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# Impact of seasonal river input on the Bay of Bengal simulation

Sudip Jana [a,b,c], Avijit Gangopadhyay [b,a], Arun Chakraborty [a,*]

[a] Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology Kharagpur, India
[b] School for Marine Science and Technology, University of Massachusetts Dartmouth, USA
[c] Department of Earth, Ocean and Atmospheric Science, Florida State University, USA

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ABSTRACT

This study seeks to better understand the impact of seasonal river input on the Bay of Bengal (BoB) using the Regional Ocean Modeling System (ROMS). To quantify the effects, two parallel climatological simulations (with and without rivers) were carried out for fifteen years. While the temperatures at river mouths along the model's coastal boundary were relaxed to the monthly climatology, observation-based reconstructed seasonal cycles were provided for salinity with monthly discharges for ten selected rivers. The result shows significant improvement (50–70%) in the model-simulated near-surface salinity, freshwater plume, stratification, mixed-layer depth and barrier-layer thickness (BLT) with river input. The river input reduced the domain-averaged annual surface salinity and surface density by 0.99 psu and 0.73 kg/m$^3$, respectively, when compared to the no-river simulation.

One of the major impacts of river inclusion in the simulation is the formation, dispersion and demise of the freshwater plume system in the Bay. Two separate large-scale (Kelvin Number $\gg 1$) freshwater plumes form by surface-advection during April–May, one near the Ganges–Brahmaputra–Meghna (GBM) river system mouths at the head of the Bay, and another further south near the mouths of the Irrawaddy–Sittang–Salween (ISS). They merge and evolve as one plume system to cover almost half of the domain in October and to occupy the largest volume in November. The formation and dispersion of the plume system correspond well with freshening in the northern Bay, affecting seasonal stratification with the formation of barrier layer, and subsequent advection of the freshwater by eddies and fronts along the East India Coastal Current (EICC). The simulated domain-averaged BLT was minimum during March–May and maximum during October–February. Simulations indicate that the river input is necessary in addition to precipitation-minus-evaporation in setting up the near-surface stratification and for the formation of barrier layer in the BoB.



## 1. Introduction

The Bay of Bengal (BoB) receives a large amount of freshwater (Varkey et al., 1996; Thadathil et al., 2002) from a number of rivers in its bordering countries. These freshwater influxes along with local precipitation make the surface layers of the northern BoB the freshest region in the Indian Ocean. The annual climatological salinity for the Bay is presented in Fig. 1 in our study domain. The north–south salinity contrast is generally attributed to excess rainfall and to the fact that the main stream of the Ganges–Brahmaputra–Meghna (GBM) is located at the northeastern corner of the BoB, and which therefore receives major part of the discharge. From hydrographic survey analysis, Murty et al. (1992a, 1992b) reported surface salinity of 26 psu during September 1983 being reduced to as low as 16 psu in the northern end of the BoB during the 1984 southwest monsoon; while remaining as high as 35 psu in its southwestern part.

The excess freshwater input produces a sharp vertical salinity gradient that leads to strong density stratification in the near-surface layer of the northern BoB (Shetye et al., 1996; Gopalakrishna et al., 2002), which complicates the hydrography. This strong stratification suppresses the overturning and turbulent mixing between surface and nutrient rich cold subsurface layers. This suppression results in warmer SST (Shenoi et al., 2002) and less productivity (Prasanna Kumar et al., 2002) in the BoB than in the Arabian Sea during summer monsoon, which indirectly affects the marine ecosystem and fishery in the Bay. The near-surface freshwater cover produces a shallow halocline above the thermocline, causing the formation of the barrier-layer (Vinayachandran et al., 2002; Rao and Sivakumar, 2003; Thadathil et al., 2007 (TM07, hereafter)) in the BoB. The existence of the barrier layer

* Corresponding author.
*E-mail address:* arunc@coral.iitkgp.ernet.in (A. Chakraborty).

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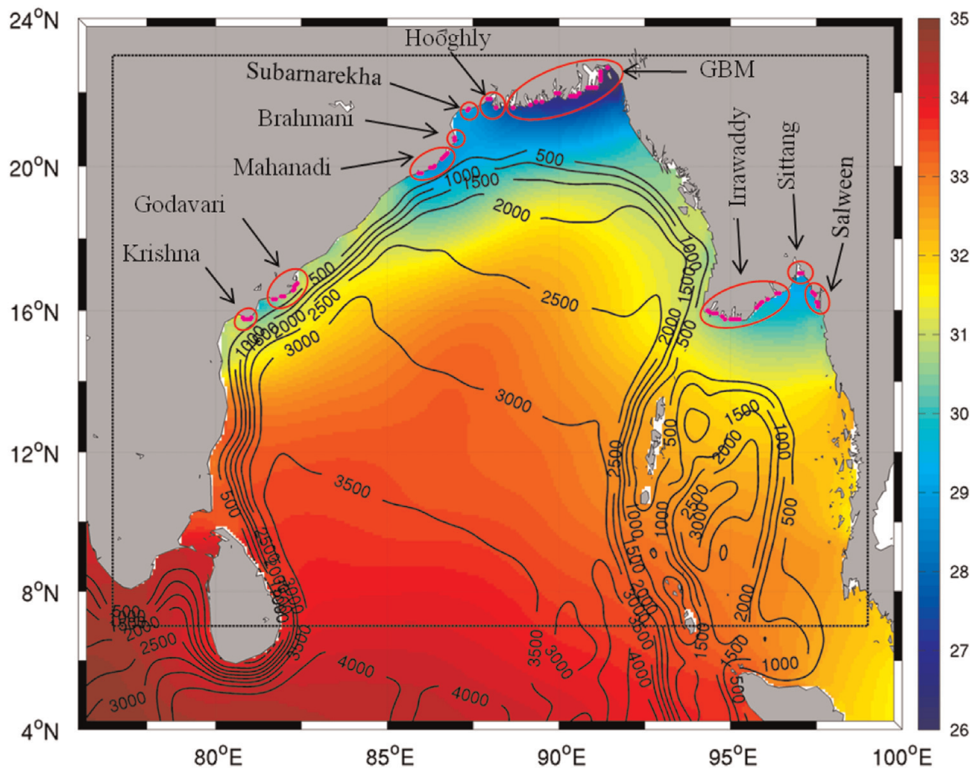


**Fig. 1.** The model domain with climatological annual salinity (shaded background). Contours represent the model bathymetry values. Dotted black line represents the boundary of the domain of analysis. Magenta points along the boundary are the locations of the point sources.

restricts the vertical heat transfer between the mixed layer and the thermocline (Rao et al., 2002). This restriction helps to form a subsurface temperature inversion (Thadathil et al., 2002; Thompson et al., 2006) by keeping the subsurface layer warmer while limiting surface heat loss within the surface layer during winter in the BoB.

The formation of the freshwater plume in the northern and western Bay during summer monsoon and its subsequent movement and dispersion during post-monsoon have been the subject of many observational studies including those by Murty et al. (1992a,b), Shetye (1993), Gopalakrishna et al. (2002), and Vinayachandran and Kurian (2007). Shetye (1993) observed a low-salinity tongue along the western boundary of the Bay extending down to 17°N which was detached from the coast south of 19°N during July–August 1989. Shetye et al. (1996) found a narrow stretch of low-salinity water along the entire coast during December 1991 and identified it as remnants of the freshwater plume. Vinayachandran and Kurian (2007) also reported a freshwater plume along the east coast of India during the summer monsoon of 1999, initially moving along the coast and then spreading offshore after being separated from the coast. They observed a very shallow mixed layer (10–15 m) within and a deeper mixed layer outside the plume area.

Several studies have sought to quantify the contribution of rivers relative to the local precipitation-minus-evaporation ($P-E$) in making up the effective freshwater influx to the Bay. Han and McCreary (2001) showed that the model simulated BoB mixed layer was 2–4 psu saltier than the climatology when forced by only $P-E$, which freshened by 1–10 psu when river input was added. They justified the excess lowering of the salinity below climatological values due to inclusion of rivers to be realistic because they were closer to the synoptic salinity observed near the head of the Bay. Although the river input has a significant impact on the BoB SSS, its effect on SST is small (Han et al., 2001; Howden and Murtugudde, 2001 (HM01, hereafter); Seo et al., 2009 (S09, hereafter)). S09 reported a summertime warming and a wintertime cooling in the BoB SST after inclusion of river runoff. The maximum intensity of both the warming and the cooling takes place at the northern end of the Bay, where the river input is maximum. HM01 reported that although the ocean absorbs more heat when river input is added, the SST is slightly cooler because of enhanced entrainment cooling of the shallower mixed layer by penetrative heat loss through the base of the mixed layer and latent heat loss.

Han et al. (2001) showed that the river water remains in the northeastern part of the Bay during summer monsoon and, being advected by the EICC, moves southward along the coast and flows out of the Bay during winter monsoon. According to Han et al. (2001), an additional freshwater plume flows along the eastern boundary of the Bay and reaches the southern end earlier than its counterpart along the western boundary. Recently, using the discharge data from 1992 to 1999, Durand et al. (2011) showed that the impact of interannual variability of Ganges–Brahmaputra discharge on the BoB salinity is mostly confined to the north of ~10°N. However, the extreme discharge anomaly of 1998 was exported from the Bay and penetrated the southeastern Arabian Sea.

The mechanisms controlling the propagation of a freshwater plume similar to the one in the BoB has been investigated by many studies in different parts of the world oceans. Yankovsky and Chapman (1997) (YC97, hereafter) developed a simple theory of governing mechanism for plume fate. They brought the ideas of buoyancy-driven surface advection and topography-constrained bottom-trapped plume advection in a competing mode within a single formulation. Garvine (1995) characterized plumes based on Kelvin Number ($K$). Lentz and Helfrich (2002) used scaling theory to identify plume characteristics distinguishable in the ocean environment. Banas et al. (2009) studied the impact of the Columbia River plume on the Washington shelf water under upwelling condition. Whitney and Garvine (2006) (WG06, hereafter) studied