La mer 43 : 1-7, 2005
Société franco-japonaise d'océanographie, Tokyo

Short-term, seasonal, and tidal variations in the Yellow River plume

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Abstract : The short-term, seasonal and spring-neap tidal variations of the Yellow River plume in the Bohai Sea were investigated using NOAA AVHRR visible band images in 2002. As a result, the followings are revealed, that is, the Yellow River plume spreads mainly from Laizhou Bay to Bohai Bay with the coast on the left hand side due to the Lagrangean tide-induced residual current and its spreading area during spring tide was wider than that during neap tide due to the re-suspension by the strong tidal current. There was no distinct seasonal variation in the Yellow River plume spreading in the Bohai Sea during 2002.

Keywords : *Yellow River, river plume, Bohai Sea, NOAA AVHRR*

1. Introduction

The river discharge of the Yellow River has decreased from 1970's due to the overuse of water on land (e.g. HAYASHI *et al.*, 2004). Yearly averaged river discharge was about 3,000 m^3/sec in 1960's but it was 1,000 m^3/sec in 1990's, and there were more than 150 days in 1996 when there was no-water-discharge at Lijin near the Yellow River mouth (see Fig. 1). Such decrease of the river discharge may affect the spreading of the Yellow River plume and the marine environment in the Bohai Sea because the Yellow River is the largest river which empties to the Bohai Sea.

There have been many studies on the tide (XIE *et al.*, 1990), the tidal current (WAN *et al.*, 1998), the residual flow (FENG, 1987), the water mass (LEE *et al.*, 2002) in the Bohai Sea, and the water discharge and the sediment discharge from the Yellow River (SAITO and YANG, 1994). However, the characteristics of the spreading of the Yellow River plume and its effect on the marine environment of the Bohai Sea have not been clarified yet.

Using NOAA AVHRR visible images obtained in 2002, we investigate the short-term, seasonal and spring-neap tidal variations in the Yellow River plume in this paper.

2. Used data

Used NOAA images were processed at the NPEC (North Pacific Environmental Center), Toyama, Japan. In case of NOAA infrared image (Bands 4 and 5), the analysis method is already established for the users (e.g. SAKAIDA *et al.*, 2000). However, it is meaningless to directly compare and/or average visible images (Band 1) of NOAA because the signal of NOAA visible image (it expresses the brightness of the sea surface) depends on the sun altitude, the air condition, the sea surface condition and so on, but no correction was made for the signal of the visible Band 1 image of NOAA. Therefore we normalized the signal of the visible Band 1 of each image by designating the signal at the river mouth of the Yellow River as 10 and that at the deepest part of the Bohai Strait as 0 because it was considered that the direct effect of the Yellow River plume did

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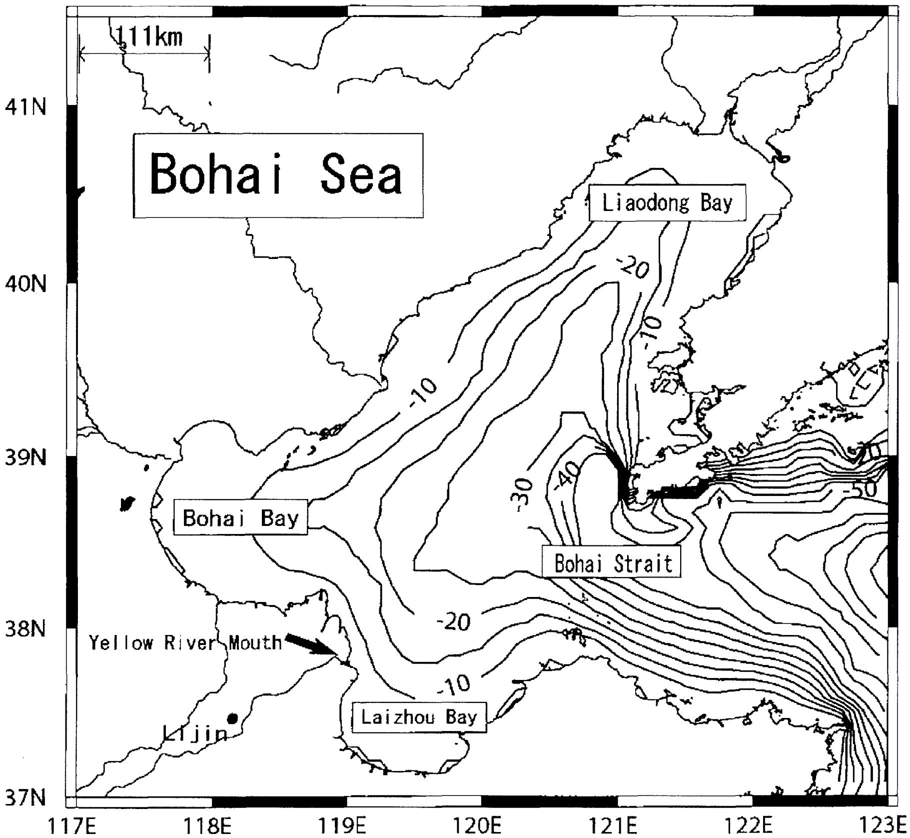

Fig. 1. The Bohai Sea. Numbers show the depth in meters.

not reach to the Bohai Strait. Large normalized number means high turbidity with large effect of the Yellow River plume and small one low turbidity with small effect of the Yellow River plume as shown in Fig. 3. Minus normalized number means lower turbidity than that at the Bohai Strait. The coverage area of each image is 37°N–41°N and 117°E–123°E, and the spatial resolution of each image is 1.1 km × 1.1 km (Fig. 1). Every snapshot images during the daytime from 30 January 2002 to 31 December 2002 with the cloud less than 50 % were analyzed. The data from 1 January to 29 January 2002 were lacking due to the problem of NPEC.

3. Results

The temporal variations in the water level, the river discharge, and the sediment load at Lijin (see Fig. 1) of the Yellow River in 2002 are shown in Fig. 2, which is obtained from HP (http://www.yellowriver.gov.cn/other/hhsq/hhsq.asp). There was no distinct seasonal variation in water discharge and sediment load except an artificial outflow in July when the water level was high, the river discharge was large and the sediment load was also large. The reason of intermittent large sediment load without high water level and large water discharge in late September 2002 is not clear now.

3.1 Short-term variation

The short-term variation in the Yellow River plume spreading related to the artificial outflow in July 2002 is shown in Fig. 3. There was no turbid water near the Yellow River mouth on 27 June (Moon age of 16) before the artificial outflow but a small area of turbid water (shown by the dark color from the Yellow River mouth in Fig. 3) existed on 6 July (Moon age of 25) just after the beginning of the artificial outflow on 29 June. It mainly spread southeastward along the coast of Laizhou Bay

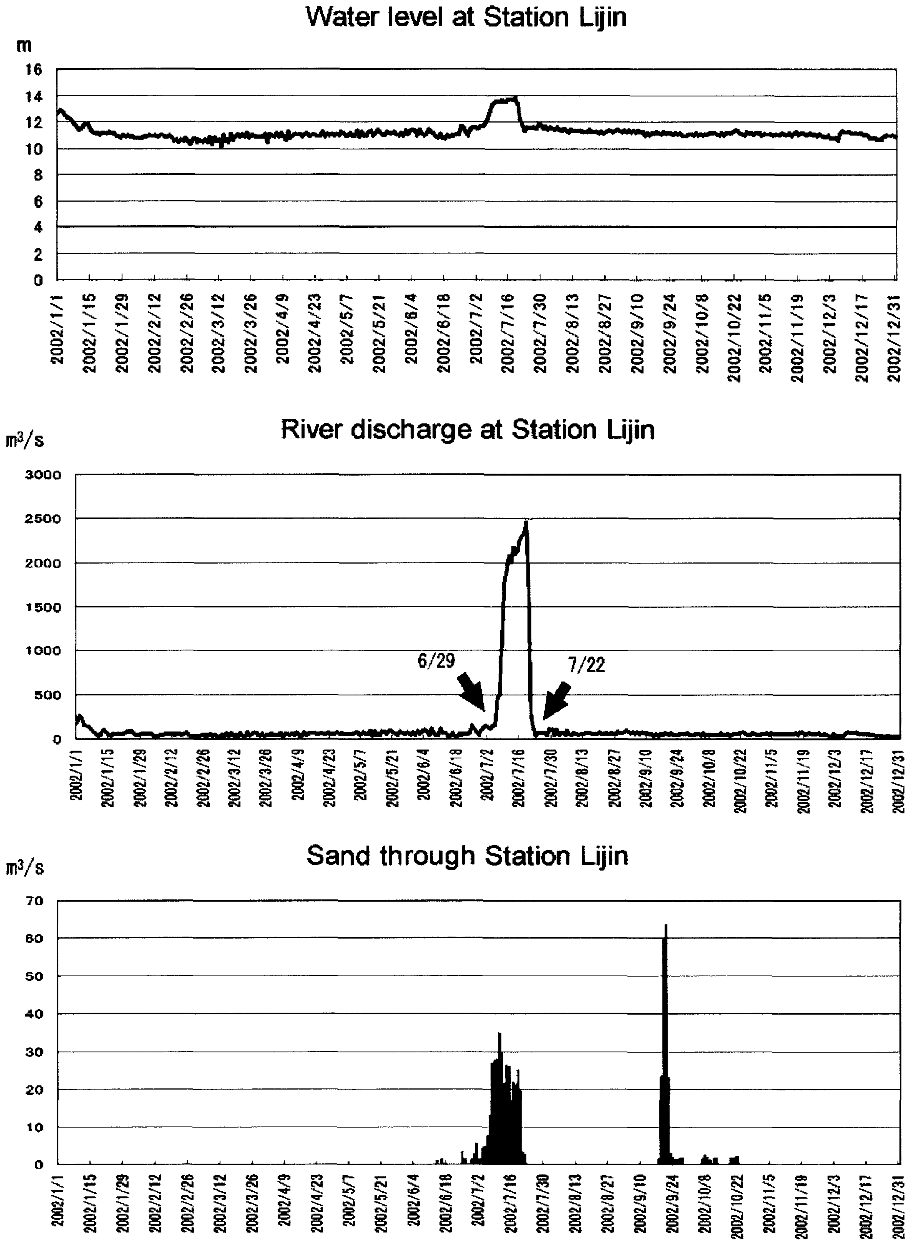

Fig. 2. Temporal variations in water level, discharge, and sediment load of the Yellow River at Lijin in 2002.

on 6 July, northwestward along the coast of Bohai Bay on 10 July (Moon age of 28; spring tide). The spreading area of turbid water took the maximum on 14 July (Moon age of 4) and its area shrank on 15 July (Moon age of 5; neap tide). There was no turbid water on 1 August (Moon age of 22; neap tide) after the end of artificial outflow on 22 July as shown in Fig. 3.

3.2 Seasonal variation

The monthly composite images from February to November 2002 are shown in Fig. 4. Ten to twenty images were composited every month except December. The image in December is not shown in Fig.4 because only one image was obtained because of too many cloudy days in December 2002. The turbid water from the Yellow

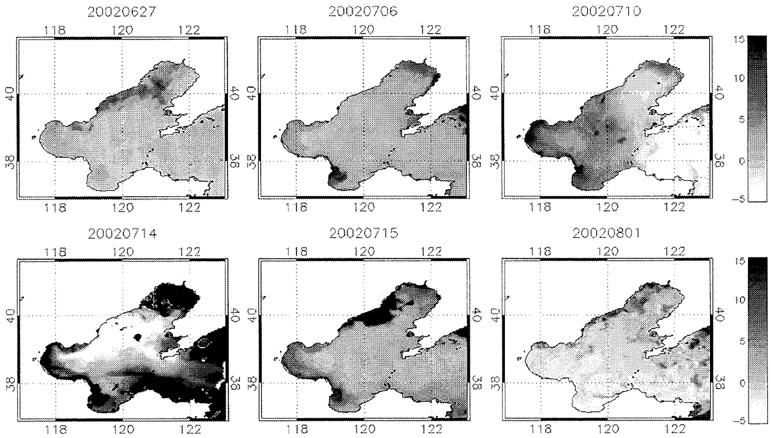

Fig. 3. Short-term variation in the Yellow River plume spreading related to the artificial outflow in July 2002.

River mouth (shown by the dark color from the Yellow River mouth in Fig. 4) spread mainly along the southwestern coasts of Laizhou Bay and Bohai Bay, and there was no distinct seasonal variation in its spreading pattern. The effect of artificial outflow in July 2002 was not distinct from Fig. 4, i.e., the turbidity was not highest in July. This suggests that the effect of re-suspension is large for the spreading pattern of the Yellow River plume, which will be discussed in the next section.

It is interesting that the Yellow River plume spread with the coast on the left hand side because the river plume usually spreads with the coast on the right hand side in the northern hemisphere (e.g. GRIFFITHS, 1986). We will discuss on this point later.

3.3 Spring-neap tidal variation

The average spreading pattern during the spring tide (which was obtained by averaging images during moon ages from 12.0 to 18.0 or from 27.0 to 2.0) and that during the neap tide (which was obtained by averaging images during moon ages from 5.0 to 9.0 or from 20.0 to 24.0) from February to November in 2002 are shown in Fig.5. The river discharge in 2002 was nearly constant except in July as shown in Fig.2. The turbidity was higher during the spring tide than during the neap tide and the spreading area was wider during the spring tide than during the neap tide. This suggests that the re-suspension by the strong tidal current during the spring tide plays an important role in the turbidity of the sea surface along the shallow coastal areas of Bohai Bay and Laizhou Bay.

4. Discussion

The yearly averaged image of the spreading of the Yellow River plume is shown in Fig. 6 (a). We consider that this image should be the characteristic feature of the spreading of the Yellow River plume, because it has the characteristic between those during spring tide and neap tide shown in Fig. 5 and there was no distinct seasonal variation on the spreading of the Yellow River plume as was shown in Fig. 4. The turbid water from the Yellow River mouth spread mainly northwestward to Bohai Bay with the coast on the left hand side. This is interesting from the viewpoint of the dynamics of the density-driven current, that is, the river plume usually spreads with the coast on the right hand side in the northern hemisphere due to the Coriolis effect. Wind may affect the river plume spreading but its effect is not large for the Yellow River plume because there was no distinct seasonal variation in the Yellow River plume spreading as shown in Fig. 4 under the distinct seasonal variation of monsoon wind in the Bohai Sea.

The preliminary calculation of Lagrangean tide-induced residual current by M_2, S_2, K_1, and O_1 constituents in the surface layer is shown in

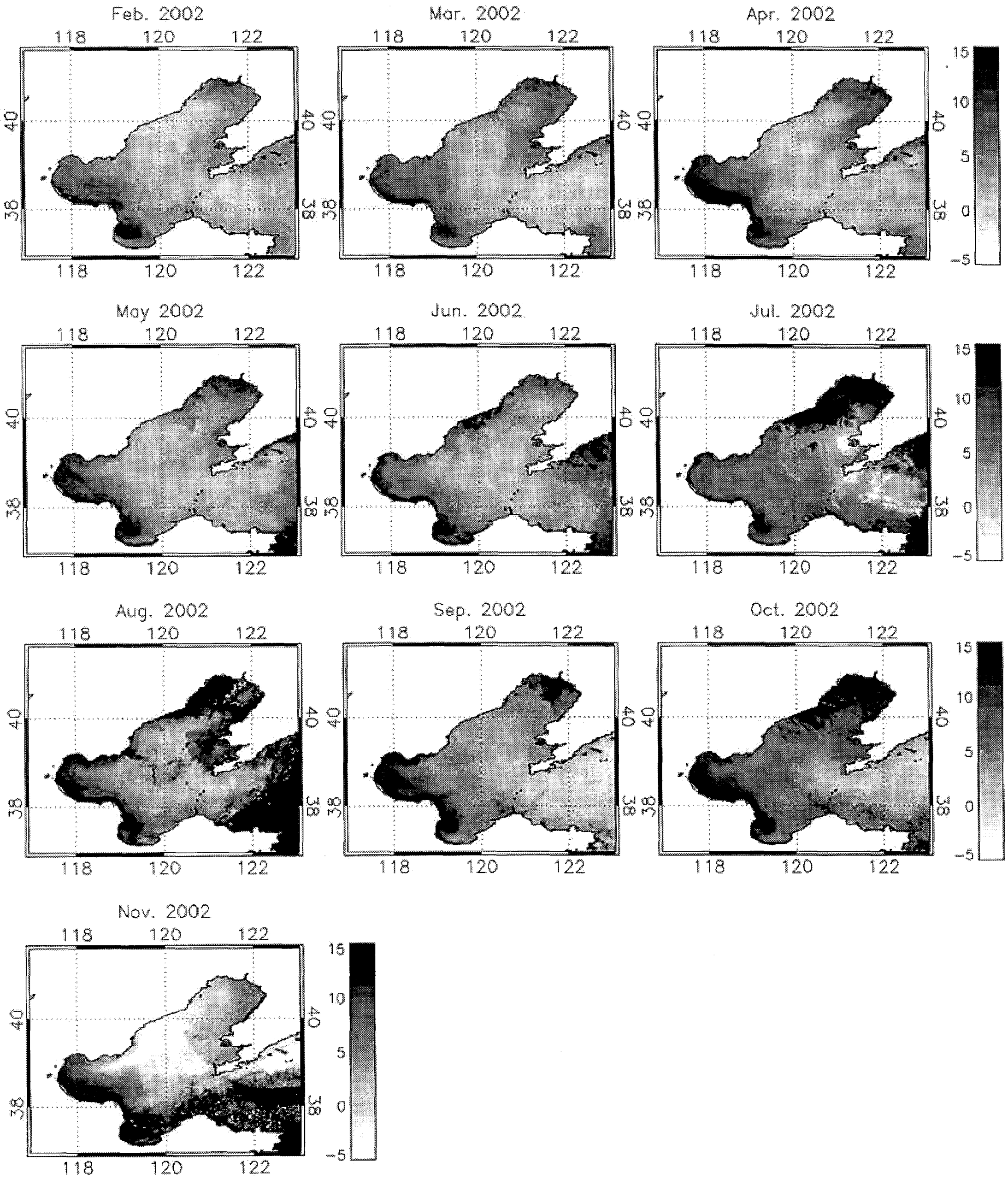

Fig. 4. Monthly composite images of the Yellow River plume spreading in 2002.

Fig. 6 (b) (CUI and YANAGI, 2005). Their numerical model is a three-dimensional one and the tides in the Bohai Sea are well reproduced. The Lagrangean tide-induced residual current in the surface layer was calculated based on the calculated M_2, S_2, K_1, and O_1 tidal currents. It directs northwestward from the Yellow River mouth and it qualitatively explains the spreading pattern of the Yellow River plume shown in Fig. 6 (a). The quantitative numerical experiment on the Yellow River plume spreading is under conducting now.

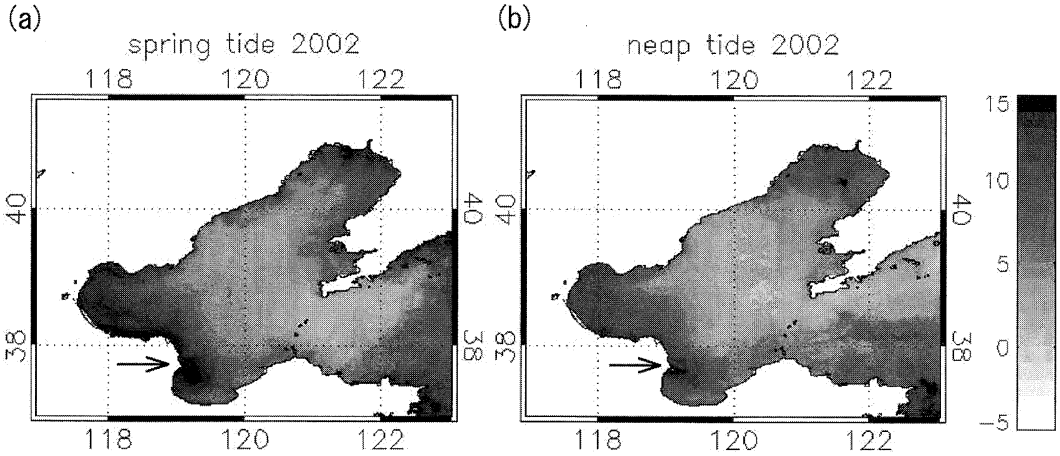

Fig. 5 The Yellow River plume spreading in spring tide (a) and neap tide (b). Arrow shows the position of the Yellow River mouth.

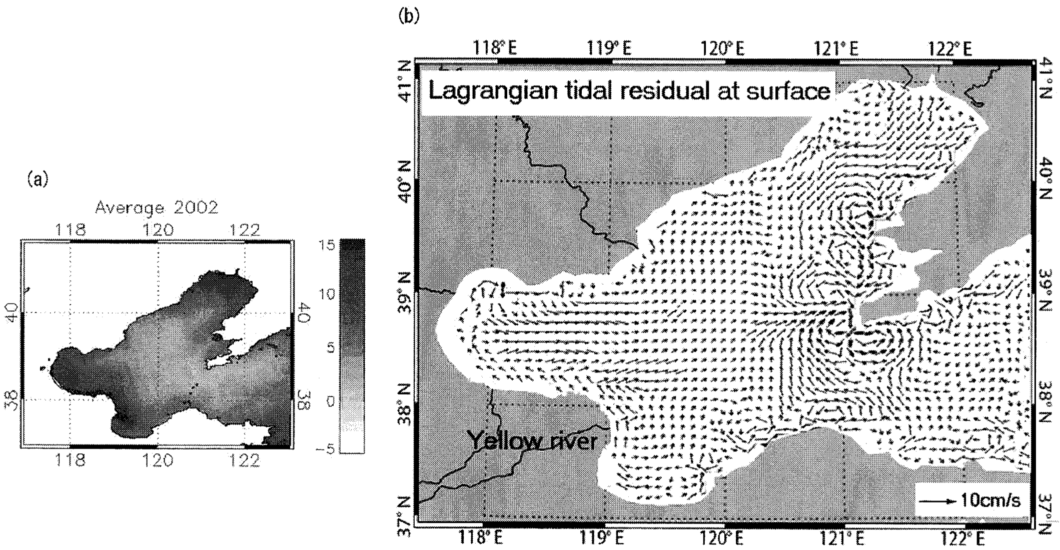

Fig. 6. Yearly average of the Yellow River plume spreading in 2002 (a) and the Lagrangean tide-induced residual current by M_2, S_2, K_1, and O_1 constituents (b) (Cui and Yanagi, 2005).

5. Conclusion

We may conclude from this study that the Yellow River plume spreads mainly from Laizhou Bay to Bohai Bay with the coast on the left hand side due to the Lagrangean tide-induced residual current and the turbidity of the river plume during the spring tide is higher than that during the neap tide due to the re-suspension by the strong tidal current. There was no distinct seasonal variation of the Yellow River plume spreading in the Bohai Sea in 2002.

Acknowledgements

The authors express their sincere thanks to the staff of NPEC at Toyama, Japan who processed NOAA images and kindly provided them to us, and the editor and anonymous reviewer for their useful comments to the first draft. This is a part of "The Yellow River Studies" sponsored by the National Institute for Human and Nature, Japan.

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Received January 31, 2005
Accepted April 7, 2005