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Evidence of double diffusion in the East China Sea

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Abstract

Double diffusion is an important phenomenon induced by the difference between the thermal conducting coefficient of the molecule and haline diffusive coefficient. Warm, salty water overlying cold, fresh water induces salt finger. On the contrary, when cold, fresh water overlies warm, salty water, diffusive convection occurs. In the East China Sea, double diffusion was observed during a cruise in September 2003. In order to describe the phenomenon precisely, Turner (TU) angle values are calculated station by station at Section YT. TU angle is a practical tool to indicate the water states. Different TU angle values represent salt finger, diffusive convection and stable stratification respectively. We map the distributions of the two forms of double diffusion at Section YT, and determine that the physical mechanism of the phenomenon is the mixing of water masses. The Changjiang Diluted Water (CDW) has great effect on the mixing of water masses, and the Kuroshio Water System dominates on the continental slope. Temperature and salinity varied in a manner consistent with double diffusion.

Keywords: Double diffusion; Salt finger; Diffusive convection; TU angle; Water mass; CDW

1. Introduction

Double diffusion is the name given to convective motions when density variations are caused by two different components which have different rates of diffusion. The typical example of this is heat and salt in the ocean. In physical oceanography, double diffusion is an important phenomenon when different water masses overlay induced by the difference between thermal conducting coefficient K_t of the molecule and haline diffusive coefficient K_s ($K_t \approx 10^2 K_s$).

When cold, fresh water overlies warm, salty water, the temperature has the unstable stratification. Because of the molecular diffusion, the lower water will lose heat to the upper water faster than it will lose salt owing to a hundred times larger heat diffusivity, i.e. $K_t \approx 10^2 K_s$. The water above/below the interface becomes lighter/denser and it will tend to rise/sink. As a result, the homogeneous layers are separated by thinner regions with large gradients. This phenomenon is called diffusive convection.

When warm, salty water overlies cold, fresh water, the water above/below the interface becomes denser/lighter and it will sink/rise to the lower/upper layer. As a result, the finger-shaped water columns of several centimeters occur in thin column. This phenomenon is called salt finger.

In total, about 44% of the oceans display double diffusion, of which 30% is salt finger and 14% is diffusive convection (You, 2002). These play an important role in the exchange of salt and heat in the ocean. The diapycnal tracer mixing rate observed in the western tropical Atlantic is 5 times that observed in the eastern subtropical Atlantic, because the temperature and

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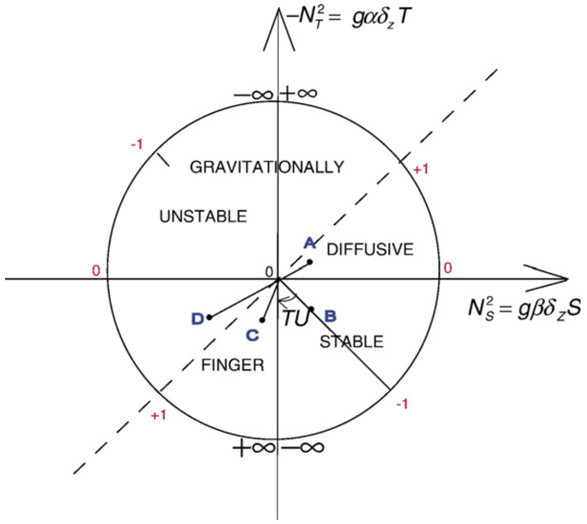

Fig. 1. Sketch of the definition of the Turner angle (R_ρ values are marked around the circle).

the salinity both decrease with depth (Schmitt et al., 2005). Oceanographers are increasingly accepting that one of the processes that can affect oceanic fine structure is double diffusion.

This paper discusses about the double-diffusive processes in the East China Sea by calculating TU angle (Ruddick, 1983) values, and discusses the relationship between double diffusion and the variation of temperature and salinity and the water masses, according to the data obtained from a cruise in September, 2003 which was carried out by the Chinese GLOBEC (Global Ocean Ecosystem Dynamics) and key international cooperation project (Hydro-geochemistry processes and their environmental effect induced by discharge in coastal sea of China, 2001CB711004), both funded by the Ministry of Science and Technology of China.

2. Method

Turner (1973) proposed the gradient ratio $R\rho = \alpha T_Z / \beta S_Z$ to indicate the relative strength of double diffusion, where $\alpha = -\rho^{-1}\partial\rho/\partial T$ is the thermal expansion coefficient on the order of 10^{-5}, $\beta = \rho^{-1}\partial\rho/\partial S$ is the haline contraction coefficient on the order of 10^{-4}, ρ is density, and T_Z, S_Z are the vertical temperature and salinity gradients respectively. Density variation due to salinity is 10 times that due to temperature when they change 1 unit.

In the oceanic case where a horizontal front is cold and fresh on one side and warm and salty on the other side, R_ρ is near 1, because temperature (T) and salinity (S) have an opposing effect on ρ and compensate each other. So both forms of double diffusion are most intense when R_ρ approaches 1.

Ruddick (1983) proposed plotting an angle that is simply related to R_ρ. Fig. 1 shows a graphic representation of the TU angle. The x- and y-axes represent, respectively, the salinity and temperature gradient contributions to the density gradient (z-axis is positive downward). Thus, a point in the water column can be represented by a point in the $-N_T^2$ vs. N_S^2 plane. The axes are defined as $N_S^2 = g\beta\delta_Z S$ and $-N_T^2 = g\alpha\delta_z T$, and the positive part of each axis corresponds to a stable stratification in the temperature and salinity (Bianchi et al.,

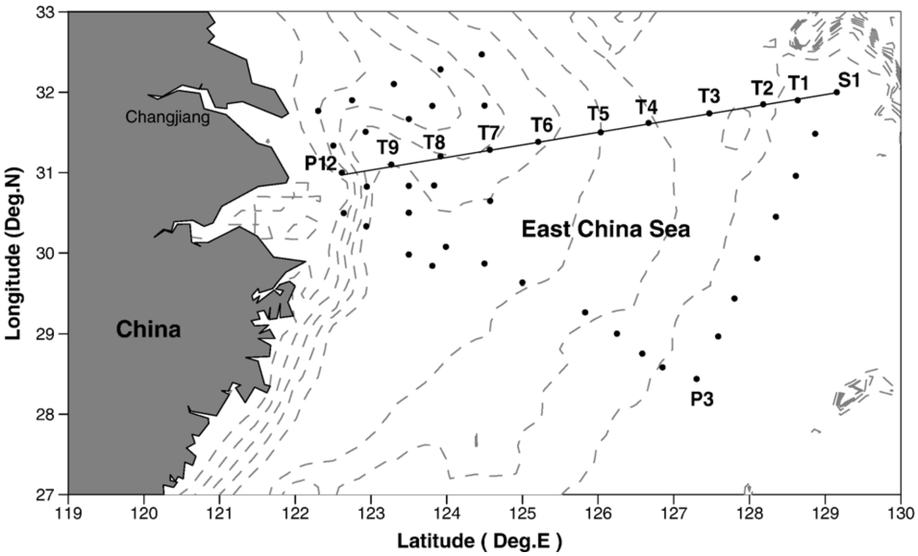

Fig. 2. Stations of the cruise in September 2003.