Response of water exchange flux through the Bohai Strait to the variation in the Yellow River discharge in the past 5 decades

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The runoff of Yellow River has been known to vary dramatically in the past five decades (Fig.1). In this study, we address the water exchange flux through the Bohai Strait (Fig.2), a channel connecting the Bohai Sea and the Yellow Sea, and its response to the variation of runoff of Yellow River. The motivation for this study is because the direct influences of the Yellow River on the Bohai Sea have been widely concerned but the indirect influences have not been noticed. Among the indirect influences, the water exchange through the Bohai Strait is an important process because the exchange water flux there is usually more than 50 times of the runoff of Yellow River and thus affects greatly the environment in the Bohai Sea.

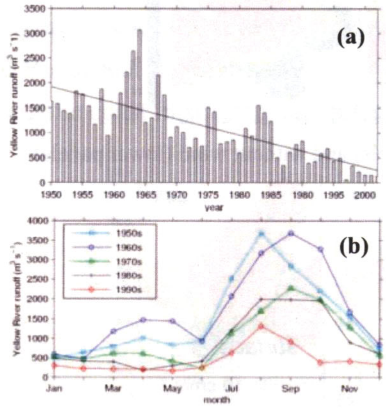

Fig.1 (a) annual variation of YR runoff;
(b) monthly YR runoff in different decades

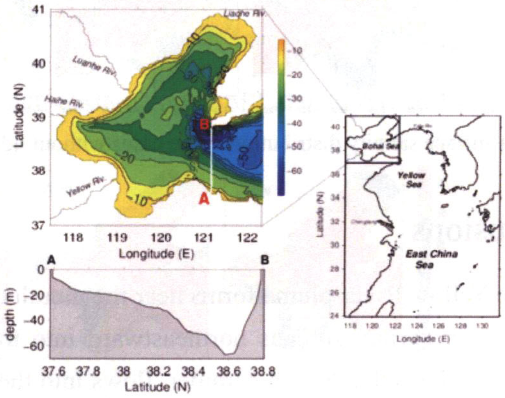

Fig.2 Topography of the Bohai Sea
and the location of Bohai Strait.

Our tool for this study is a three-dimension ocean model with a resolution of 1/18 degree in both zonal and meridian directions and 20 layers in vertical. The model domain included not only the Bohai Sea and Yellow Sea, but also the East China Sea, which allow us to avoid the problems related to the open boundary conditions in a regional ocean model. The results of a nested ocean general current model (Guo et al., 2003) and four leading tidal constituents are given along the open boundary. On the surface, the model is forced by monthly averaged forcing including wind stress, sea surface temperature, net heat flux, evaporation and precipitation, and air pressure. Six major rivers in the model domain, including the Yellow River and Changjiang River, are considered in the model. We carried out five numerical experiments to study the response of the water exchange through the Bohai Strait to the change of Yellow River runoff. The five experiments correspond to five decades (1950s, 1960s, 1970s, 1980s, and 1990s). The differences among these cases are the Yellow River runoff and the location of Yellow River mouth.

Model results represent successfully some well-known features on the water exchange through the Bohai Strait. Generally, water flows into the Bohai Sea through the northern part of the Bohai Strait and flows out through the southern part of the strait (Fig.3). In spring it's a little special, when a two-layer current is dominant in the southern part of the strait, outflow in upper layers and inflow in lower layers. By analyzing model results, we concluded that it's mainly due to wind-driven current in autumn and winter and due to density-driven current in spring and summer. Tidal residual current also has some contribution but its effects are confined near the coast. The net water flux through the Bohai Strait is negative in the first half year and positive in the second half year, which means that in the first half year water flows into the Bohai Sea to make the sea level in the Bohai Sea increase, and in the second half year water flows out of the Bohai Sea to make the sea level decrease.

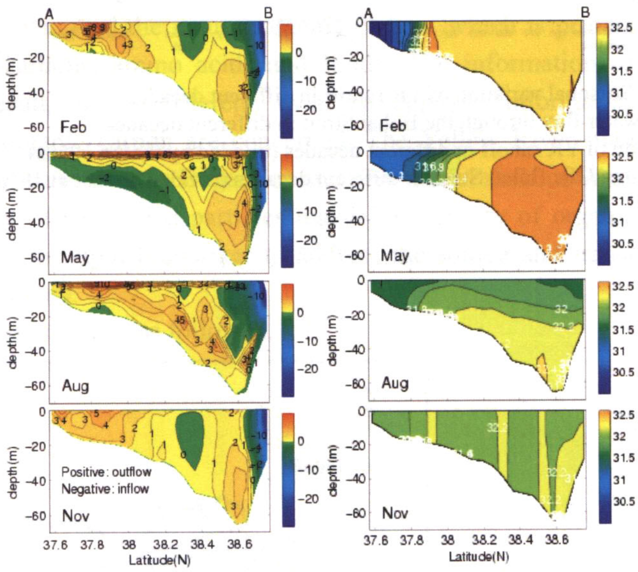

Fig.3 Water flux through the Bohai Strait (left panels) and salinity distribution along transect AB (right panels) in different seasons

Corresponding to the different Yellow River runoff in the past five decades, water exchange flux through the Bohai Strait shows significant variation. As the Yellow River runoff decreases from 1733 $m^3\ s^{-1}$ (1960s) to 444 $m^3\ s^{-1}$ (1990s), the annual water exchange flux through the Bohai Strait decreases from $5.86\times10^4\ m^3\ s^{-1}$ to $5.40\times10^4\ m^3\ s^{-1}$, whose difference is approximately 3.5 times of the reduction of the Yellow River runoff. Furthermore, we found that the response of water exchange flux has a significant season-dependence (Fig.4). The maximum response occurs in spring, when the reduction of water exchange flux through the Bohai Strait is 7 times of the reduction in the Yellow River runoff. However, in autumn the water exchange flux keeps almost unchanged in the five experiments. This can be explained by the current pattern through the Bohai Strait. In spring, halocline comes into being along the Bohai Strait and induces a two-layer current (Fig.3), which enhances the water exchange between the Bohai Sea and the Yellow Sea. With the Yellow River runoff decreasing from 1950s to 1990s, the salinity gradient along the Bohai Strait is weakened. In spring this weakening of salinity gradient is great than in other seasons, and results in a larger response of water exchange flux through the Bohai Strait. In other seasons it shows less response, especially in autumn, the water exchange flux through the Bohai Strait almost doesn't show any change.

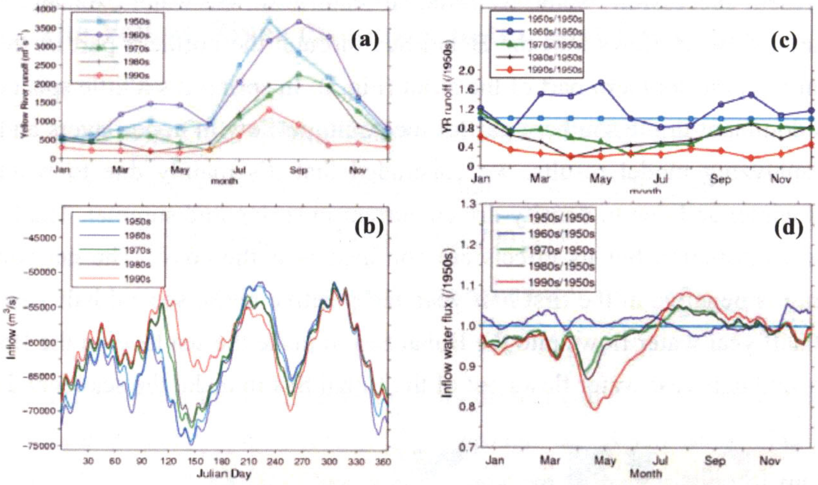

Fig.4 (a) Seasonal variation of YR runoff in different decades
(b) inflow water flux through the Bohai Strait in different decades
(c) Seasonal variation of YR runoff in different decades (divided by that in 1950s)
(d) inflow water flux through the Bohai Strait in different decades (divided by that in 1950s)