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Simulation of temperature, salinity and suspended matter distributions induced by the discharge into the East China Sea during the 1998 flood of the Yangtze River

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Abstract

A three-dimensional model simulated the distributions of current, water temperature, salinity and suspended matter in the Yangtze estuary area and the East China Sea caused by the discharge of freshwater from the Yangtze (Changjiang) River for 3 years from May 1996 to April 1999. The calculation was conducted using a longitude–latitude mesh of 5 min × 5 min, in assimilating the daily average discharge from the Yangtze with the meteorological conditions on the sea surface obtained from the atmospheric global circulation model (European Centre for Medium-range Weather Forecasts, ECMWF) and the daily average precipitation over the sea surface obtained from the TRMM (Tropical Rainfall Measuring Mission) satellite data. The calculated water temperatures were in excellent agreement with the measurement data observed by the marine meteorological buoy robot (ST22001). For the surface salinity distribution on the east–west transection line across the East China Sea and the cross-sectional distribution of salinity in the Tsushima Strait, the calculated values were in excellent agreement with the observed data. During the Yangtze flood in 1998, turbid water was discharged in repeated pulses from the Yangtze and penetrated the East China Sea. This behavior of suspended matter discharged from the Yangtze was clearly identified by the 3D model results in salinity, suspended matter and current distributions. The model results revealed the fact that the freshwater and suspended matter originating from the Yangtze crossed the East China Sea and reached as far as the coasts of Kyushu, the Japan Sea and the Pacific coast of mainland Japan.

Keywords: freshwater discharge; Tsushima Strait

1. Introduction

The East China Sea has one of the world's major continental shelves known for its high biological productivity (Chen et al., 2003). The circulation of the sea shows very complicated characteristics influenced by tides, inflows of freshwater from rivers, wind and meteorological conditions, as well as the Kuroshio Current (Beardsley et al., 1985). The water mass at the estuary area and the continental shelf of the East China Sea has a complicated structure consisting of four masses of water for the upper layer: the Yangtze plume, coastal water of the warm current system, Yellow Sea Mixed Water, and Kuroshio Surface Water (Beardsley et al., 1985; Chen et al., 1994). There are also three masses of water for the lower layer: Yellow Sea Bottom Cold Water, Kuroshio Bottom Water, and continental shelf bottom water of the warm current system (Beardsley et al., 1985; Ichikawa and Beardsley, 2002).

It has become clear that, coupled with interactions with water dilution by the Yangtze, the seawater brought by the Kuroshio Current and the coastal water of the Chinese continent, large temporal and special fluctuations occur (Kagimoto and Yamagata, 1997; Ichikawa and Chaen, 2000). In the East China Sea, located in the Asian monsoon zone, the determinant factors of salinity distribution are river discharge, precipitation and the Taiwan Warm Current. The Taiwan Warm Current carries relatively less saline water, especially in summer, originating from the South China Sea

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(Chang and Isobe, 2003). There are eight major rivers in this region (from high to low latitude), they are Han river, Yalu river, Liao river, Hai river, Huanghe, Yangtze, Qiantangjiang and Minjiang. The Yangtze is the largest river in terms of volume discharge with an annual mean of about 3.0×10^4 m^3/s, which accounts for almost 90% of the whole river discharge into this region (Beardsley et al., 1985). The annually averaged precipitation had been considered to be almost completely balanced by the amount of evaporation in this region, and thus the freshwater flux through the sea surface was not treated as an important source when considering the annual average freshwater budget in this region (Chen et al., 1994). However, the difference of precipitation and evaporation changes seasonally and is always positive during summer period (Chen et al., 1994). For the short-term (in the order of day) budget of salinity in the East China Sea, the freshwater supply from the sea surface becomes very important. The distribution of wind shear on the sea surface greatly varies in hourly bases depending on the season (in particular typhoon and winter seasons) and has a definitive impact on the current field in the East China Sea.

The Yangtze catchment area is approximately 1.8 million km^2 and the length of the Yangtze is about 6300 km, starting from the Himalayas reaching to the estuary in the East China Sea. Therefore, river discharge during the 1998 flood in the mainstream of the Yangtze was affected by the spatial distribution of the precipitation in the catchment and showed several peaks during the flood period due to hydrological characteristics in the tributary catchment (Chen et al., 2001b). Turbid water was discharged in repeated pulses from the Yangtze into the East China Sea and at each peak discharged water penetrated into the East China Sea and entrained ambient seawater mixed with a mass of turbid water (Yangtze Diluted Water, YDW). A high concentration of suspended matter was recorded in the river mouth area, where 450 million tonnes of sediment load during the 2.5-month flood season were delivered to the estuary and the East China Sea, about 3.8 times more than in a normal flood season (Xu et al., 2005). The behavior of the Yangtze plume with freshwater and a high concentration of suspended matter must be influenced by complex density changes caused by mixing with ambient seawater in the estuary and the East China Sea, and therefore the effect of not only temperature and salinity but also suspended matter should be considered in the density equation $\rho = \rho(\theta, S, M)$, where water temperature is θ, salinity is S, and suspended matter is M.

The concentration of total suspended matter (TSM) in the water column on the shelf of the East China Sea is very high in comparison with other shelves in the world, due to two large sediment loads from the Huanghe (Yellow River) and the Yangtze. It was suggested that suspended matter in the East China Sea was separated by climbing water from the Kuroshio Current in most months during the summer period (April–November) and could be transported to the Okinawa Trough only during the winter period (December–March) due to the retreat of climbing water back to the Okinawa Trough and a strong mixing of water column caused by winter storms (Milliman et al., 1985a,b, 1989; Yang et al., 1992, 1998). However, the dynamic factors of TSM transport from the East China Sea to its eastern deeper waters remain unsolved.

There have been many comprehensive numerical modeling studies applied to the Yellow and East China Seas (Takahashi et al., 1995; Kagimoto and Yamagata, 1997; Bao et al., 2001; Kang et al., 2002; Ko et al., 2003; Chang and Isobe, 2003; Huang et al., 2005; Moon, 2005; Isobe and Beardsley, 2006). However, due to the difficulty of estimating the rainfall supplied directly from the atmosphere to the sea surface and wind shear distribution in hourly base in the East China Sea, none of the modeling analyses considered these effects before. The discharge from the Yangtze during the 1998 big flood showed a large variation with time, and therefore the daily river discharge from the Yangtze is essential for an accurate simulation of temperature, salinity and the current field in the East China Sea.

The measurement of the spatial and temporal variations of tropical rainfall around the globe remains one of the critical unsolved problems of meteorology. TRMM (Tropical Rainfall Measuring Mission) will fill many gaps in our understanding of rainfall properties and their variation. These include: (a) frequency distributions of rainfall intensity and areal coverage, (b) variation of the timing of heaviest rainfall – particularly nocturnal intensification of large mesoscale convective systems over the oceans, and (c) diurnal intensification of orographically and sea-breezed forced systems over land.

The European Centre for Medium-Range Weather Forecasts (ECMWF) has been producing real-time medium-range forecasts at an operational level since August 1, 1979. Reanalysis of the forecasts for the full period 1979–2001 based on information provided by the data-assimilation system (model and analysis) and on external information from observations and boundary conditions creates a new understanding of the climate of the earth and its variations. The marine meteorological buoy robots (ST22001, Fig. 1a) have been used for the validation of re-analysis and the results from ECMWF will provide distributions of meteorological parameters over the surface of the East China Sea.

In this paper, the distributions of water temperature, salinity, suspended matter and current velocity in the estuary and the East China Sea have been presented by using a 3D ocean circulation model and a suspended matter model coupled with the results of an atmospheric global circulation model (GCM), with daily average precipitation based on the rainfall radar of TRMM (Tropical Rainfall Measuring Mission) satellite and with the daily average discharge based on the results of the Yangtze flood in the summer of 1998 (Xu et al., 2005; Zhang et al., 2005).

2. The numerical model

The numerical model used in this study is the 3D coastal ocean circulation model developed originally by Blumberg and Mellor (1987). The model incorporates the (Mellor and Yamada, 1974, 1982) level 2.5 turbulence closure scheme as modified by Galperin et al. (1988) to provide a time and space-dependent parameterization of vertical turbulent