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The structure of thermal field underneath an evaporative water surface

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ABSTRACT

The temperature field beneath an evaporating water surface during natural convection has been investigated using Laser Induced Fluorescence (LIF) technique. Experiments were conducted at two different surface heat flux conditions under thermally unstable stratification. The mean temperature profiles show three distinct regions beneath the water surface where the depth dependency of temperature is different. In the conduction layer, the temperature varied linearly with depth. In the intermediate region, the temperature varied as z^{-1} whereas, in the bulk region, the temperature varied as $z^{-1/3}$. These depth dependencies are consistent with the theoretical predictions. The results also show that the relationship between the scales of conduction and convection layers for velocity and temperature defined for wall bounded natural convection are also valid for free surface natural convection however, the length scales ratio showed the opposite trend.

1. Introduction

Turbulent thermal convection in horizontal fluid layers cooled from above has been of considerable interest due to its wide range of applications from geophysical flows in oceanography and meteorology, to technologically relevant flows in heating, ventilation and air conditioning (HVAC), and chemical and nuclear engineering. In free-surface thermal (natural) convection, i.e. a case of warm water body cooled from above by air, heat flows from the bulk warm water to the surface through conductive and convective modes. At the interface, heat is transferred through molecular conduction (sensible heat transfer) and evaporation (latent heat transfer). Evaporation results in the formation of a cool thin layer at the interface. The bulk warm water underneath has a lower density compared to the cool and denser interface which results in an unstable situation in the fluid layers.

Most of the previous studies on thermal convection were performed between parallel plates uniformly heated from below and cooled from above (i.e. wall-bounded natural convection). However, the convection beneath an evaporative water surface has not been adequately studied. There are only few studies reported in the literature that investigated the flow and thermal behavior beneath the air water interface during natural convection. Volino and Smith [1], Flack et al. [2] and Saylor et al. [3] measured water surface temperature using infrared imagery. All these studies observed that the temperature field at the water surface is complex and comprised of different scales of thermal structures that appear to be randomly located on the water surface. The results presented in these studies however, are mostly qualitative description of the surface temperature field.

The only detailed analysis of the temperature field in the thermal boundary layer beneath the water surface during thermal convection is reported by Katsaros et al. [4]. They measured the mean and instantaneous temperature profiles using resistance thermometer, traversing parallel and perpendicular to the surface. From the data and visualization of the flow, they deduced that the cold fluctuations were due to cold water plunging down from the boundary layer just under the surface. They argued that the thermal boundary layer acts as a source of the fluid for the cold sheets, and warm water enters the boundary layer from below by advection.

Volino and Smith [1], Flack et al. [2] and Bukhari and Siddiqui [5] have reported velocity measurements beneath the water surface during natural convection. Flack et al. [2] found that the surfactant influences the subsurface flow field and reduces the magnitude of turbulent fluctuations. Bukhari and Siddiqui [5] observed that the waterside flow field is three-dimensional that undergoes different flow interactions locally, which result in the formation of complex flow patterns. They also observed self-similar behavior in the turbulent velocities for different surface heat flux conditions and showed that the scaling parameters used for the flow above

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