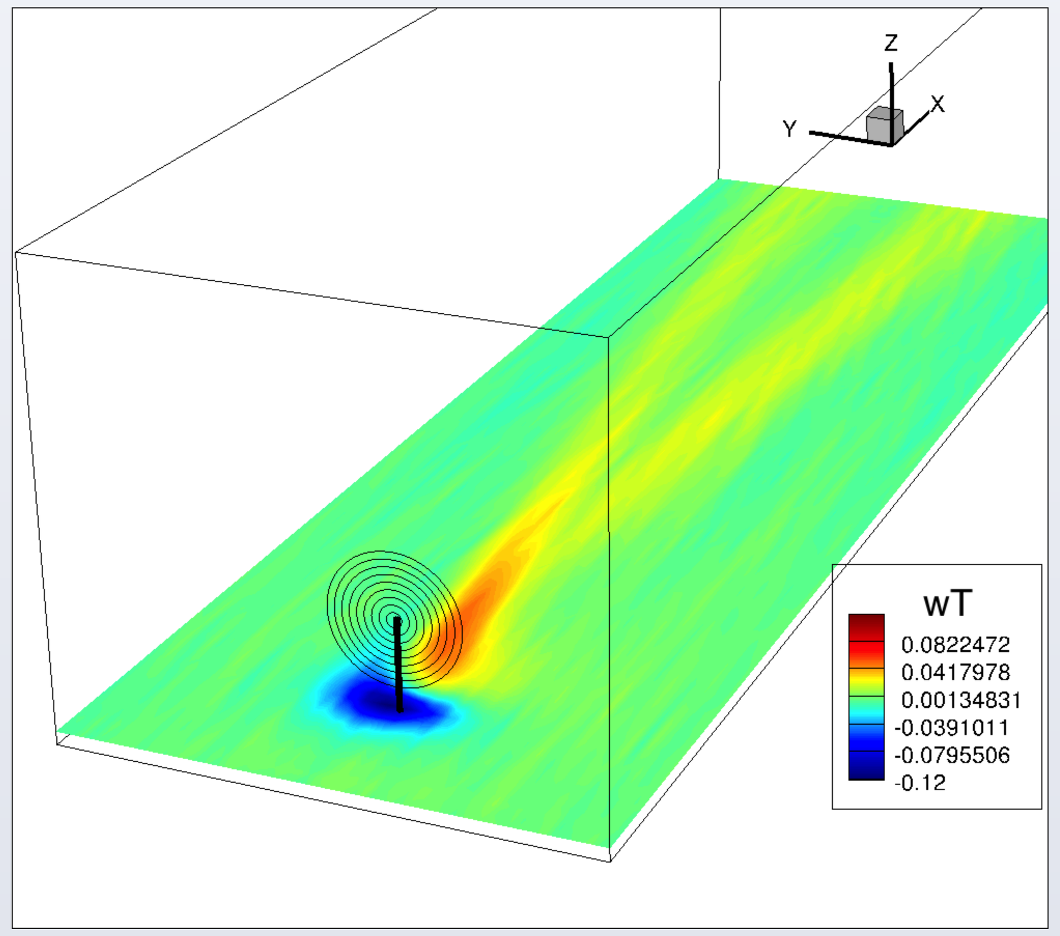


Figure 1: Contour plots of LES averaged surface heat flux in a horizontal plane section (the legend shows surface heat flux in units of K·m/s).

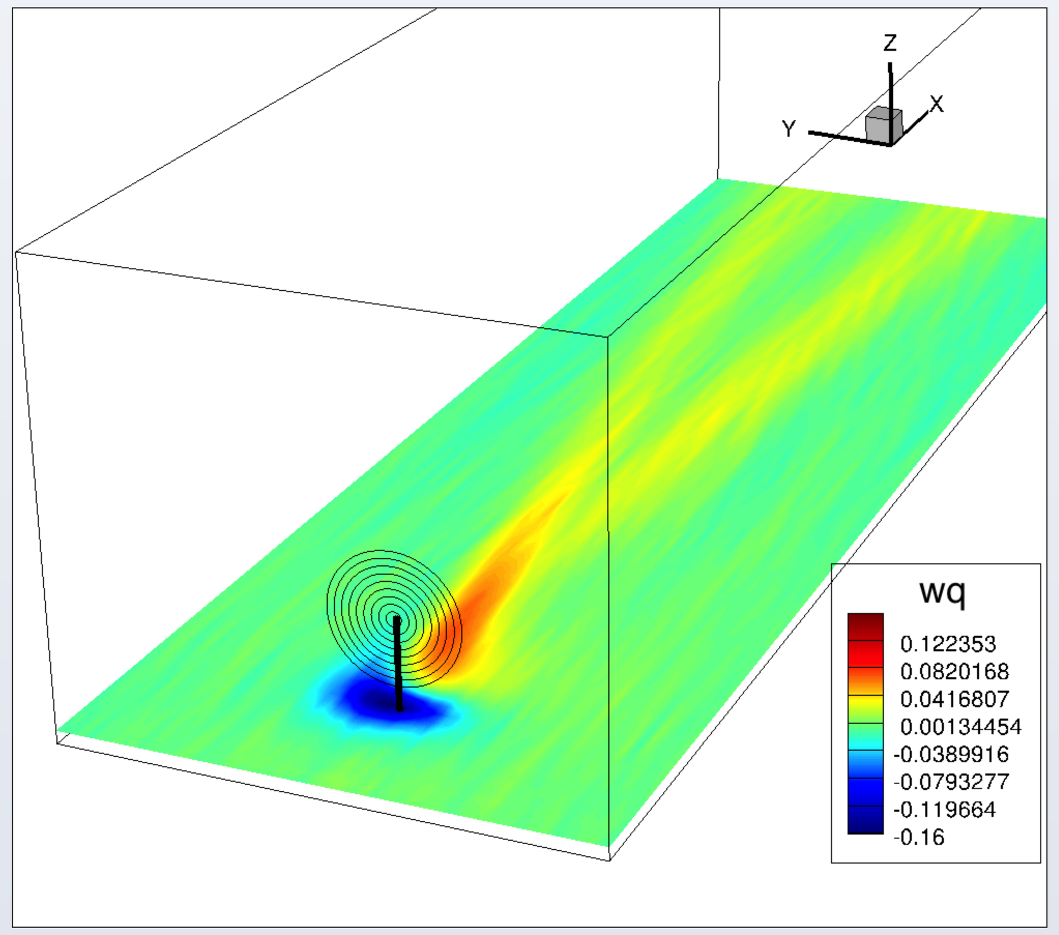


Figure 2: Contour plots of LES averaged surface moisture flux in a horizontal plane section (the legend shows surface moisture flux in units of $kg_{water\ vapor}/kg_{total\ air}$·m/s).

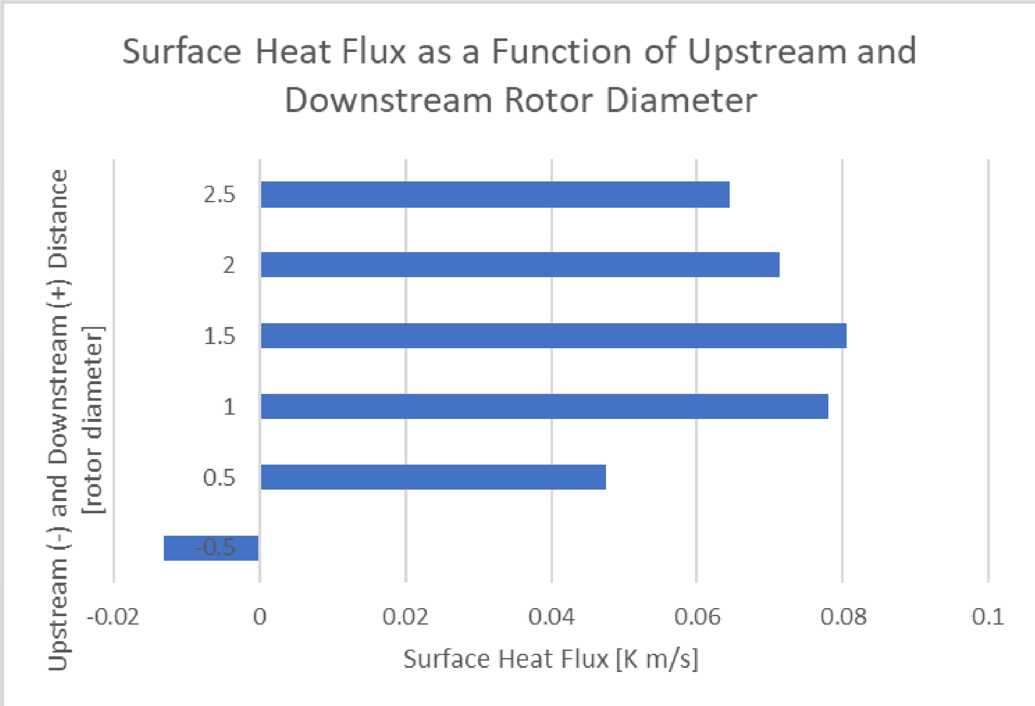


Figure 3: Observed values of surface heat flux, as a function of upstream and downstream rotor diameter, obtained by a meteorologically-instrumented unmanned aircraft in a horizontal plane 3 m above the crop canopy.

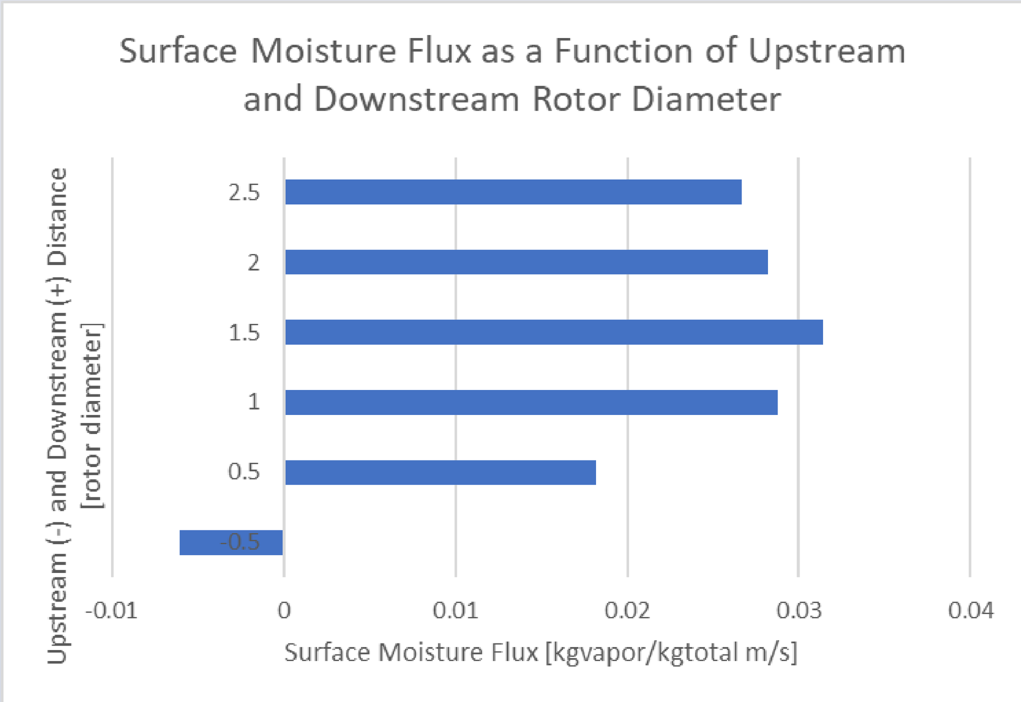


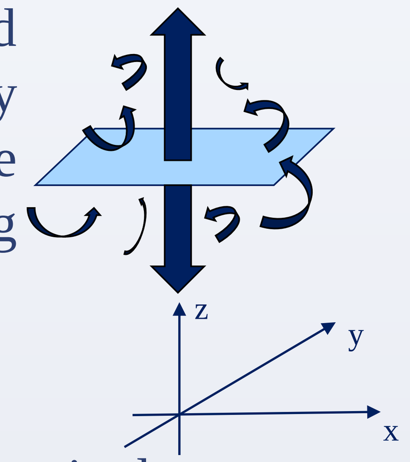
Figure 4: Observed values of surface moisture flux, as a function of upstream and downstream rotor diameter, obtained by a meteorologically-instrumented unmanned aircraft in a horizontal plane 3 m above the crop canopy.

DISCUSSION AND CONCLUSION

Numerical simulation output using a thermal stratification of 0.57 K per 100 m and a geostrophic wind of 6 m/s is contrasted with observations made 3 m above the crop canopy (wheat) along the centerline of the near-wake of an analogous 80 m hub height wind turbine with a 100 m rotor diameter. Average ambient conditions observed during the flight showed a 0.49 K per 100 m lapse rate and a hub height wind speed of 6.65 m/s. Observed surface fluxes for both heat and moisture are similar in magnitude and showcase the same distinctive spatial gradient along the wake's centerline as LES output.

KINEMATIC FLUXES MOVE AIR VERTICALLY

The kinematic heat flux, $\overline{w'\theta'}$, and kinematic moisture flux, $\overline{w'q'}$, naturally transport thermal energy and moisture vertically by turbulent eddies along gradients from higher to lower values.



OBSERVATIONS

Measurements were made around a single upstream GE 1.7 MW wind turbine with an 80 m hub height and 100 m rotor diameter.

The UA was instrumented with a resistor temperature detector, capacitive humidity sensor, barometer, and two orthogonally mounted acoustic resonance anemometers.

Figure 5: (Left) Measurements were made around a single upstream GE 1.7 MW wind turbine with an 80 m hub height and 100 m rotor diameter. (Right) Fully instrumented unmanned aircraft, microcontroller, power supply, data storage and telemetry are centrally located with all meteorological instruments mounted on booms: (a) on the ground; (b) in the air.

NUMERICAL SIMULATION

Numerical simulation was performed using large eddy simulation (LES) which employs a pseudo-spectral method in the horizontal and a second-order accurate centered difference scheme in the vertical. Time marching is performed using a fully-explicit second-order accurate Adams-Bashforth scheme. Subgrid scale stress, heat and momentum are modeled using a Lagrangian scale-dependent model. A periodic boundary condition wraps the domain boundary from one lateral boundary to the other and a precursor simulation is written to the end of the main domain to provide turbulent inflow.

References

[1] Atmospheric Boundary Layer. (2019) https://www.e-education.psu.edu/meteo300/node/697.

[2] Stull, R. B. (1988) *An Introduction to Boundary Layer Meteorology*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Acknowledgements and Contact

The authors would like to acknowledge the contributions of Dr. Adrian Sescu of Mississippi State University who conducted the numerical simulation. Also Mr. Peter Wambolt of the Gaetz Aerospace Institute who piloted the meteorologically-instrumented UAS during the acquisition of the empirical data.

Contact: Dr. Kevin A. Adkins, Embry-Riddle Aeronautical University, Daytona Beach, FL, Kevin.Adkins@erau.edu

RESEARCH POSTER PRESENTATION DESIGN © 2015
www.PosterPresentations.com