JAN 21, 2016

Large-eddy simulation of rough wall turbulence: effects of complex topography, evidence of inner-outer effects, and the role of turbulence in aeolian systems

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ABSTRACT:

High Reynolds number rough wall turbulent flows are ubiquitous in engineering and geophysical flows. Turbulence influences the aero-/hydro-dynamic signature of bluff bodies and the performance of vapor power systems; in geophysical flows, turbulence impacts urban dispersion, the hydrologic cycle, and sedimentary processes in fluvial/aeolian systems. Recently it has been shown that spanwise topographic heterogeneity can induce a mean domain-scale (δ) circulation. We demonstrate that these circulations are Prandtl's Secondary Flow of the Second Kind: sustained and driven by spanwise—wall-normal heterogeneity in the Reynolds stresses (all of which vanish in the absence of spanwise topographic heterogeneity). These findings are supported by large-eddy simulation (channel flow: Anderson et al., 2015: J. Fluid Mech.) and experimental measurement (boundary layer: Barros and Christensen, 2014: J. Fluid Mech.) Mejia-Alvarez and Christensen, 2013: Phys. Fluids termed the resulting heterogeneity in spanwise—wall-normal streamwise velocity low- and high-momentum pathways (in order to draw distinction against low- and high-momentum regions – LMR, HMR – which are a spatially meandering, transient feature of wall turbulence). In other work, we have explored the presence of an "amplitude modulation" effect of the roughness sublayer by inertial layer coherent motions; we show that periods of momentum excess(deficit) in the inertial layer precede periods of elevated(depressed) streamwise—wall-normal Reynolds shearing stress in the roughness sublayer (Marusic et al., 2010: Science). A decoupling procedure (Mathis et al., 2009: J. Fluid Mech.) is used to illustrate that an amplitude modulation effect is indeed present for rough wall flows. Finally, we present results from LES of neutrally stratified atmospheric boundary layer flow over a sparsely vegetated, arid landscape, to explore the role of coherent structures in driving aeolian processes. Conceptual models for aeolian erosion typically indicate that sediment mass flux, q (via saltation or drift), scales with imposed aerodynamic stress raised to some exponent, n, where $n > 1$. Since aerodynamic stress (in fully rough, inertia-dominated flows) scales with incoming velocity squared, u2, it follows that q ~ u2n (where u is some relevant component of the flow, u(x,t)). Thus, even small (turbulent) deviations of u from its time-averaged value may be important in aeolian activity. We have used conditional averaging predicated on aerodynamic surface stress during LES (where threshold selection is guided by probability density functions of local surface stress). This averaging procedure provides an ensemble-mean visualization of flow structures responsible for erosion "events". Preliminary evidence indicates that surface stress peaks are associated with the passage of inclined, high-momentum regions flanked by adjacent low-momentum regions.

BIOGRAPHY:

Anderson received his PhD in Mechanical Engineering from The Johns Hopkins University in July 2011. He began as a tenure-track faculty in the Mechanical Engineering Department at Baylor University in Fall 2011, and moved to the University of Texas at Dallas in Fall 2014. His research interests focus on rough wall turbulent flows; this has relevance to planetary boundary layers, aerospace engineering, and mechanical engineering. His research activities are currently supported by the Army Research Office (ARO), Air Force Office of Scientific Research (AFOSR), National Science Foundation (NSF), and the Texas General Land Office (TGLO). He is a 2014 recipient of the AFOSR Young Investigator Program award.