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Turbulence sources, character, and effects in the stable boundary layer: Insights from multi-scale direct numerical simulations and new, high-resolution measurements

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A number of sources contribute to intermittent small-scale turbulence in the stable boundary layer (SBL). These include Kelvin-Helmholtz instability (KHI), gravity wave (GW) breaking, and fluid intrusions, among others. Indeed, such sources arise naturally in response to even very simple "multi-scale" superpositions of larger-scale GWs and smaller-scale GWs, mean flows, or fine structure (FS) throughout the atmosphere and the oceans. We describe here results of two direct numerical simulations (DNS) of these GW-FS interactions performed at high resolution and high Reynolds number that allow exploration of these turbulence sources and the character and effects of the turbulence that arises in these flows. Results include episodic turbulence generation, a broad range of turbulence scales and intensities, PDFs of dissipation fields exhibiting quasi-log-normal and more complex behavior, local turbulent mixing, and "sheet and layer" structures in potential temperature that closely resemble high-resolution measurements. Importantly, such multi-scale dynamics differ from their larger-scale, quasi-monochromatic gravity wave or quasi-horizontally homogeneous shear flow instabilities in significant ways.

The ability to quantify such multi-scale dynamics with new, very high-resolution measurements is also advancing rapidly. New in-situ sensors on small, unmanned aerial vehicles (UAVs), balloons, or tethered systems are enabling definition of SBL (and deeper) environments and turbulence structure and dissipation fields with high spatial and temporal resolution and precision.

These new measurement and modeling capabilities promise significant advances in understanding small-scale instability and turbulence dynamics, in quantifying their roles in mixing, transport, and evolution of the SBL environment, and in contributing to improved parameterizations of these dynamics in mesoscale, numerical weather prediction, climate, and general circulation models. We expect such measurement and modeling capabilities to also aid in the design of new and more comprehensive future SBL measurement programs.