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Editorial

Editorial Summary: Boundary Layer Processes in Geophysical/Environmental Flows

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Boundary layer processes play a crucial role in establishing the circulation patterns of the oceans and atmosphere, significantly affecting both regional and global climate, as well as the distributions of heat, nutrients, species, pollutants and more. This Special Issue of *Fluids* is dedicated to recent advances in the theoretical, numerical, observational, and experimental investigation of geophysical/environmental boundary layer processes, and how those process may influence regional and global circulation. While traditional geophysical boundary layers, such as the major eastern and western boundary currents [1–3], or those associated with the air–sea interface [4], have enjoyed over a decade of intense study, our understanding of their dynamics continues to evolve.

Lyu et al. [5] advance the understanding of momentum exchanges across the air–sea boundary. Such exchanges are an integral component of the earth system, and their parametrization is essential for climate and weather models. This study focuses on the impact of gustiness on the momentum flux, using three months of direct flux observations from a moored surface buoy. Gustiness, which quantifies the fluctuations of wind speed and direction, is shown to impact air–sea momentum fluxes. It is shown that, during runs classified as gusty, the aerodynamic drag coefficient [6] is increased up to 57% when compared to their non-gusty counterparts. This is caused by a correlated increase in vertical fluctuations during gusty conditions, and explains variability in the drag coefficient for wind speeds of up to 20 m/s.

Quintana et al. [7] advance the understanding of the seasonality of surface-balanced motions in eastern boundary currents. Balanced motions and internal gravity waves account for most of the kinetic energy budget, and capture most of the vertical velocity in the ocean. However, estimating the contributions of balanced motions to both issues at time scales of less than a day is a challenge, because balanced motions are obscured by internal gravity waves. To remove this obscurity, a dynamic filtering protocol that separates these motions is developed. The feasibility of such a filter is confirmed, which opens new possibilities for more accurate estimation of the vertical exchanges of any tracers at any vertical level in the water column.

Kuehl and Sheremet [8] advance the understanding of so-called gap leaping boundary currents [9–12] by considering the effects of coastline geometry. For traditional straight, parallel gaps, such systems are known to exhibit two dominant states (gap penetrating and leaping), with the transitional dynamics between states displaying hysteresis [13,14]. However, for more complex geometries, such as angled or offset gap configurations, the question of multiple states and hysteresis was unresolved. It is shown that the presence of multiple states with hysteresis for gap-leaping western boundary current systems is robust to both angled and offset gap geometries. This result contributes to larger discussions about how basin geometry, and how the distribution of both side and bottom boundary dissipation throughout the basin in particular, influence the basin scale circulation patterns [15–17].

While such traditional geophysical boundary layers have enjoyed over a decade of intense study, the inaccessibility of the deep ocean and the need for large spatial arrays to resolve scale dependent processes has limited our understanding of the ocean bottom

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boundary layer. Indeed, this is an emerging field of study, and the need to revise classical works [18,19] is recognized. The remaining manuscripts in this Special Issue, in one way or another, advance the understanding of how steep and complex topography influences ocean circulation. At the present time, this open question is at the forefront of climate science (IWG-NOPP [20]).

Polzin et al. [21] report a novel attempt to utilize a turbulence flux current meter on a conventional mooring. The physical situation is a downwelling Ekman layer supported by sub-inertial flow in excess of 0.2 m s^{-1}, slope Burger number of 0.7, and moderate stratification with $N/f = 40$. Importantly, the mooring was placed immediately in the lee of a ridge superimposed on the continental slope, and flow speeds were within a transitional regime for non-rotating hydraulics. The observations are at odds with conventional wisdom concerning the arrested Ekman paradigm [22] and one-dimensional models of boundary layers associated with mixing over sloping topography (see [23] for a review). The moored data document a well-mixed region smaller than the stratified Ekman layer [24] and significantly smaller than Ekman arrest metrics. The limited height of the well-mixed region occurs in conjunction with buoyancy and momentum fluxes in an internal wave band regime, with internal waveband vertical momentum fluxes directed directly upslope. The observations also document a near-boundary downslope turning of the velocity vector in the boundary layer that is antiparallel to the turbulent stress vector and larger than standard Ekman theory. The internal waveband fluxes are relatively broadly distributed in the frequency domain, rather than appearing at the frequency associated with internal wave rays paralleling the slope (e.g., [25]). The author's opinion is that the limited extent of the well-mixed layer and internal wave band fluxes are casually related, i.e., the internal waveband process represents a rapid ventilation of the boundary layer. If the observations are a round hole, concepts of boundary layer ventilation accomplished by modifying the internal waveguide to support submesoscale instabilities [26] or near-inertial wave trapping [27] represent a square peg. A key issue is that such theoretical concepts are developed for planar sloping boundaries rather than complex topography.

Ruan [28] also advances the understanding of the ocean bottom boundary layer by considering bulk dissipation estimates. Large-scale ocean currents are primarily powered by atmospheric winds and astronomical tidal forces, which have been well quantified through satellite observations. However, there is a significant disagreement regarding where the kinetic energy (KE) is lost, and one of the major uncertainties lies in the bottom drag, which converts the KE from mean flows to heat loss through irreversible molecular mixing in the oceanic bottom boundary layer (BBL). Typically, the contribution from bottom drag is quantified using a formula proposed by G.I. Taylor [29], which relates the integrated BBL dissipation rate to a drag coefficient and a flow magnitude outside of the BBL. Building upon Taylor's formula, the study by Ruan [30] offers a theoretical basis for better estimating BBL dissipation, given measured mean flows outside of the BBL. It shows that Taylor's formula only provides an upper bound estimate for the BBL dissipation, and should be applied with caution since the performance of the bulk formula depends on the distribution of velocity and shear stress near the seafloor, which can be disrupted by bottom roughness in the real ocean.

Nagano et al. [31] advance the understand of the ocean bottom boundary layer through observations performed around Japan under a unique cooperative project among oceanographers and seismologists, which has unveiled the ocean variabilities near the bottom [32–36]. In this Special Issue, a bottom-intensified current was found on the continental slope off the southeast coast of Hokkaido, Japan. The thickness varies, being affected by the El Niño and the southern oscillation (ENSO). The ENSO-timescale thickening of the oceanic bottom boundary layer is represented by superposed coastal-trapped wave modes excited on the slope by ENSO-related Rossby wave disturbances.

Kozelkov et al. [37] further advance the understanding of bottom boundary layer dissipation by considers turbulence effects on tsunami runup. The turbulence effects on tsunami propagation and runup are studied using the Reynolds-averaged Navier–Stokes shear stress transport (RAN SST) over a nonuniform-bottom pool and collapsing with a barrier. While turbulence is found to have little effect on wave shape and propagation, turbulence effects during the runup and collapse became noticeable and could boost the flow (increasing the pressure force and the total force) by up to 25 percent.

Gundersen et al. [38] advance the understanding of complex topography by experimental investigation of the flow produced by mound-bearing impact craters. Both an idealized crater and a scaled model of a real Martian craters are investigated using high-resolution planar particle image velocimetry (PIV) in a refractive-index matching (RIM) flow environment [39]. The experimental investigation revealed significant structural differences between a simple crater with or without a mound, and a Gale Crater model showed both similarities with and differences from the primary flow features found for the idealized model. These results have implications for intra- to extra-crater mass and momentum exchange, and for sediment transport processes.

Hu et al. [40] also advance the understanding of the complex interactions between turbulent flow and sediment transport utilizing a lattice Boltzmann method [41,42]. It is found that the presence of heavy particles substantially reduces the maximum fluid streamwise velocity fluctuations, and that particles suppress the generation of the large-scale coherent vortices and simultaneously create numerous small-scale vortices in the near-wall region. Moreover, several typical transport modes of the sediment particles, such as resuspension, saltation, and rolling, are captured by tracking the trajectories of particles.

Finally, Burmasheva et al. [43] advance the understanding of how bottom conditions affect flow structure by considering exact solutions for flows of a viscous incompressible fluid with unknown free boundaries. Exact solutions are extremely insightful for understanding fundamental dynamics [44,45], and there is a known procedure for taking into account the boundary conditions for a free boundary by adding a new force to the equations of fluid motion. Fluid flows with the Rayleigh friction force are considered. Accounting for this force makes it possible to consider large-scale currents of the world's oceans with an unknown function for the bottom and for the boundary of water with the atmosphere. The class of exact solutions announced in this Special Issue will be useful for modeling and simulating fluid flows in the ocean and thin layers with unknown boundaries.

Ultimately, geophysical boundary layer interactions are at the cutting edge of environmental science. It is my hope that this Special Issue both advances the knowledge pool and offers new avenues of research for the larger scientific community.

Conflicts of Interest: The author declares no conflict of interest.

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