Role of buoyancy in driving upper ocean mixing across timescales

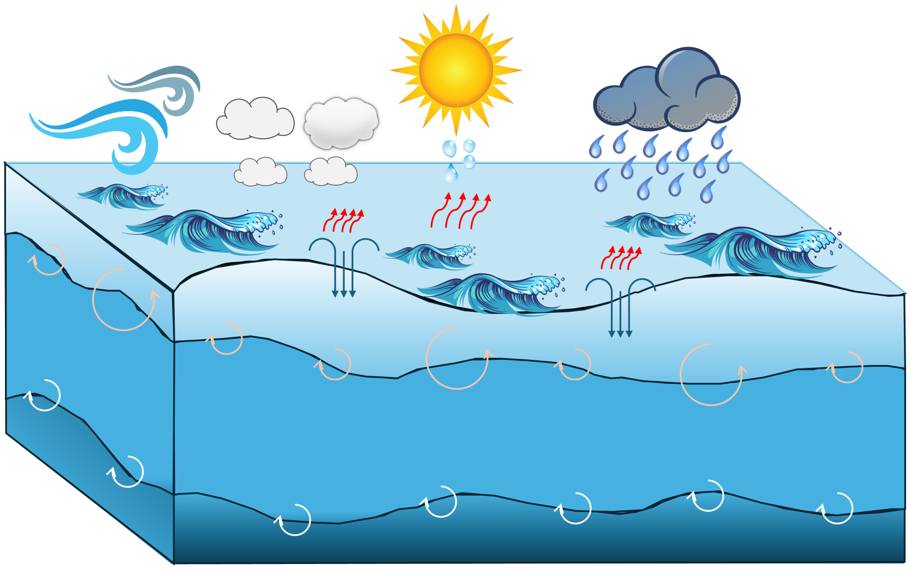

Figure 1: Different upper ocean flow processes.

Exchange of momentum, heat and freshwater at the ocean-atmospheric interface is the major driver of ocean circulation over a wide range of time and length scales. The fluxes of momentum (wind stress) and buoyancy (heating/cooling and evaporation/precipitation) give rise to ocean waves and currents, boundary layer turbulence, vertical transport and mixing, thereby shaping sea surface temperature (SST) and sea surface salinity (SSS). In this thesis, I explore the response of the upper ocean to surface fluxes on different timescales using theory, numerical simulations and observation-based datasets.

We first consider the diurnal (or diel, 24 hour) variability of upper ocean mixing. The diurnal timescale is one of the most prominent modes of variability of the surface fluxes mentioned above. Most previous studies have focussed on the effects of diurnally varying momentum and heat fluxes on the upper ocean. However, the role of evaporative fluxes in modifying the irreversible turbulent mixing in the ocean mixed layer is relatively unknown. Here we use large-eddy simulations (LES) to quantify the role of surface evaporation in modulating diurnal mixed layer turbulence and mixing in the presence of wind forcing. We find that surface evaporation increases the depth of the turbulent boundary layer and enhances irreversible mixing through convection, both during nighttime and daytime, leading to improved prediction of the diurnal cycle of sea surface salinity (SSS) and sea surface temperature (SST).

Next we investigate upper ocean mixing caused by the passage of a tropical cyclone. Using high-fidelity LES simulations and moored observations away from the storm track, we show that mutually interacting shear and convective processes, govern the upper ocean evolution. We chose the salinity-stratified Bay of Bengal as a representative basin, and the case of category 5 cyclone Phailin (October 2013), which lasted for about 5 days. We find that surface buoyancy loss enhances ocean mixing via convective entrainment and shear driven turbulence, eroding erode stratification and deepening the mixed layer. Both mixing efficiency and eddy diffusivity are highly variable throughout the cyclonic event, reaching high values intermittently during surface forced convection. Our study provides new insights into the energetics of such an extreme event where both high surface wind stress and high surface buoyancy loss play important roles.

To address the effect of buoyancy on ocean mixing on longer timescales, we focus on a climate change scenario (timescale $\sim \mathcal{O}(10)$ years or more), particularly on the hydrological cycle. Many studies in the last two decades suggest that the global hydrological cycle is intensifying, with dry regions getting ‘drier’ and wet regions getting ‘wetter’, in response to global warming. The patterns of global SSS reveal the fingerprint of such a process, where salty subtropical waters have become saltier and fresh tropical waters have become fresher. Using various observation-based datasets of subsurface temperature and salinity, we quantify the subsurface trends of stratification in the subtropical North Atlantic, around the SSS maximum region. We provide the the first observation-based evidence of enhanced salinification causing subsurface destratification. In addition, the unstable salinity gradient at the base of the SSS maximum region also increased due to this enhanced salt uptake. The reduced subsurface stratification has consequences in increasing ocean heat content, dissolved oxygen and tracer uptake.