Reply to Reviewer #2

Dear Prof. Hui Wu,

We thank you very much for your very insightful and constructive comments to improve our manuscript. According to your comments, we have carefully revised the manuscript. Please see the detailed responses to each comment below. The comments are cited in black. The response to each comment is set out in blue. The revised manuscript will be submitted at the stage of revision.

Lei Lin

In this paper the authors investigated the tidal effects on freshwater transport in shelf seas of China with a numerical model. The results indicated that tide slows down the shelf currents and increases the time scale of freshwater retained in the shelf seas. Then the authors argued that only parameterizing the tidal mixing in model cannot faithfully reflect the actual tidal effects, thus they suggest the climate models should include the tidal forcing in an explicit way. Over all the scientific point of this paper is very clear and the conclusion is well supported by the model results. I enjoyed in reading this paper and recommend to accept it after some revisions.

1. My major concern is on the dynamics. The authors attribute the slowdown of shelf current under tidal effects to the enhanced bottom stress. This mechanism was discussed too in their earlier paper (Lin et al., 2020, JGR) by citing the results of previous papers. I should say that this mechanism applies more or less to barotropic region only. In stratified region, tidal can also adjust the baroclinic structure thus affect the currents in other ways. It is a complicated process and the authors cannot simply attribute it to the enhanced effective friction. More discussions are necessary besides the sensitivity experiments, and also the authors should cite the seminal paper instead of just Lin et al. (2020).

   Response: Following your comment, we discussed the effect of tides on the shelf currents in-depth and cited more seminal papers to support the analysis in the revised manuscript.

The comparison of the shelf currents between the Control run and NoTide case shows that the change in the shelf currents mainly occurred in the coastal region and the central Yellow Sea (Figures S1a-S1d), and the change in winter is more significant than that in summer (Figures S1e-S1f). The analysis of water transport fluxes by Lin et al. (2020) showed the winter season accounted for ~73% of the volume transport for the entire year and suggested that the winter processes dominate the water exchange of the Yellow Sea. Due to the strong surface cooling, the coastal water (even in the central Yellow Sea) in winter was well-mixed. Thus, the change in the barotropic process could dominate the change of the shelf currents. In addition, the change in the coastal current along the Jiangsu and Zhejiang coasts shows southward in winter and northward in summer (Figure S1e and S1f), which are consistent with the directions of the seasonal wind-driven currents (northerly wind in winter and southerly wind in summer). This indicates that the wind-driven coastal current was significantly weakened by tides, which can be explained by the nonlinear interaction between tides and wind-driven current in a quadratic bottom friction term (e.g., Moon, 2005; Wu et al., 2018). When considering tides, the period-mean bottom resistance becomes about one order larger due to the quadratic nature of the bottom friction and thus greatly reduced the wind-driven coastal currents (Wu et al., 2018). Besides the tidally enhanced bottom resistance, the tidally enhanced mixing and induced residual current and residual transport could also modulate the shelf currents, especially during the stratified season (e.g., Moon, 2005; Lie and Cho, 2016; Moon et al., 2009; Wu et al., 2011; Wu et al., 2014; Wu and Wu, 2018). Moon et al (2009) suggested that the tidal forcing induces a strong southward residual flow along the western slope of the Yellow Sea in summer, which can explain the change of northward current in the NoTide case in the middle of the Yellow Sea (Figure S1f). Wu et al. (2011) suggested that tidally enhanced mixing resulted in a strong horizontal salinity gradient at the north of the Changjiang River mouth, which acted as a dynamic barrier and restricts the northward transport of the Changjiang River water to the Jiangsu coast in summer.

In addition, strong tidal mixing induces a mixing front along the Zhe-Min coast and maintains a down-shelf frontal current (Wu and Wu, 2018), which is important for the southward transport of the Changjiang River water. Overall, the tidal effect on the shelf current is complicated and diverse. However, the tidally enhanced bottom stress should be the dominant mechanism due to the important role of winter currents in the water exchange and the significant change in the winter coastal current in the Control run and NoTide case.

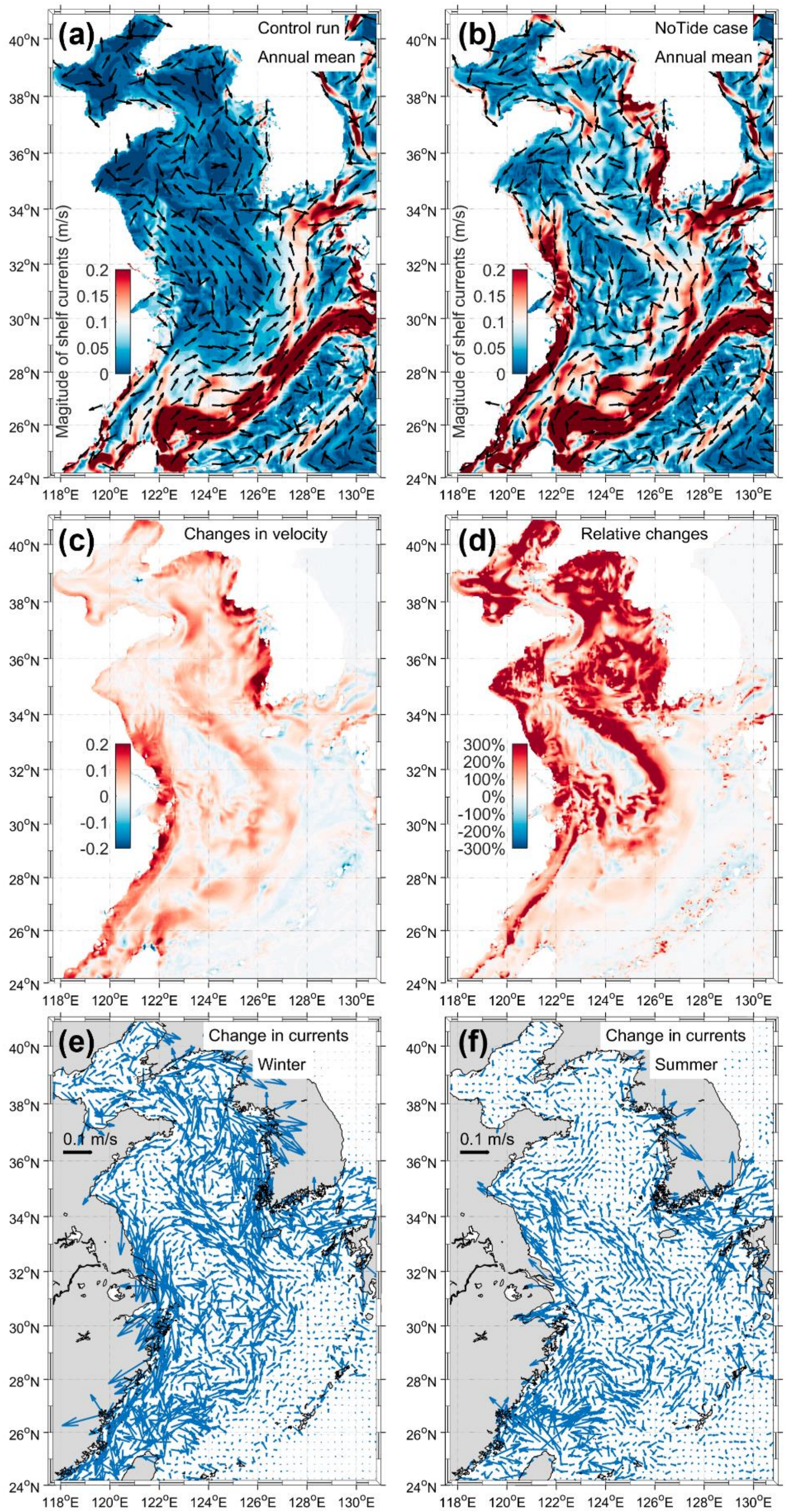

Figure S1. Comparison of the shelf currents between the Control run and NoTide case. (a) and (b) are the annual mean and vertically averaged velocities for the Control run and No-Tide case, respectively. The arrow and color in (a) and (b) denote the direction and magnitude of the velocity, respectively. (c) and (d) show the change and relative change in the magnitude of the shelf currents after removing tides in the model. (e) and (f) show the changes in shelf currents in February and August, respectively.

2. Between Line 285-290 the authors stated that "the decrease in coastal currents results in a smaller gradient of sea surface height across the continental shelf, thus weakening Yellow Sea Warm Current in the control run compared to the no-tide run". This mechanism needs justification because (1) under the tidal effects the currents is no longer geostrophic (2) it is unclear why the decreased SSH gradient would weaken the YSWC, mechanism and citations are needed. I understand such a mechanism could be discussed in previous results, but here you might give a clear explanation.

Response: Following your comment, we explained the effect of tides on the Yellow Sea Warm Current in-depth and cited more papers to support the discussion in the revised manuscript.

(1) Yes, under the tidal effects the high-frequency currents were no longer geostrophic. However, the Yellow Sea Warm Current (YSWC) in this study was discussed on the timescale of as least one month (i.e., only the subtidal transport is concerned), and the YSWC can be considered quasi-geostrophic on the timescale of months. For instance, the model results in Moon (2005) showed that the momentum at the YSWC in February was balanced by the pressure gradient, Coriolis force, and vertical vorticity term when considering tides (Figure 11 in Moon, 2005). In addition, tides might influence subtidal transport by inducing tidal stress. Wu et al. (2018) showed that the tidal stress mainly occurred in the shallow coastal water and less influenced the central Yellow Sea (Figure 10 in Wu et al. 2018). Thus, the YSWC on the subtidal timescale should be quasi-geostrophic even under the tidal effect.

(2) Several studies have interpreted the formation of the YSWC using the upwind theory (e.g., Hsueh and Yuan, 1997; Isobe, 2008; Lin et al., 2011). The mechanism is outlined below. In the semi-enclosed Yellow Sea, the wind stress is the dominant

forcing in winter and thus the currents along the eastern and western coasts are in the same direction as the northerly wind. The outward coastal currents on both sides can reduce the water elevation inside, pile up water mass at the downwind end, and form the negative pressure gradient (decrease to the north). Along the trough of the central Yellow Sea, the water is deep. The depth-averaged wind stress is small and too weak to counter the northward pressure gradient force. This imbalance results in a pressure-driven flow that is opposite to the direction of the surface wind along the trough of the Yellow Sea. Under the effect of the Coriolis force, the upwind current is further geostrophically adjusted and slightly shifted to the western side of the trough to satisfy the balance of the potential vorticity (Lin et al., 2011). When considering tides, enhanced bottom friction weakened the coastal currents and thus decreased the water elevation difference and thus the pressure gradient (Moon 2005; Lin et al., 2020). Meanwhile, the enhanced bottom friction below the YSWC further counters a part of the northward momentum (Moon 2005). Thus, the weaker YSWC was presented in the model with tides. The response of the YSWC on the change in bottom friction was also reproduced in an idealized semi-enclosed region and more detail is discussed by Lin et al. (2011).

3. Line 190 “suggesting the YSCWM region could trap river water for several years”. YSCWM is in the bottom, how could it trap the surface river water? Mechanism should be given.

   Response: Yes, the YSCWM occurred at the bottom of the Yellow Sea during the stratified season. It formed mainly due to the retention of the winter cold water (Zhang et al., 2008). The water in winter is well mixed in the Yellow Sea (e.g., Zhu et al., 2018; Lin et al., 2019). Thus, some surface river water in the Yellow Sea could be mixed in the whole water column in winter and partially stay at the bottom during the stratified season. We have added this comment to the revised manuscript.

4. Can you provide a more in-depth explanation as to why tides induced more dispersed transport pathways for the Yellow and Yalujiang Rivers, but more concentrated transport pathways for the Changjiang River? It is very interesting to know the underlying mechanism.

   Response: The mechanism is summarized in Figure S3. The different tidal effects should be related to the different water transport patterns of the rivers. For the Yellow and Yalujiang Rivers water, the west coast of the Korea Peninsula with strong tides and cross-shelf tidal currents (Figure S2) is their main transport pathway (Figure 2 in the manuscript). As shown in Figure S1e, without considering tides, the southward coastal current along the west coast of the Korean Peninsula was intensified, especially in winter, which accelerated the river water export and reduced the transport timescales of the Yellow and Yalujiang Rivers' waters. When considering the tides, on one hand, the cross-shelf tidal currents along the coast can increase the cross-shelf water dispersion as the magnitude of tidal dispersion is proportional to the tidal velocity (Geyer & Signell, 1992). On the other hand, the weakened coast current slowed down the along-shore transport of the river waters and further promoted the cross-shelf water dispersion. Thus, compared to the NoTide case, the Control run obtained a more dispersed transport for the Yellow and Yalujiang Rivers' waters. For the Changjiang River, there are three major branches for the river water transport, i.e., the northeastward branch to Cheju Island, the northward branches to the Jiangsu coast, and the southward branch to the Zhejiang coast (Wu et al., 2014). The northeastward branch to Cheju Island is the dominant one for the Changjiang River water transport. In the NoTide case, the intensified coastal currents could increase the river water transport to the Yellow Sea along the Jiangsu coast in summer and to the East China Sea along the Zhejiang coast in winter, which intensified the northward and southward branches of the Changjiang River water transport. Thus, the water particles of the Changjiang River in the NoTide case were more dispersed than those in the Control run. We have added this discussion to the revised manuscript.

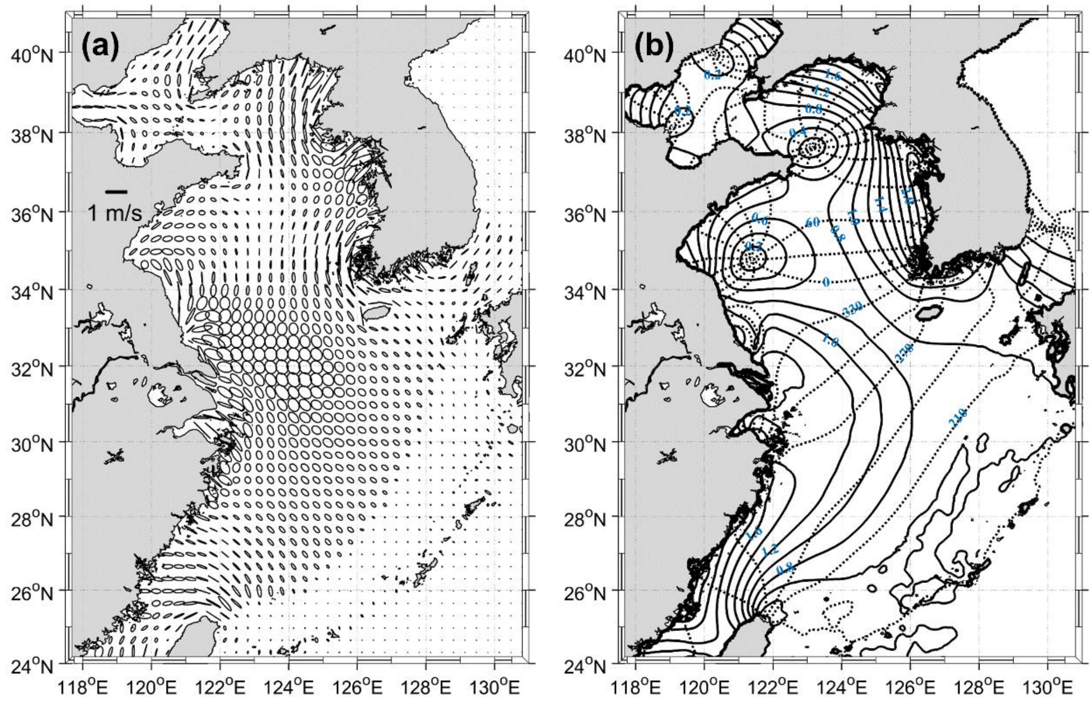

Fig. S2. (a) Tidal ellipses for M2 tide. (b) Contour lines of coamplitude (solid lines, with an interval of 0.2 m) and cophase (dashed lines, with an interval of 30°) for M2 tide.

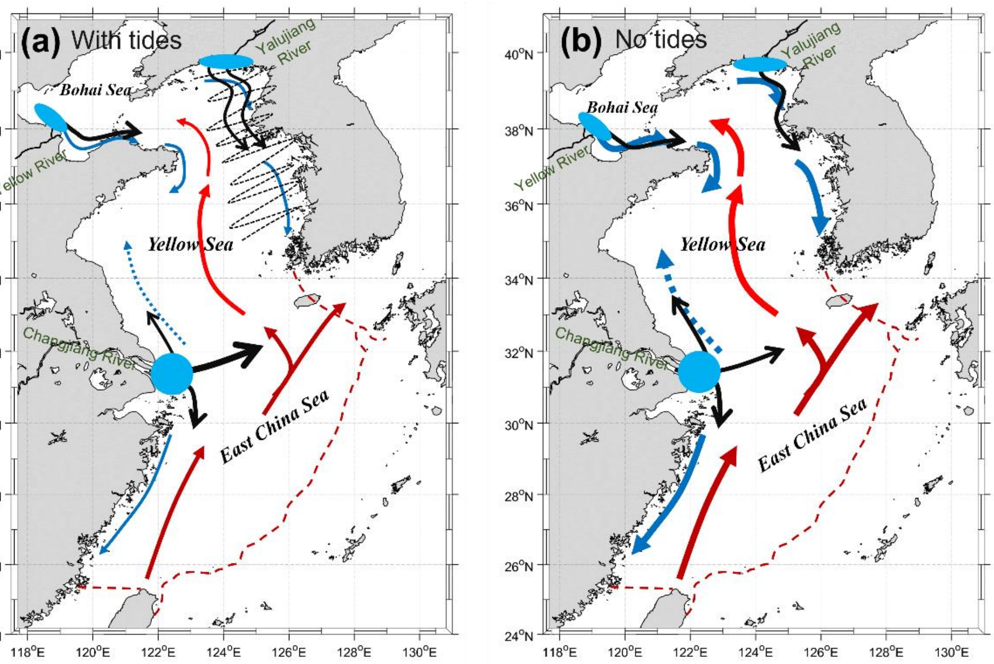

Figure S3. Schematic map of the shelf currents and the major pattern of the river water transport for the Control run (a) and NoTide case (b). The blue and red arrows denote the coastal currents and warm currents, respectively. The blue dashed arrow at the Jiangsu Coast denotes the coastal current in summer. The thickness of the arrows denotes the intensity of the shelf currents. The black dashed wavy line in (a) denotes the cross-shelf dispersion induced by tides. The black arrows denote the direction and the branches of the river water transport.

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