Upper Ocean Response to the Super Tropical Cyclone Phailin (2013) over the Freshwater Region of the Bay of Bengal

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Abstract

This study investigates the impact of salinity stratification on the upper-ocean response to a category-5 TC, *Phailin*, that crossed the northern Bay of Bengal (BOB) from October 08-13, 2013. A drastic increase of up to 5.0 PSU in sea surface salinity (SSS) was observed after *Phailin*'s passage, whereas a weak drop of below 0.5℃ was observed in sea surface temperature (SST). Rightward biases were apparent in surface current and SSS but not evident in SST. *Phailin*-induced SST variations can be divided into the warming and cooling stages, corresponding to the existence of the thick barrier layer (BL) and temperature inversion before and erosion after *Phailin*'s passage, respectively. During the warming stage, SST increased due to strong entrainment of warmer water from the BL, which overcame the cooling induced by surface heat fluxes and horizontal advection. During the cooling stage, the entrainment and upwelling dominated the SST decrease. The pre-existence of the BL, which reduced entrainment cooling by ~1.09 ℃ d^{-1}, significantly weakened the overall *Phailin*-induced SST cooling. The HYbrid Coordinate Ocean Model (HYCOM) experiments confirm the crucial roles of entrainment and upwelling in the *Phailin*-induced dramatic SSS increase and weak SST decrease. Analyses of upper-ocean stratification associated with 16 super TCs that occurred in the BOB during 1980-2015 show that intensifications of 13 TCs were associated with a thick isothermal layer, and 5 out of the 13 were associated with a thick BL. The calculation of TC intensity with and without considering subsurface temperature demonstrates the importance of large upper-ocean heat storage in TC growth.

Introduction

In the BOB, previous studies noted that in regions of weaker upper-ocean stratification, TC-induced SST cooling is around 2～6 ℃, while over the northern Bay with stronger upper-ocean stratification due to low surface salinity, the SST decrease is below 1.5 ℃. Using OGCM simulations, it has been suggested that in the BOB during the post-monsoon season, the salinity stratification accounts for 40% of the cooling reduction (Neetu et al. 2012). However, due to the lack of observations, an observational depiction of the effect of the BL, particularly with a pre-existing temperature inversion between the BL and ML, on TC induced SST cooling, is still lacking and the associated processes require in-depth investigation over the BOB.

Data and methods

- **DATA. Time-series observations from the RAMA buoy located at 15° N, 90° E, together with TS profiles from the three Argo floats are used to examine the evolution of atmospheric conditions and ocean response during *Phailin*. To provide a basin-scale view of the upper ocean response, we also analyze the gridded products of ocean surface currents, sea surface height (SSH), SST, SSS, ocean surface wind, surface heat flux, and precipitation. The 5-day resolution SODA 3.3.1 ocean reanalysis data are used to examine the barrier layer thickness (BLT), isothermal layer depth (ILD), and SST near the tracks of 16 super TCs for the period of 1980-2015.**
- **Methods. The effects of the BL, with a pre-existing temperature inversion between the ML and BL, on *Phailin*-induced surface cooling are quantitatively assessed, using field observations and a diagnostic ML temperature equation together with a hierarchy of experiments using the HYbrid Coordinate Ocean Model (HYCOM).**

Result

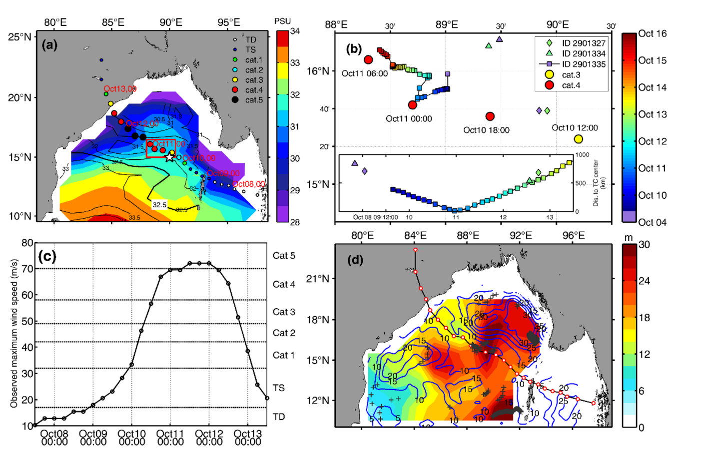

Fig1. (a) 6-hourly positions of TC *Phailin* and sea surface salinity (SSS) distribution for October 2013. (b) The positions of Argo profiles. (c) Time evolution of maximum wind speed and intensity of *Phailin*. (d) Barrier layer thickness (BLT; m).

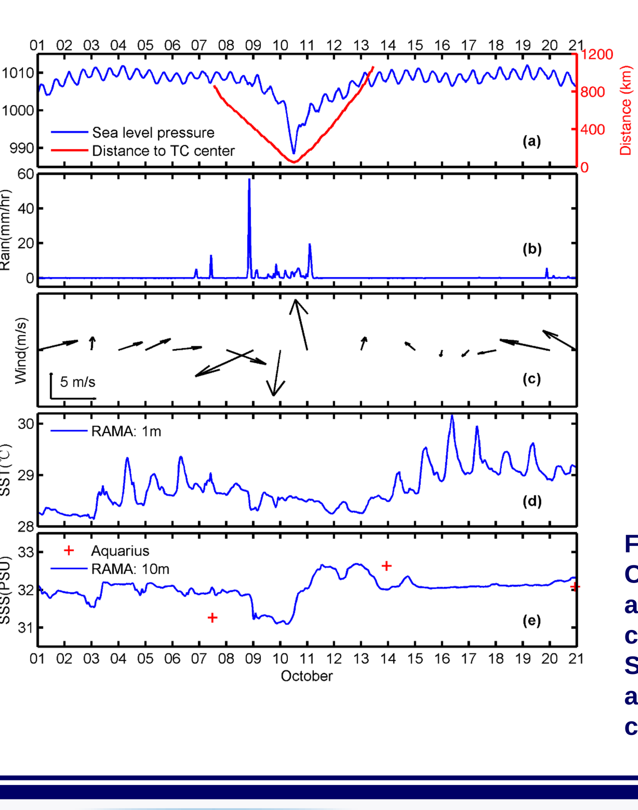

Fig2. Observations from the RAMA buoy at 90° E, 15° N:

(a) Sea level pressure

(b) Rainfall

(c) ASCAT 10m surface wind

(d) Sea surface temperature (SST)

(e) SSS measured at 10m depth

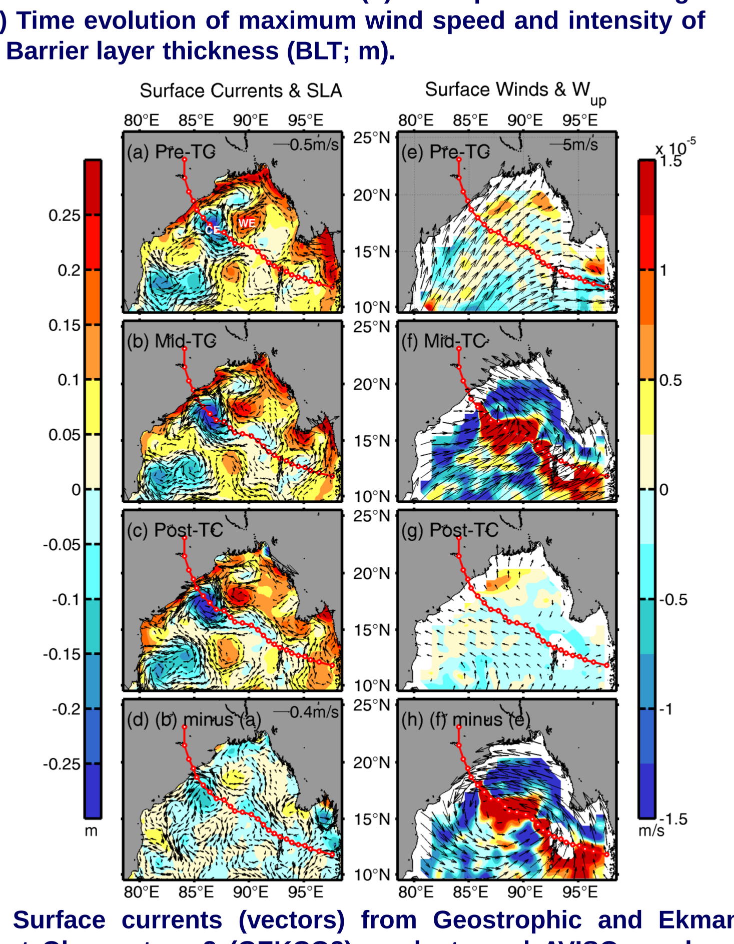

Fig3. Surface currents (vectors) from Geostrophic and Ekman Current Observatory 2 (GEKCO2) products and AVISO sea level anomaly averaged for: (a) Pre-cyclone (2-7 October), (b) mid-cyclone (8-13 October), and (c) post-cyclone (14-19 October); (d) Surface currents and SLA differences between (b) and (a); (e)-(h) are the same as (a)-(d) but for 10m ASCAT wind (vectors) and the corresponding Ekman pumping velocity (W_{up}, positive upward)

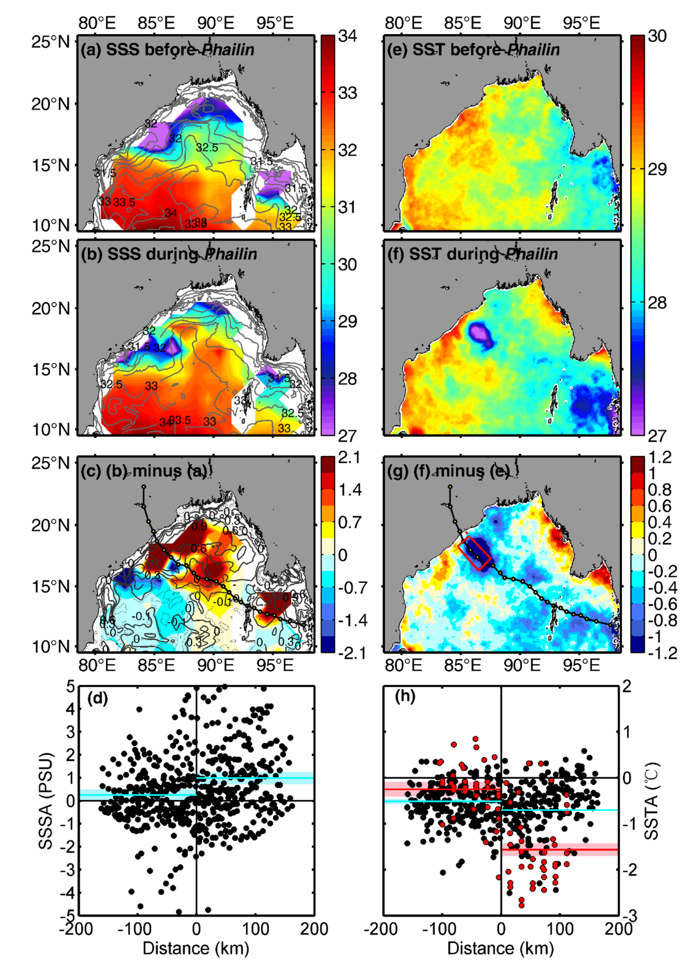

Fig4. Aquarius (shading) and HYCOM reanalysis (contours) SSS averaged for the periods: (a) before *Phailin* (1-7 October), (b) during *Phailin* (8-14 October), (c) the difference for (b) minus (a); and (d) scatter plot of SSS anomalies (SSSA) shown in (c) versus distance. (e)-(h) are the same as (a)-(d), respectively, but for SST anomalies (SSTA) from daily OISST.

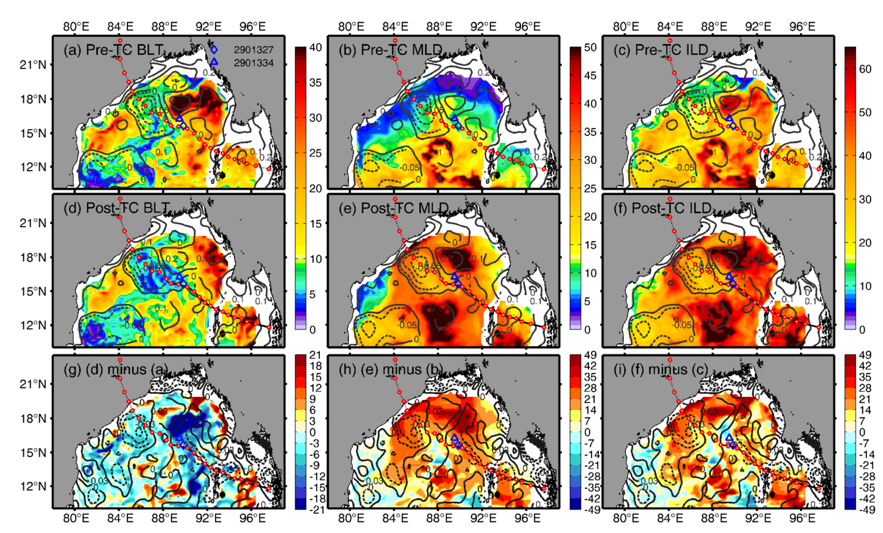

Fig5. Distribution of BLT (m; left panels) derived from HYCOM reanalysis (shading) and AVISO SLA (m; contours) for (a) 7 October before *Phailin*'s passage, (d) 12 October after *Phailin*'s passage, and (g) their difference, (d) minus (a). The middle column plots (b), (e) and (h), and the right column plots (c), (f) and (i) are the same as those on the left column but for MLD and ILD, respectively.

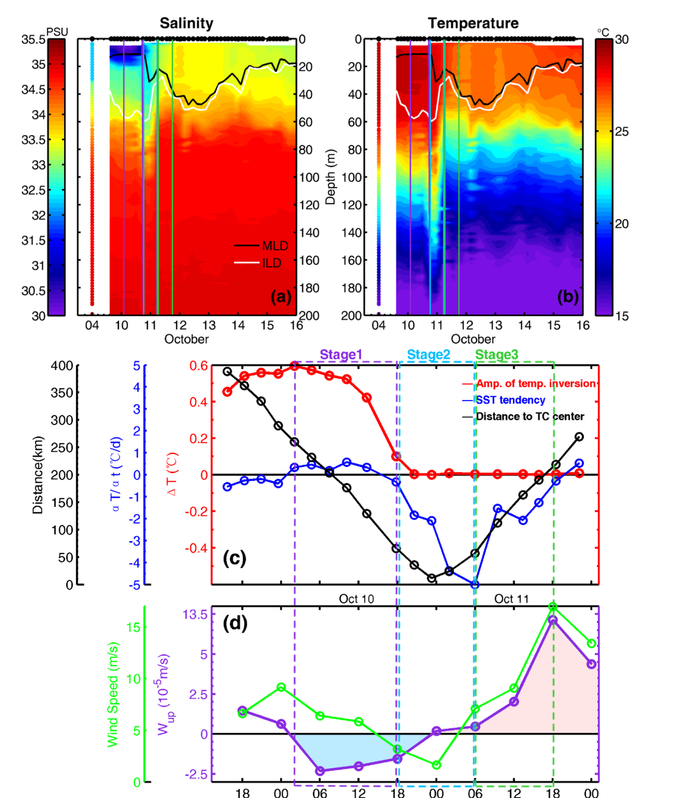

Fig6. Argo profiles of salinity (a) and temperature (b) from 4 Oct to 16 Oct observed by float 2901335. (c) Amplitude of the temperature inversion (red line); SST tendency (blue line); and distances (dark line) from Argo profiles to the TC center. (d) The same as (c), but for Ekman pumping velocity (W_{up}, positive upward, purple curve) and surface wind speed (green curve) estimated from 6 hourly CCMP2 wind.

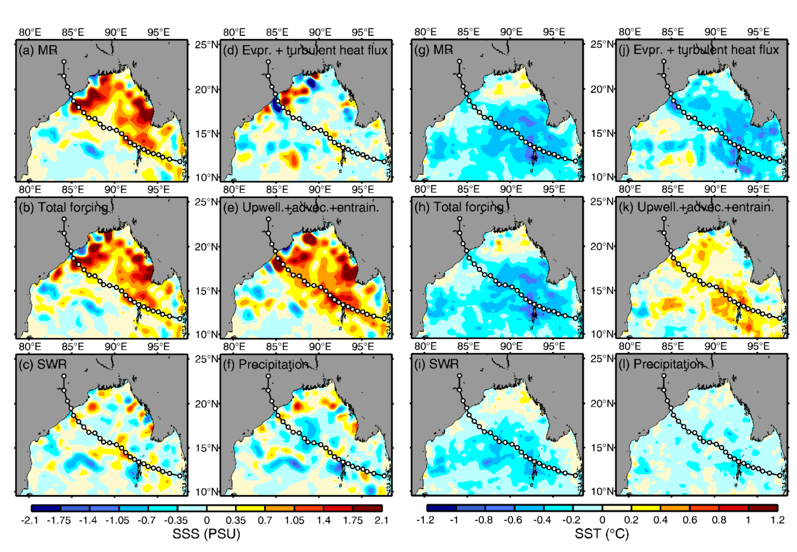

Fig7. (a) SSS difference (psu) between the period during *Phailin* (October 8-14 mean) and the period before *Phailin* (October 1-7 mean) from the HYCOM MR solution. Panels (b)-(f) are SSS differences from: (b) the HYCOM experiment runs that isolate the effects of total TC forcing, (c) SWR forcing, (d) the evaporative and turbulent heat fluxes associated wind speed forcing, (e) upwelling+advection+entrainment associated with wind stress, and (f) precipitation forcing; panels (g) - (l) are the same as (a) - (f), respectively, but for SST.

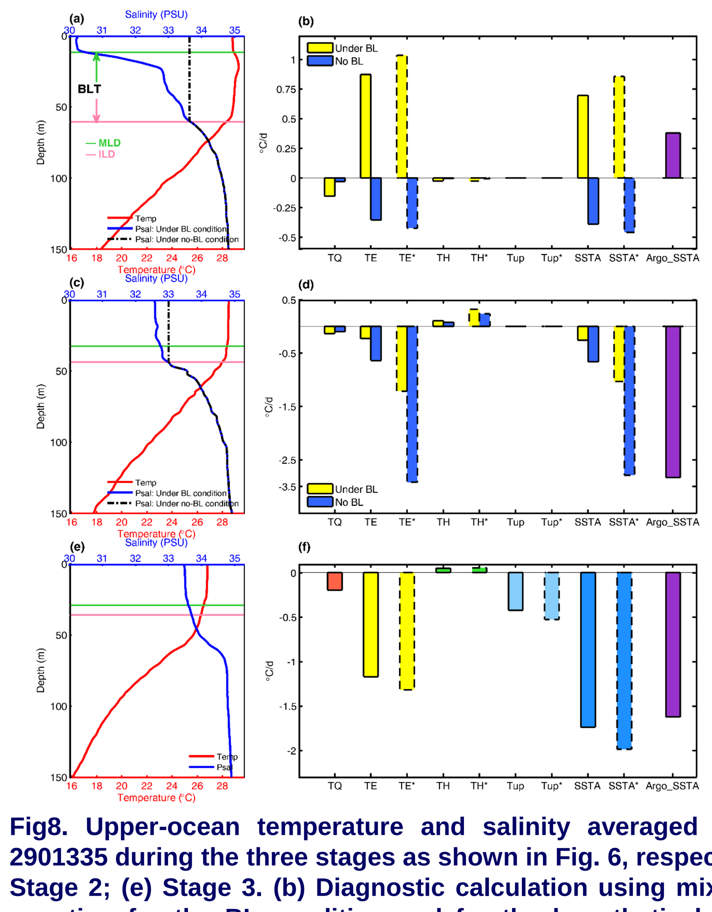

Fig8. Upper-ocean temperature and salinity averaged from the Argo float 2901335 during the three stages as shown in Fig. 6, respectively: (a) Stage 1; (c) Stage 2; (e) Stage 3. (b) Diagnostic calculation using mixed-layer temperature equation for the BL condition and for the hypothetical situation with no BL during Stage 1. The SSTA is the sum of TQ, TE, TH, and Tup, and Argo_SSTA is the observed SST tendency. Panels (d) and (f) are the same as (b) but for Stages 2 and 3, respectively.

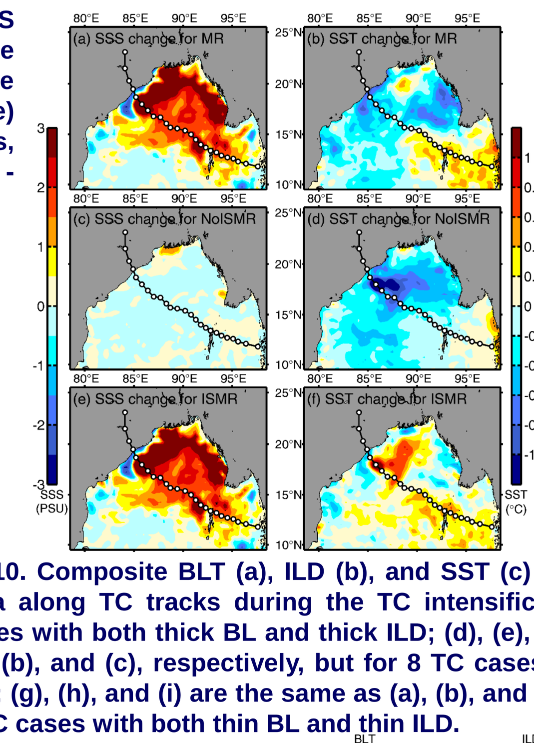

Fig9. (a) SSS difference for Oct 12 minus Oct 8 from the HYCOM MR; (c) the same as (a), but from HYCOM NoISMR, which suppressed the effects of freshwater fluxes from summer monsoon rainfall and river discharges; (e) SSS difference between HYCOM MR and NoISMR; panels (b), (d) and (f) are the same as (a), (c) and (e), respectively, but for SST.

Fig10. Composite BLT (a), ILD (b), and SST (c) from the SODA pentad data along TC tracks during the TC intensification periods for 5 TC cases with both thick BL and thick ILD; (d), (e), and (f) are the same as (a), (b), and (c), respectively, but for 8 TC cases with thin BL but thick ILD; (g), (h), and (i) are the same as (a), (b), and (c), respectively, but for 3 TC cases with both thin BL and thin ILD.