Reply to anonymous referee #3

Dear referee,

We appreciate your valuable questions and comments on our manuscript. The point-by-point answers to the questions and comments are listed as follows.

Your sincerely,

Jianrong Zhu, on behalves of the co-authors

Major issues:

Major issue 1: There are many studies about the influence of winds on saltwater intrusion in the estuary. But authors only mentioned two papers (Xue et al., 2009; Li et al., 2012) about the Changjiang Estuary. Even about the Changjiang Estuary, there are not only two papers.

Reply: Thanks for your good suggestion. Now we added the following papers the influence of winds on saltwater intrusion in the estuary.

Aristizabal, M. F., and Chant, R. J. (2015): An observational study of salt fluxes in Delaware Bay, Journal of Geophysical Research-Oceans, 120, 2751-2768, 2015.

Chen, S. N., and Sanford, L. P.: Axial wind effects on stratification and longitudinal salt transport in an idealized, partially mixed estuary, Journal of Physical Oceanography, 39(8), 1905-1920, 2009.

Duran-Matute, M., Gerkema, T., and Sassi, M. G.: Quantifying the residual volume transport through a multiple‐inlet system in response to wind forcing: The case of the western Dutch Wadden Sea, Journal of Geophysical Research: Oceans, 12, 8888-8903, 2016.

About the Changjiang Estuary, the following papers the influence of winds on saltwater intrusion were added.

Wu H., Zhu J. R., and Choi B. H.: Links between saltwater intrusion and subtidal circulation in the Changjiang Estuary: a model-guided study, Cont. Shelf Res., 30, 1891-1905, 2010.

Zhang E, Gao S, Savenije H. H. G, Sic C, and Cao S: Saline water intrusion in relation to strong winds during winter cold outbreaks: North Branch of the Yangtze Estuary, Journal of Hydrology, 574: 1099-1109, 2019.

Ding L., Dou X. P., Gao X. Y., Jiao J., and Hu J.: Response of salinity intrusion to winds in the Yangtze Estuary, Proceedings of 5th International Conference on Hydraulic Engineering, CHE2017, 241-247, 2017.

Major issue 2: About the strong wind event, it should be defined such as wind speed and duration. Authors said that from February 5 to 14, 2014 a persistent and strong northerly wind occurred lasting ten days. And they presented that only a strong northerly wind lasting 8 days can produce a severe saltwater intrusion in the Changjiang Estuary. But seen from plot c of Figure 2, on 5-6 the wind directions were southerly and easterly, and the winds seemed not strong. On 12-14, the winds were not strong as well. Authors should show what magnitude of wind event could induce severe saltwater intrusion. In plot c of Figure 2, the curve of wind speeds should be added. Thus the magnitude of winds can be seen clearly. What kind of data was used in plot c, instantaneous value, 2 minutes average, or maximum in a gust of wind? They should be presented clearly. In addition, the weather station locates inside the estuary near the mouth. The wind direction at this station may be different from the sea.

Reply: Thanks for your good question. There is really no definition of strong wind causing severe saltwater intrusion in the Changjiang Estuary. From the observed and simulated wind, and results of numerical experiments for wind effect on saltwater intrusion in the estuary, wind with speed of greater than 10 m/s and lasting 8 days can be called strong wind.

We checked the wind in plot c of Figure 2, the wind was southerly on 3 and easterly on 4, and was northeasterly on 5 with speed of approximately 10 m/s. The mean wind speed on 12-13 was approximately 10 m/s, and was only 5 m/s on 14. In fact, the measured wind at the weather station on the Chongming eastern shoal was just used to describe the phenomenon of persistent and strong wind, and was not used to simulate the severe saltwater intrusion event. The actually used wind in the model was the one simulated by the WRF, which wind speed adjacent sea near the Changjiang River mouth was stronger than on the Chongming eastern shoal (Figure R3-1). Now the sentence “a persistent and strong northerly wind from February 5 to 14, 2014, lasting ten days” was changed to “a persistent and strong northerly wind from February 5 to 13, 2014, lasting nine days”.

In plot c of Figure 2, the curve of wind speeds has been added (Figure R3-2).

This figure was enlarged to be seen clearly the wind vector and wind.

The wind data used in plot c was 2 minutes average one, and was illustrated in the revised manuscript.

Yes, the weather station locates inside the estuary near the mouth, and the wind direction at this station was somewhat different from the sea (seen in Figure R3-1 and Figure R3-2). It needs to be emphasized again that the actually used wind in the model was the one simulated by the WRF, which wind speed on the sea was stronger than the one on the Chongming eastern shoal.

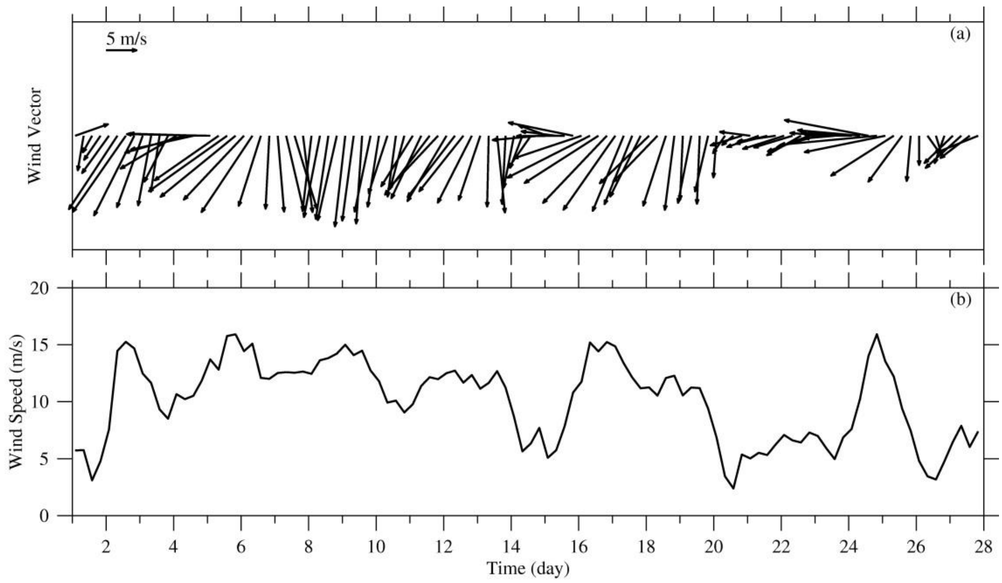

Figure R3-1 Temporal variations in wind vector (a) and wind speed (b) simulated by the WRF model off the Subei coast in February 2014.

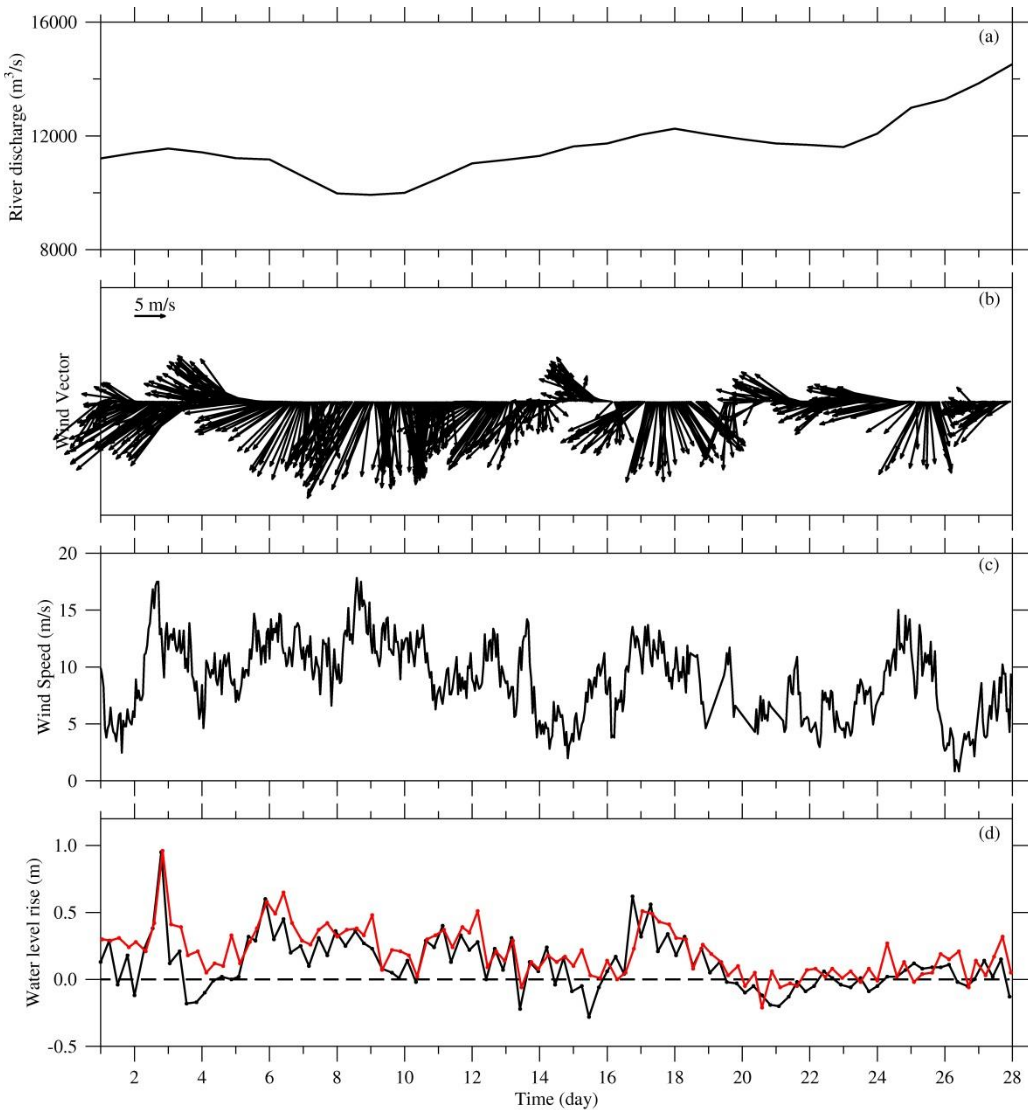

Figure R3-2 Temporal variations in the measured river discharge at Datong station (a), wind vector (b) and wind speed (c) at WS, and water level rise obtained by subtracting the data in the tide table from the measured water level at Sheshan station (black line) and Luchaogang station (red line) (d) in February 2014 in February 2014.

Major issue 3: This severe saltwater intrusion event is strange. The peak salinity at Baozhen and Nanmen stations reached 20.1 and 12.4 respectively. But why did the salinity only reach 8.6 at Qingcaosha? The location of Qingcaosha is close to Baozhen, and downstream of Nanmen. It can be seen from plot a of Figure 2 that salinity at

Qingcaosha was much lower than Baozhen. In addition, salinity at Chongxi station is from the North Branch. Before 7 February salinity was high at Chongxi, very low even close to zero at other stations. But during the severe event salinity was very high at other stations, but low at Chongxi station. These need explanation.

Reply: It's a good question, and is exactly what this manuscript wants to reveal. From the longitudinal view, the extremely saltwater intrusion in February 2014 was came from the downstream sea, consequently the peak salinity at Baozhen, Nanmen and Chongxi stations was 20.1, 12.4 and 4.0 during the event, respectively.

From the transverse perspective, although the location of Qingcaosha is close to Baozhen and downstream of Nanmen, the salinity only reached 8.6 at Qingcaosha, and was much lower than Baozhen. This was because the saltwater water was brought by the flood current and turned to right under the effect of Coriolis force that made the salinity was higher on the north side than on the south side of the North Channel. The simulated salinity distribution showed the same phenomenon. No matter in normal condition or in the abnormal condition (i.e., the studied case), this transverse difference of salinity was same.

At normal condition with climatic wind in dry season, there exits the saltwater-spill-over (SSO) from the North Branch into the South Branch in spring tide that results in the salinity at Chongxi station is higher than at Nanmen and Baozhen stations. This is the most feature of saltwater intrusion in the Changjiang estuary, and is a well-known phenomenon, that makes salinity is high at Chongxi station than at Nanmen and Baozhen stations. While during the abnormal condition with persistent and strong northerly wind in February 2014, the opposite was occurred. This is what we want to reveal.

Major issue 4: Authors presented that the water level rose distinctly at the coast during the event (Figure 2, line 91). Why did the water level inside the estuary not rise obviously (Figure 5, lines 133-135)? Authors said that the water level inside the river mouth was mainly determined by tide and river discharge. This needs explanation. Seen from plot b of Figure 4 and plot b of Figure 7, the water level rise inside the estuary was much larger than the coast. This is inconsistent with authors' expression and observations at Baozhen. The water level rises in figure 7 and figure 8 seem the same both for 10-13 February. In addition, about plot d in Figure 2, how was the water level rise obtained or how did authors calculate the water level rise? This should be presented clearly in methods section.

Reply: Thanks. The two different concepts of water level and water level rise need to be distinguished here. The water level rise at Sheshan and Luchaogang stations in Figure 2d was almost same as the one in Figure 5a. We said that the water level at Baozhen station inside the river mouth was mainly determined by tide and river discharge because the temporal variations in the observed and modeled water level was roughly same.

In plot b of Figure 4 and plot b of Figure 7, the time-averaged water level from February 10 to 13, 2014 was shown, not the water level rise. The mean water level was much higher in inside the estuary than the coast due to the river discharge.

The residual water level from February 10 to 13, 2014 in figure 7b and figure 8a was the same one, wad duplicated. These two figures were redrew, plot a of Figure 8 was deleted, and the residual surface current was moved to plot b of Figure 7 (Figure R3-3).

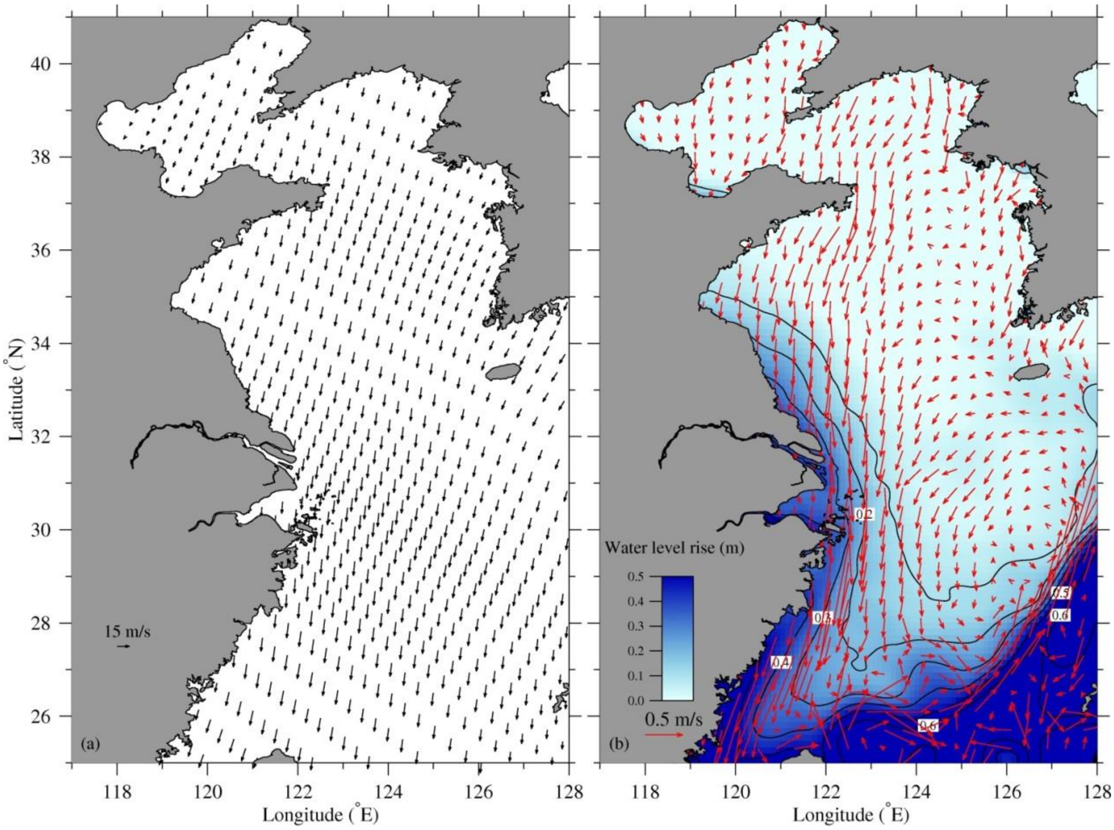

Figure R3-3 Distributions of the temporally averaged wind field from February 7 to 14, 2014, as simulated by the WRF model (a), and the time-averaged water level and surface current from February 10 to 13, 2014, as simulated by the model encompassing the Bohai Sea, Yellow Sea and East China Sea (b).

About plot d in Figure 2, the water level was provided by Shanghai Hydrology Administration, and the water level rise was obtained by subtracting the data in the tide table from the measured water level value. Those were illustrated in the revised manuscript.

Major issue 5: The main work of this manuscript is modeling of salinity and water level during the severe event. But authors only presented the results at Baozhen station (Figure 5). The results at other stations should be shown as well. Figures 6-8 only present the time-averaged results on10-13 February.

Reply: It's a good suggestion. Now we presented the measured results of salinity at Baozhen, Nanmen, Chongxi and Qingcaosha staions, and of water level at Baozhen, Sheshan and Luchaogang staions (Figure R3-4, and Figure R3-5). The model was validated for salinity and water level (reviewer 1 suggested).

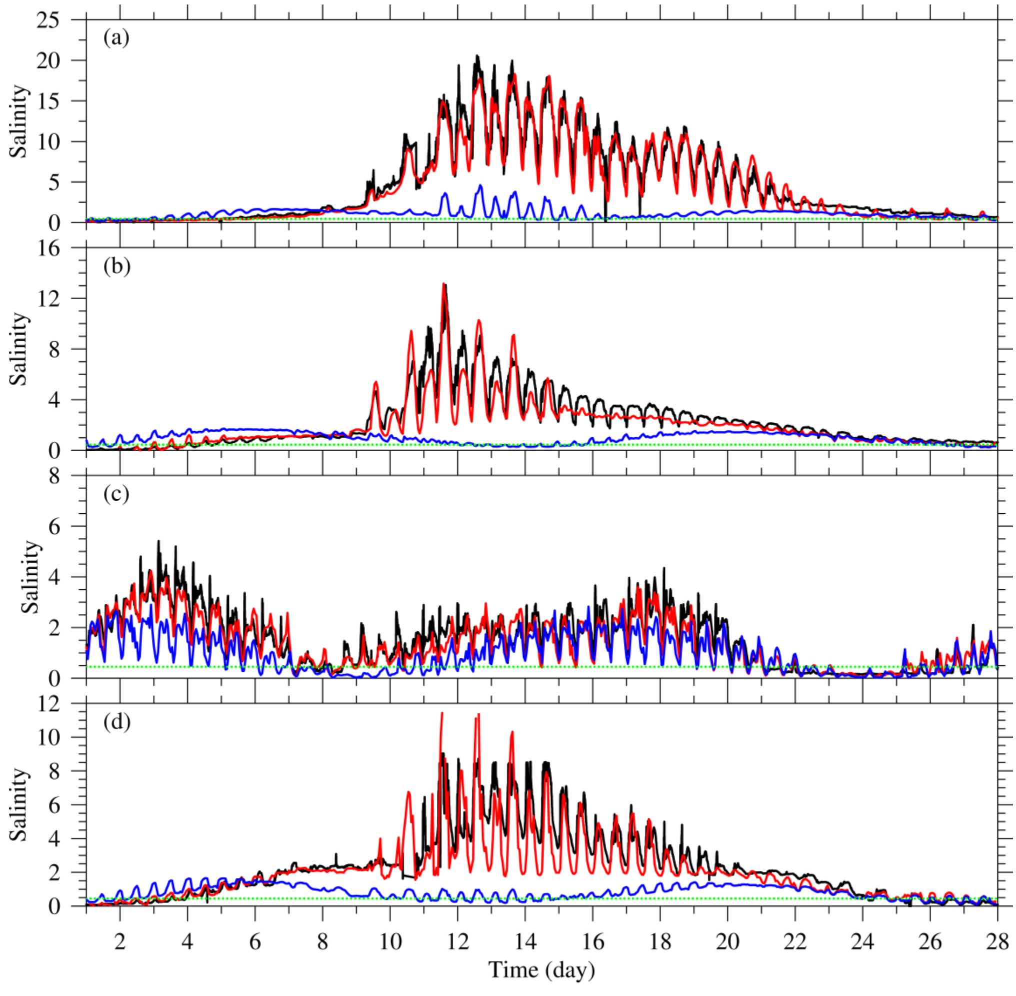

Figure R3-4 Temporal variations in salinity in February 2014 at hydrologic stations. a:

Baozhen station; b: Nanmen station; c: Chongxi station; c: Qingcaosha station. Black line: measured salinity; blue line: simulated salinity under climatic wind and residual water level conditions at open sea boundaries; red line: simulated salinity under a realistic wind and residual water levels at the open sea boundaries. The dashed green line represents salinity of 0.45, which is the standard for drinking water.

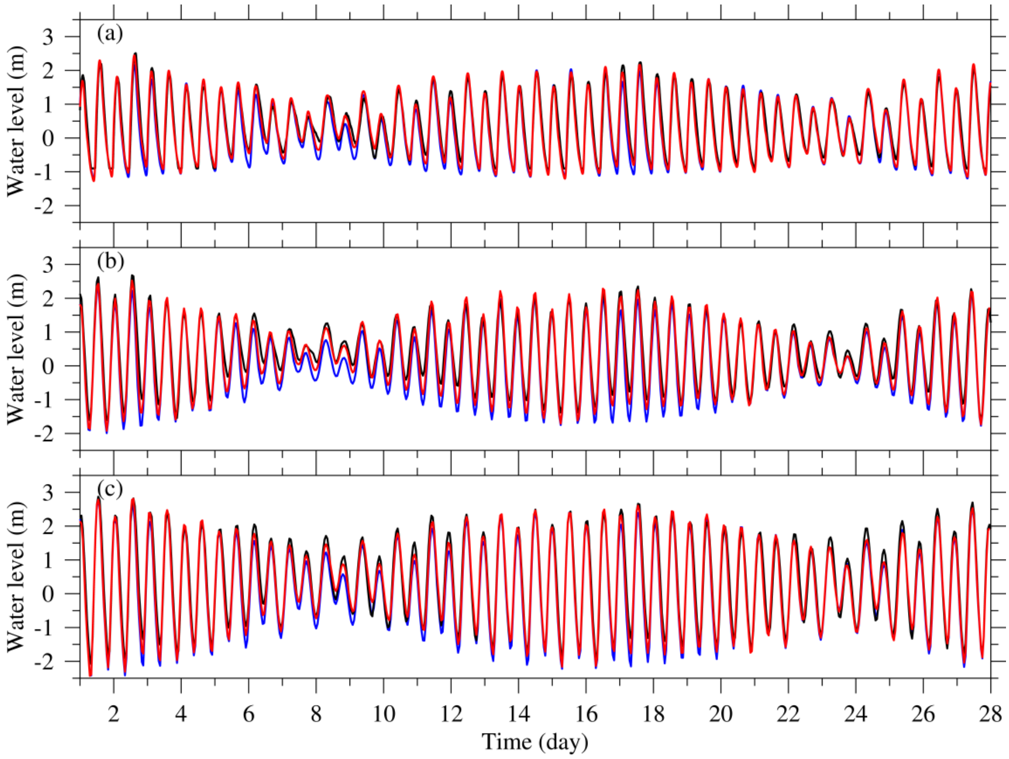

Figure R3-5 Temporal variations in water level in February 2014 at hydrologic stations. a: Baozhen station; b: Sheshan station; c: Luchaogang station. Black line: measured data; blue line: simulated data under climatic wind and residual water level conditions at open sea boundaries; red line: simulated data under a realistic wind and residual water levels at the open sea boundaries.

Major issue 6: The dynamic mechanism of the severe saltwater intrusion event is the objective of this manuscript. The manuscript proposed the mechanism:

landward Ekman transport forms a horizontal estuarine circulation that flowed into the North Channel and out of the South Channel. This mechanism or result is not new. It has been presented in authors' previous work (Wu Hui, Zhu Jianrong, Choi Byung Ho, 2010. Links between saltwater intrusion and subtidal circulation in the Changjiang Estuary: a model-guided study. Cont. Shelf Res. 30 (17): 1891–1905.). But authors did not mention this work. This reference did not occur in the manuscript as well. The strong winds were not persistent for very long time. And the wind directions were not always northerly, even southerly in some periods. Why did the severe saltwater intrusion last 23 days? This is the question the manuscript should answer. About the results presented in discussion part and figure 9, it is doubtful. About plot b, can two-day strong winds induce the higher than normal salinity in after 8 days? About plots c and d, there are similar doubts. What is the mechanism of this? This needs detailed explanation. In addition, many studies mentioned that water withdrawal between Datong and estuary could increase saltwater intrusion in dry season. Is there possibility that during the severe event water withdrawal downstream Datong was large contributing to this event as well?

Reply: This is a really misunderstanding. Wu et al. (2010) did presented a horizontal estuarine circulation that flowed into the North Channel and out of the South Channel, but is was pure wind-driven current under the northerly wind of 7 m/s (Figure 10 in their paper). Li et al. (2012) also presented a pure wind-driven current (Figure 14 in their paper). This pure wind-driven current was used to explain how the northerly wind effected the saltwater intrusion in the Changjiang Estuary. The pure wind-driven estuarine current can enhance saltwater intrusion in the North Channel, and weaken it in the South Channel. In this study, the horizontal estuarine circulation was a total (net) circulation induced by the river discharge, tide and persistent and strong northerly wind, was not a pure wind-driven circulation, which surpassed the strong seaward runoff. This result was unexpected and surprising, and was found for the first time. The relevant illustration was added in the revised manuscript. The paper of Wu et al. (2010) was cited in the revised manuscript.

This rarely happened that the northerly wind with speed of great than 10 m/s and lasting more than 8 days in the Changjiang Estuary, but it did occurred (Figure R3-2), which caused the severe saltwater intrusion in February 2014, influencing the water intake of Qingcaosha reservoir for 23 days. If the wind directions were not always northerly, even southerly in some periods, the saltwater intrusion would be more severe and more serious impact on the Qingcaosha reservoir. This manuscript exactly answers why the extremely saltwater intrusion happened and what was the dynamic mechanism.

In Figure 9, the strong northerly wind lasts two, four, six and eight days in plot a, b, c and d, respectively. Two-day strong winds is in plot a, not in plot b. This is true that several days strong wind can induce the higher than normal salinity in after 8 days, because the strong wind Ekman transport brought the salinity front in sandbar area upstream and closer to the Baozhen station (model output site in Figure 9), and then move upstream and downstream with the oscillation of flood and ebb current for 8 days after the strong northerly wind became northerly wind with speed of 5 m/s. It will take about 8 days to eliminate the impact of the upstream forward salinity front on the salinity at Baozhen station. This phenomenon was also shown in Figure 2a, 2c. The relevant illustration was added in the revised manuscript.

Yes, many studies pointed out that water withdrawal between Datong and the estuary could increase saltwater intrusion in dry season, but there was no possibility that the water withdrawal downstream Datong had large contributing to the severe saltwater intrusion event, because water withdrawal amount by the South-to-North Water Diversion Project, and water diversion and drainage along the river was approximately 1000 m^3/s, and the monthly mean river discharge was 11,500 m^3/s.

Major issue 7: The structure of the manuscript is strange. In section 2.1 observed data, authors introduced the severe saltwater intrusion events, which should be moved to introduction section or results section. In section 3 results, section 3.1 is not necessary. The results under normal situations and special situations can be compared in order to show the difference. But the result under normal situation is not the important results for the objective of the manuscript. In other words, it is not necessary presented separately. In addition, the discussion part is too simple.

Reply: Thanks for your good suggestion. Now we moved the section 2.1 observed data to the section 3 results in the revised manuscript, and deleted the title of 3.1 Climatic wind and residual water level conditions at open sea boundaries, and 3.2 Under a realistic wind in February 2014 and residual water levels at the open sea boundaries in the original manuscript.

According to the reviewer 1 and your suggestions, the discussion part has been greatly expanded. How much contribution the SSO had in the saltwater intrusion event, how the wind affects the individual terms in the momentum equations, the relationship between residual water level rise and wind, and the generation of Ekman transport and the resulted horizontal circulation were added and discussed in the revised manuscript.

Major issue 8: Some presentations or data in the manuscript are unreliable. Besides some mentioned above examples are as follows.

(1) About the data source, in section 2.1 (observed data), authors said that the observed data was conducted by State Key Laboratory of Estuarine and Coastal Research, East China Normal University. But in acknowledgements part authors said that the observed data was provided by Shanghai Hydrology Administration.

(2) Page 3, line 57, "... caused by very low river discharge of approximately 7000 and 8000 m^3s^{-1} lasting three mouths (mouths should be months), respectively". In this sentence, "8000 m^3s^{-1} in 1999" and "lasting three months" are not correct. In dry season of 1979, river discharges in January and February were really very low between 7000 and 8000 m^3s^{-1} at Datong station. In March the monthly mean discharge was more than 10000 m^3s^{-1} during which severe saltwater intrusion also occurred. In 1999 the monthly mean river discharges at Datong were all larger than 9000 m^3s^{-1}. In February extremely severe saltwater intrusion occurred as well inducing continuous 25 days of unsuitable drinking water at Chenhang Reservoir

upstream of Qingcaosha, during which discharge was 9110 m^3s^{-1}.

Reply: Thanks for pointing out the some incorrect expressions in the original manuscript.

(1) In section 2.1 (observed data), we modified the expression as: the observed salinity and wind data was conducted by State Key Laboratory of Estuarine and Coastal Research, East China Normal University, and the observed water level data was conducted by Shanghai Hydrology Administration. In acknowledgements part, we modified the expression as: the authors thank Shanghai Hydrology Administration providing the observed water level in the Changjiang Estuary.

(2) We checked and drew the variation processes of river discharge measured at Datong station in dry seasons of 1979 and 1999 (Figure R3-6). In dry season of 1979 from January 1 to March 15, the river discharge at Datong station was between 6000 and 9280 m^3s^{-1} with mean value of 7485 m^3s^{-1}, lasting 2.5 months. In dry season of 1999 from January 1 to March 16, the river discharge at Datong station was between 7650 and 1,0900 m^3s^{-1} with mean value of 9246 m^3s^{-1}, lasting 2.5 months.

Therefore, we modified the sentence “Historically, there have been two severe saltwater intrusion events in the Changjiang Estuary in the dry seasons of 1979 and 1999, which were caused by very low river discharge of approximately 7000 and 8000 m^3s^{-1} lasting three months” to “Historically, there have been two severe saltwater intrusion events in the Changjiang Estuary in the dry seasons of 1979 and 1999, which were caused by very low river discharge of mean value of 7485 m^3s^{-1} from January 1 to March 15, 1979, and 9246 m^3s^{-1} from January 1 to March 16, 1999, both lasting 2.5 months".

The word "mouths" has been changed to "months".

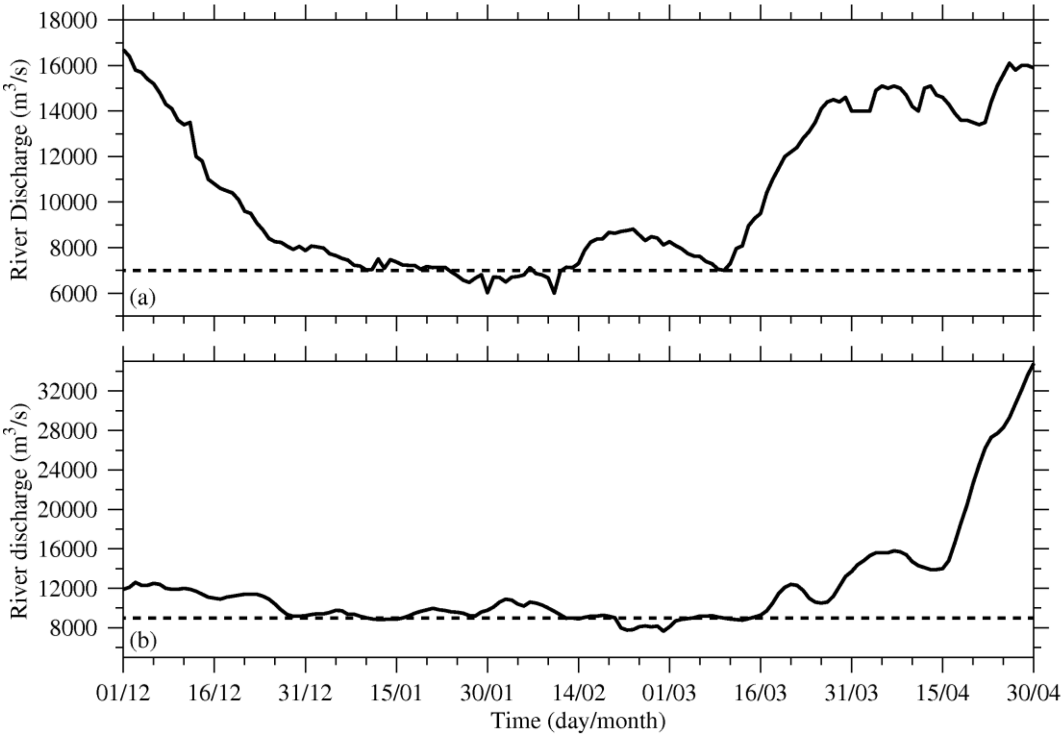

Figure R3-6 Temporal variations in river discharge measured at Datong station from December 1, 1978 to April 30, 1979 (a), and from December 1, 1998 to April 30, 1999 (b).

Minor issues:

Minor issue 1: In page 2, lines 30-31, what is the maximum spring tide and minimum neap tide? The proper expressions should be the maximum tidal range of spring tide and minimum tidal range of neap tide. Or, the maximum tidal range and minimum tidal range are enough.

Reply: Thanks. "the maximum spring tide" was changed to "the maximum tidal range", and "the minimum neap tide" was changed to "minimum tidal range".

Minor issue 2: In page 3, lines 49-50, “which was the largest estuarine reservoir in the world, the Qingcaosha Reservoir, was built”. There is syntax error in this sentence.

Reply: “which was the largest estuarine reservoir in the world, the Qingcaosha Reservoir, was built” was changed to “that the largest estuarine reservoir in the world, the Qingcaosha Reservoir, was built”.

Minor issue 3: In the last paragraph of introduction, authors said that an extremely severe saltwater intrusion event in February 2014 occurred, and this is a catastrophic event never occurred. But we did not see how severe and catastrophic. The compare between this event and historical severe events should be presented as well in order to show the severe magnitude.

Reply: The extremely severe saltwater intrusion event in February 2014 resulted in the continuous period of unsuitable drinking water reaching 23 days, and caused a serious threat to the water intake of the Qingcaosha Reservoir and water safety in Shanghai. So, we called the saltwater intrusion a catastrophic event. Historically, there were severe saltwater intrusions, such as in dry seasons of 1979 and 1999, but there was no reservoir in the Changjiang Estuary at that time. So, we only called these saltwater intrusions severe events. A catastrophic event refers to water security.

Minor issue 4: About the river discharge used during modelling, did you consider the time required for water traveling from Datong to the estuary? Usually the discharges several days in advance are used because Datong station is located more than 600 km upstream of the estuary.

Reply: It's a good question. The west open boundary of the Changjiang River in the model is up to Datong station in the Changjiang River. So, it is not necessary to consider the time required for water traveling from Datong to the estuary.

Minor issue 5: Caption of Figure 2: Temporal variations in the measured data in February. Plot d does not present the measured data. The water level rises are calculated results.

Reply: Thanks. Now the caption of Figure 2 was changed to "Temporal variations in the measured river discharge at Datong station (a), wind vector (b) and wind speed (c) at WS, and water level rise obtained by subtracting the data in the tide table from the measured water level at Sheshan station (black line) and Luchaogang station (red line) (d) in February 2014.

Minor issue 6: Caption of Figure 3 is not clear. And there are syntax errors.

Reply: The caption of Figure 3 was rewritten.

Figure 2 Model grids of the Changjiang Estuary (a), and model grids of the Bohai Sea, Yellow Sea and East China Sea (b). Domains of the models (c); within the red line: the Changjiang Estuary model domain; within the green line: model domain of the Bohai Sea, Yellow Sea and East China Sea; the black dashed lines: the two-fold nested WRF model domain.

Minor issue 7: What is the climatic wind? This expression is strange.

Reply: Climate wind means monthly mean wind for many years.

Minor issue 8: Captions of Figures 5, 6, 8 are not clear.

Reply: The captions of Figures 5, 6, 8 were rewritten. The Figures were reorganized and redrew, and the modified captions were presented in the revised manuscript.