Ocean dynamics of the ROFI regime –theoretical and experimental approach to the ballooning of river plumes

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Simpson (1997) calls the coastal region where the river plume spreads a region of freshwater influence (ROFI). In strict terms, he defines the ROFI as the region where the local input of freshwater buoyancy from the coastal source is comparable with, or exceeds the seasonal input of buoyancy as heat. In the present study, we emphasize that characteristics (the horizontal scale and freshwater transport) of ROFIs are not determined by the buoyancy-driven current alone, but by a joint effect of buoyancy-driven and transient ambient currents.
River plumes induced by a coastal freshwater source have two noticeable features. One is the formation of a coastal boundary current turning to the right (in the Northern Hemisphere) from the viewpoint of an observer at the river mouth looking seaward. Another noticeable feature of river plumes is the formation of an anticyclonic eddy (hereinafter referred to as the bulge) in front of the river mouth. It is well known that a bulge growing offshore (ballooning) hardly reaches a steady state in the absence of either ambient currents or wind forcing. This study provides a physical interpretation for the ballooning of river-plume bulges by conducting numerical experiments in which a river plume is induced by a coastal freshwater source. Part of the freshwater released to the model ocean undergoes inertial instability. Near-inertial oscillations are predominant when disturbances are not forced in ambient waters of the river plume. These isotropic disturbances are amplified by inertial instability, so that unstabilized freshwater can move in arbitrary directions. Thus, unstabilized freshwater does not need to move toward the coastal boundary current on the right-hand side of the river mouth. Freshwater unstabilized for a long time can stay in the bulge for a long time. Unstabilized freshwater accumulates gradually in the bulge, and so ballooning occurs. When the direction of disturbances is prescribed in ambient waters, unstabilized freshwater is forced to move in the same direction. Thereby, motion of unstabilized freshwater is restricted in the alongshore direction when background disturbances are induced by alongshore tidal currents. It is therefore concluded that tidal currents play a role in stabilizing the offshore growth of river-plume bulges in coastal and shelf waters.
In addition, the above argument provides us a possibility that the ballooning is potentially controlled by the curvature of the river-mouth sidewall. This is because the riverine water firstly moves along the sidewall on the rotating frame, and because the curvature affects the centrifugal force (hence, inertial instability) exerted on riverine water. In the present study, we will demonstrate the dependency of river-plume behavior on the curvature (geometry of river mouths) through a rotating tank and numerical experiments. Exploring non-linear and unsteady river plumes is a major frontline of ocean dynamics even at the present time, although the rive plume is the oceanic process nearest to the everyday life.

Keywords: river plume, ballooning

Tsunami Simulation along Kitakami River with Effects of Morphological Changes and Breaching of River Embankments

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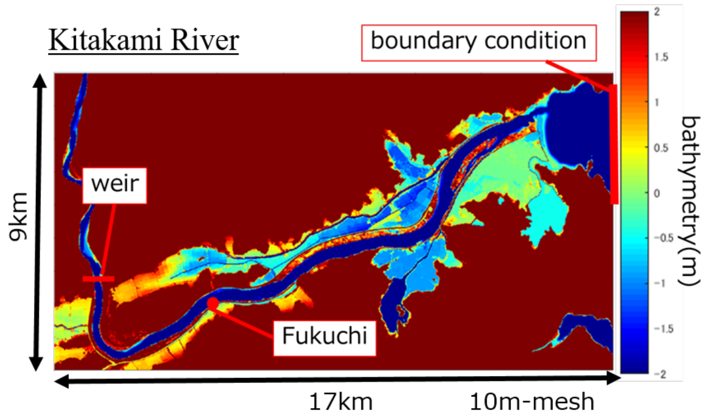
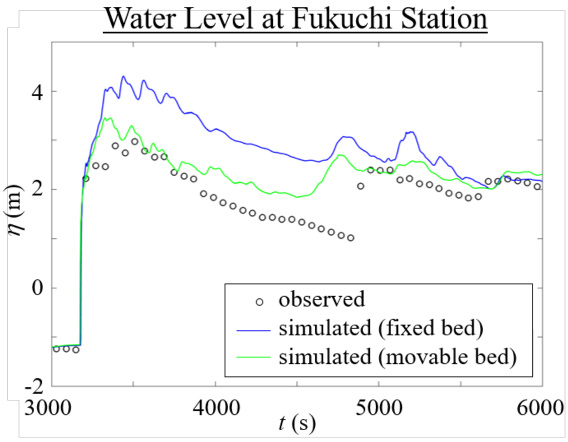
The 2011 Great East Japan Earthquake Tsunami induced huge damages on Pacific Coast of Japan. The rapid and farther run-up of the tsunami along rivers extended the damaged area to the area farther from the coast. Although there have been many researches on numerical simulation of tsunami run-up into rivers, due to its huge scale the 2011 tsunami has some features which have not been considered well before this event. One of the biggest differences is big morphological changes especially around river mouths. Sand spits at the river mouths were flushed by the tsunami and also erosion of river mouth terraces was observed. Morphology of river mouths has been considered as one of the important factors to limit the volume of the tsunami flow running into the rivers. Another important feature is the tsunami wave height more than heights of river embankments. The tsunami overflow flushed the river embankments completely in many areas. These phenomena themselves are important problems which should be considered well, and their effects on the tsunami waves running up along the rivers also should be included in numerical models for the proper designs of hard and soft countermeasures. In this study, numerical simulations with different numerical conditions were done to discuss the effects of morphological changes and collapse of river embankments on their propagation along rivers.

In this study, propagation of the 2011 tsunami into Kitakami River, located in Miyagi Prefecture, Japan, was simulated with Shallow Water Equation (SWE) model, which is horizontal 2D model and commonly used for tsunami simulation. A sand spit at the river mouth was flushed and a part of river embankment along this river was broken by the 2011 tsunami. Many water level stations were damaged by the earthquake and the tsunami, while one station survived and recorded the time series of the water level during this event with 1 min of sampling rate. Input wave condition of water level and velocity was calculated in advance through a simulation from the wave source to the numerical domain. In order to include the interaction between the tsunami intrusion into the river and the morphological changes around the river mouth, a sediment transport model proposed by Takahashi et al. (1999) was coupled with SWE model. The river and coastal embankments were included in the bathymetry data. Only in the area where actually the embankments were flushed by the tsunami, they were considered as a part of the movable bed, and no morphological changes were calculated in the other part of the embankments to keep their height. The result of the movable bed simulation was compared with real observed water level data at Fukuchi Station and the simulated data with fixed bed to have no erosion of the embankments and the river mouth sand spit.

In the movable bed simulation, the embankments were rapidly eroded by the strong flow over them. The peak of the water level at the Fukuchi Station shows overestimate by about 1 m in the fixed bed simulation, while the peak with the movable bed shows good agreement with the observed data. However, the decrease of the water level after the first peak was smaller in the both simulation cases. In the movable bed case, the erosion around the river mouth was not as big as the real condition, no flushing of the spit was observed in the simulation. And there is also an uncertain point on the time when the collapse of the embankment happened in the real tsunami. More discussion should be done on sediment transport model and embankment collapse model under tsunami waves to improve the accuracy of simulation of tsunami run-up into rivers.

Keywords: Shallow Water Equation, Tsunami run-up into river, sediment transport model





Effects of suspended sediment matters induced by high riverine discharge on coastal mixing: a model simulation

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Rivers transport fresh water, suspended sediment matters (SSMs) and nutrients from land to coastal seas where biological productivity is high. Rivers directly supply dissolved inorganic nutrients to coastal areas. On the other hand, riverine buoyant freshwater inputs induce horizontal river plumes and vertical circulations which indirectly supply nutrients from the deeper nutrient-rich layer to the surface layer. The form and strength of horizontal river plumes and vertical circulations (e.g., estuary circulation) depend on the density difference between river water and seawater. SSMs are not just passively transported to coastal seas by such plumes and circulations but also change them by influencing the density of river water and seawater, as seen in the case of hypopycnal flows. The change of coastal mixing driven by the plumes and circulations due to the density-change by SSMs is expected to be important for coastal biogeochemistry, especially when a lot of SSMs are supplied to the sea, that is, huge flooding. However, the interaction between the physical (i.e., horizontal plumes and vertical circulations) and the biogeochemical (i.e., SSMs) processes has not been quantitatively discussed. In this study, we employ a non-hydrostatic ocean model (kinaco) with Lagrangian particles, which represent SSMs and affect the density of seawater, in order to estimate the mixing effect by SSMs. We used experimental settings of a realistic topography of Tango Bay, Japan during the flooding in Sep. 2013. Tango Bay is a region of freshwater influence by Yura River where extraordinary river-discharge was observed in Sep. 2013. We especially focus on influenced vertical mixing due to upwellings and downwellings accompanied by sinking of SSM-particles near the coast, and investigate the sensitivities of physical processes to density of SSM-particles, etc.

Keywords: Flood, Suspended sediment matter, Interaction between physical and biogeochemical processes

High-resolution observation of a river plume by using the geostationary ocean color satellite

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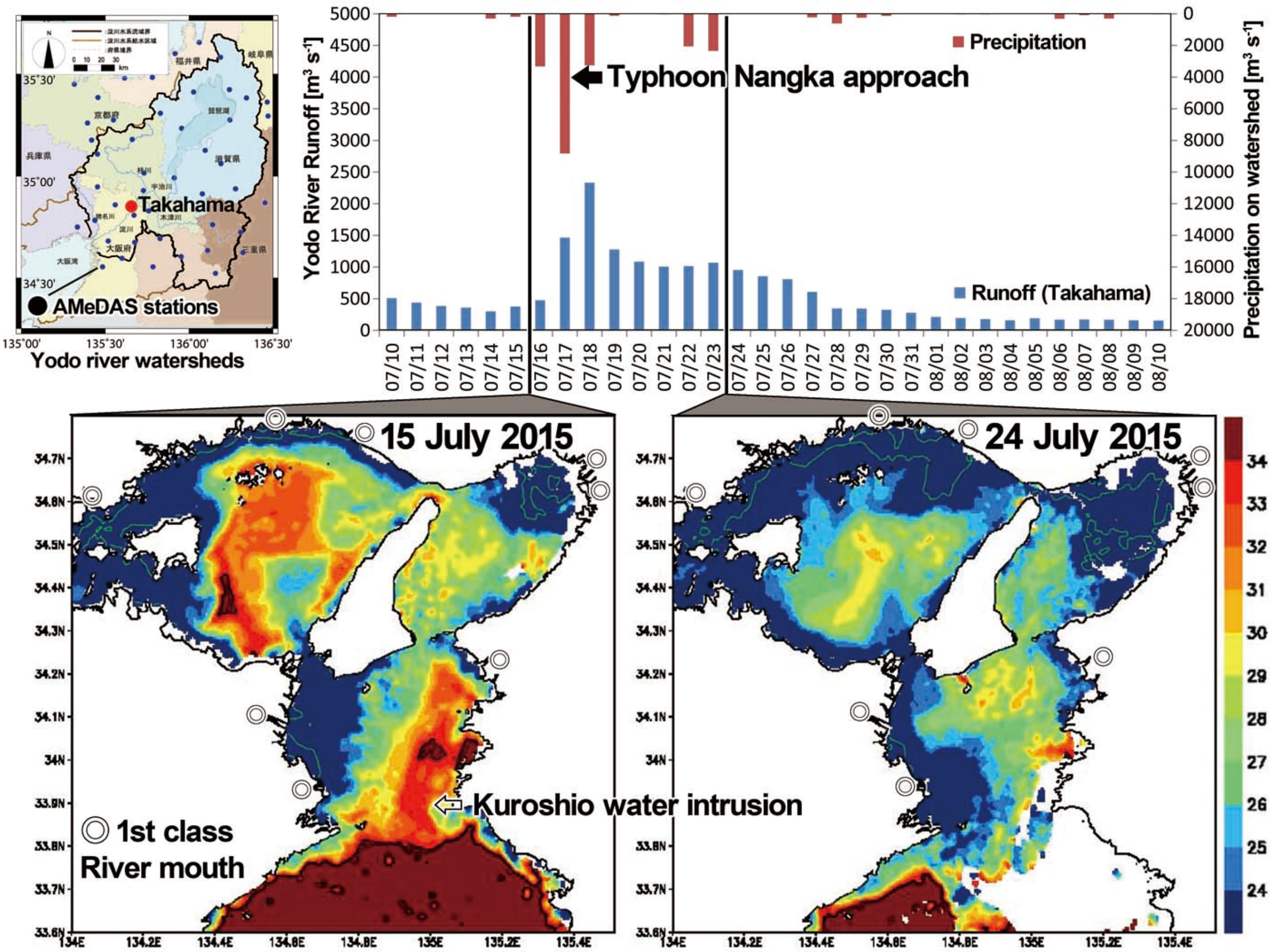
Sea-surface salinity (SSS) is a direct indicator of a freshwater plume associated with river discharge. The river plume spreading from the estuary can determines the water density structure and circulation system in coastal oceans. The riverine materials provided to the coastal oceans are a crucial contributor and often yield significant fishery resources and may often be associated with eutrophication transporting the deposition, resuspension, and dissolved materials such as nutrients from land-derived sources. However, to date, satellite-derived SSS maps based on microwave measurements (L-band radiometers) such as the Aquarius/SAC-D was not designed to resolve the river plume at temporal and spatial resolutions sufficient because the SSS associated with a riverine plume vary highly in time and space in coastal oceans. It has been known that the relationship between the SSS and optical absorption coefficient of colored dissolved organic matter (aCDOM) has a significant negative correlation, leading to the successful estimation of the SSS in the marginal and coastal oceans based on ocean color satellite products. Recently, the geostationary satellite, the Korean Communication, Ocean and Meteorological Satellite (COMS) mounts the world's first geostationary ocean color sensor, the Geostationary Ocean Color Imager (GOCI) to obtain hourly ocean color images with visible and near-infrared band at eight times during the daytime around Japanese Islands and Korean peninsula with a spatial resolution of approximately 500 m. This paper presents the high-resolution and hourly SSS maps in the coastal oceans, Osaka Bay, Harima-nada, and Kii Straight to sufficiently analyze the river plume based on the observational data of ocean color sensor mounted on the geostationary satellite (GOCI-COMS). Using the spatiotemporally high-resolution SSS datasets, we examine the dynamics of river plume induced by the extreme typhoon. As a result of the field surveys in the study area during the period of the larger riverine runoff from summer to autumn, the regression between satellite-derived and in-situ CDOM shows a good correlation coefficients (R=0.88) and highly negative correlation between in-situ CDOM and SSS (R=-0.92). These results indicate that the satellite-derived CDOM can be useful to derive the estimated SSS map for our analysis. As an example of SSS data analysis, we exhibited the episodic changes of the SSS induced by the Category 4 typhoon that attacked Kinki-region during the pre-typhoon period in 15 July to post-typhoon period in 24 July, 2015 along with the time-series of the river runoff and precipitation in the watershed of the Yodo River (Figure 1). After the heavy precipitation and increased runoff induced by the typhoon, the river plume formed in the bay head enlarged to offshore, and largely extended to the whole eastern part of the bay. The narrow-width plume formed along the northern coast of the Harima-nada enlarged to offshore several kilometers in post-typhoon. The salinity of the saline Kuroshio water intruded in Kii Straight in 15 July decreased by the large river runoff in 20 July. Thus, the characteristics of the river plume can be qualitatively and quantitatively detected by using the satellite-derived SSS map based on GOCI. The SSS maps products has been started to be used for the initial condition and verification data of high-resolution coastal ocean simulation. An accurate determination of the SSS maps is essential to a better estimation of ocean environment and ecosystems relevant to coastal fisheries, aquaculture, and marine harvesting, and to measures for disaster reduction against the typhoon and tsunami.

Keywords: Colored dissolved organic matter, Sea surface salinity, River plume, Coastal oceans, Geostationary ocean color satellite



A development of global-scale river discharge estimation framework by assimilating satellite altimetry

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Understanding spatial and temporal variation of surface waters is important for global hydrological cycle studies and water resources management. The future SWOT (Surface Water and Ocean Topography) satellite mission will measure the elevation and slope of surface waters at a spatial resolution <100 m, and will be utilized for river discharge estimation at a global scale. In order to achieve spatially and temporally continuous discharge estimation, frameworks for assimilating the SWOT measurements into river hydrodynamic models have been developed. However, previous studies on SWOT assimilation were performed only at regional or local scales. In this research, we developed a global-scale framework for river discharge estimation for the first time. We used the CaMa-Flood global river model as a hydrodynamics core and assimilated SWOT-observed water surface elevations using LETKF (Local Ensemble Transform Kalman Filter). The developed framework was tested by virtual experiments using synthetic SWOT observations, and we estimated truth river discharge by correcting simulations with corrupted runoff forcing. We found the assimilation significantly improved river discharge estimation in continental-scale rivers. Especially in the downstream reaches, discharge was estimated with little errors even when there is no local SWOT observation since corrected hydrodynamic states in upstream propagated downstream. We also found that discharge at the most downstream reaches could be accurately estimated by assimilation even if realistic precipitation or runoff forcing data is unavailable. These results suggested the potential of the future SWOT mission for spatially and temporally continuous estimation of river discharge at a global scale.

Keywords: data assimilation, SWOT, LETKF, river discharge, satellite altimetry

Tidally-induced instability processes governing the river plume behavior in a non-rotating regime

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River plumes play a significant role on the ecosystem as well as the ocean circulation in coastal waters, because they include terrigenous nutrients, sediments, and pollutants in addition to the buoyancy, and thus behavior of river plumes has been an important topic in the coastal oceanography. Recently, an attention has been placed on river plumes fluctuating owing to tidal currents near the river mouth (tidal plume). However, previous numerical studies on the river-plume dynamics have been almost conducted under the hydrostatic assumption, and so it was difficult to investigate how fine structures such as Kelvin-Helmholtz (K-H) bellows observed at the base of tidal plumes alters behavior of river plumes. This is the objective of the present study reproducing the fine structures in tidal plumes using a non-hydrostatic numerical model (MITgcm with 5-m grid cell). First, two sets of field observations were conducted around the Hiji River mouth, the Seto Inland Sea, Japan on July 1st, 2013. One is the CTD casts to depict a vertical section of the river plume, and the other is an aerial photography using a ship-towed balloon equipped with a digital camera to depict a horizontal view of the river plume. The estuarine front visualized by accumulated debris and foams was accompanied by a meander with a wavelength of a few ten meters. The river plume with a thickness of a few meters had the undulated plume owing to the development of small eddies horizontal length less than ˜100 m. Numerical experiments were conducted to reproduce the river plume fluctuating owing to the tidal currents, and to investigate the effect of fine structures to the behavior of the river plume. It is confirmed that the horizontal and vertical disturbances observed in the field observations were likely to occur due to the inertial instability and K-H instability, respectively. It is indicated that these disturbances are generated by a combination between river plume and ambient tidal currents, act as friction to prevent for the river plume from expanding offshore-ward.

Keywords: river plume, inertial instability, Kelvin-Helmholtz instability

