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

*Atsuhiko Isobe[1]

1. Research Institute for Applied Mechanics, Kyushu University

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

*Yuta Mitobe[1], Yasuhisa Aoyama[1], Hitoshi Tanaka[1], Daisuke Komori[1]

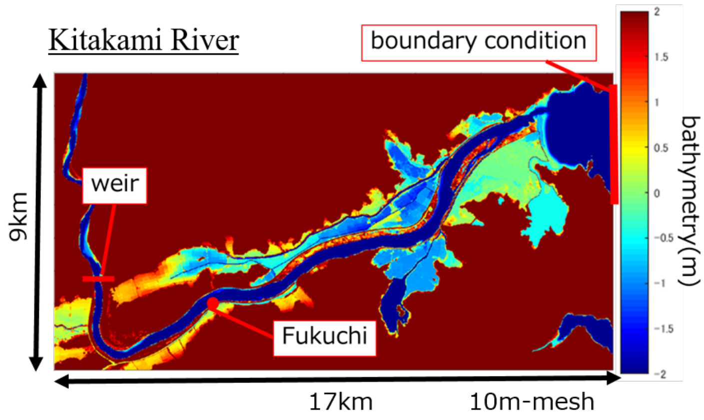
1. Tohoku University

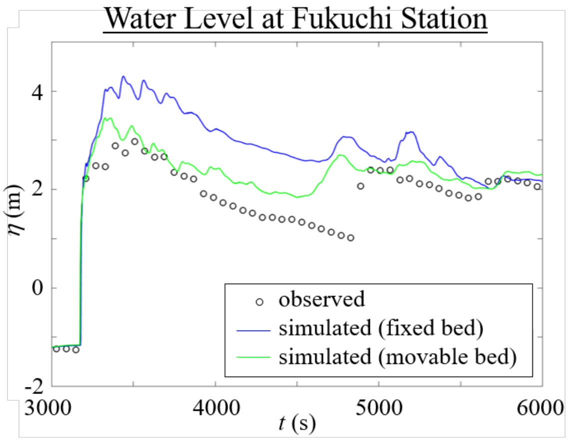
The 2011 Great East Japan Earthquake Tsunami induced huge damages on Pacific Coast of Japan. The rapid and farther run-up of the tsunami along rivers extended the damaged area to the area farther from the coast. Although there have been many researches on numerical simulation of tsunami run-up into rivers, 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

*Yasuhiro Hoshiba[1], Yoshimasa Matsumura[2], Hiroyasu Hasumi[1], Sachihiko Itoh[1], Yoh Yamashita[3]

1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Institute of Low Temperature Science, Hokkaido University, 3. Field Science Education and Research Center, Kyoto University

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

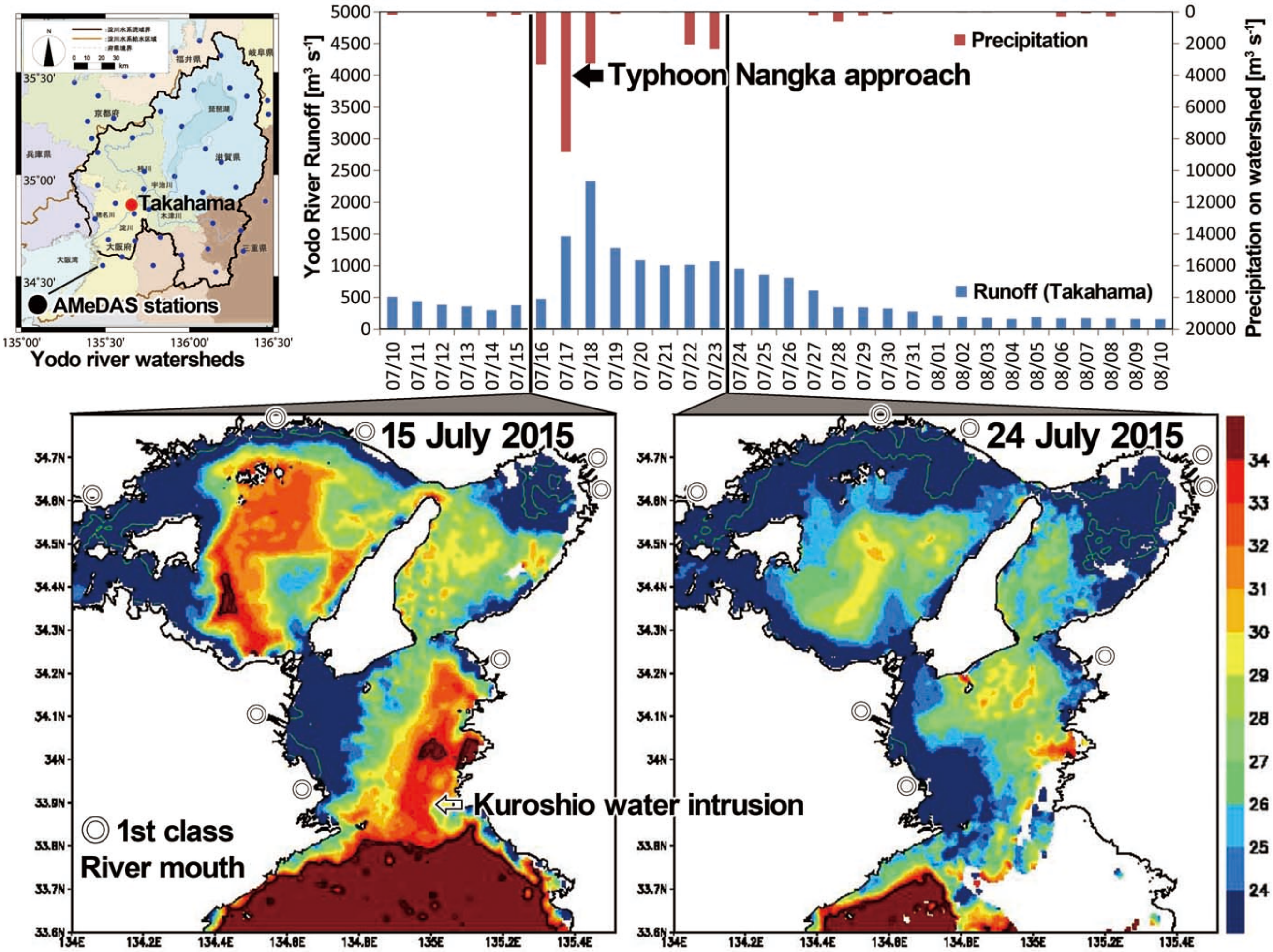
High-resolution observation of a river plume by using the geostationary ocean color satellite

*Satoshi Nakada[1], Shiho Kobayashi[2], Joji Ishizaka[3], Masataka Hayashi[4], Masaki Fuchi[1], Masaki Nakajima[5], Satoshi Akiyama[5]

1. Graduate School of Maritime Sciences, Kobe University, 2. Field Science Education and Research Center, Kyoto University, 3. Institute for Space-Earth Environmental Research, Nagoya University, 4. Graduate School of Environmental Studies, Nagoya University, 5. Research Institute of Environment, Agriculture and Fisheries, Osaka Prefecture

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

*Daiki Ikeshima[1], Dai Yamazaki[2], Shinjiro Kanae[1]

1. Tokyo Institute of Technology, 2. Japan Agency for Marine-Earth Science and Technology

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

*Yuichi Iwanaka[1], Atsuhiko Isobe[2]

1. Kyushu University, 2. RIAM, Kyushu University

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

Incorporation of sea level variation into a global river routing model and its impact assessment

Hiroaki Ikeuchi[1], Yukiko Hirabayashi[1], *Dai Yamazaki[2]

1. Graduate Schoolf of Engineering, the Universiy of Tokyo, 2. Japan Agency for Marine-Earth Science and Technology

Global river routing models have been applied to river flood risk assessment such as in regions with poor data of topography observation, and global mapping of flood inundated areas and its interregional comparisons. In these years they have been developed in various research institutions around the world. However, since previous studies mainly focused on flood risk assessment in land areas, sea level variations have not been taken into consideration, and fluvial flood simulations in areas vulnerable to tides and storm surges have been underestimated.
The objective of this study is to elucidate the influence of sea level variation on fluvial flooding by employing a global river ruoting model capable of appropriately expressing the backwater effect, and a global reanalysis of tide and surge that was developed in recent years. First, we modified the river routing model to express sea level variation. Next, we developed a scheme for delivering sea level data from a global reanalysis of tide and surge to the global river routing model, conducted coupled simulation, and evaluated the influence.
Coupled simulation on the global scale revealed that river water levels increased by 0.5 m or more in comparison with the case without considering sea level variation. We found that the sea level fluctuation significantly affected fluvial flood simualtions. Time series of river water levels was analysed for large rivers with catchment areas larger than 160,000 km^2 in the Asian region. As a result, peak water levels increased by 1 m or more in some rivers, and the seasonal variation of river water levels were enhanced in others. In sum, it was clarified that sea level variation had a meaningful impact on fluvial flood simulations.

Keywords: Fluvial flooding, Storm surge, Global river routing model, Global reanalysis of tide and surge

Phosphorus in groundwater discharge to the ocean –A potential source for coral reef degradation

*Jun Yasumoto[1], Masashi Nozaki[2], Ko Yasumoto[3], Mina Yasumoto Hirose[4], Mariko Iijima[3]

1. Faculty of Agriculuture, University of the Ryukyus, 2. Graduate School of Agriculture, University of the Ryukyus, 3. School of Marine Bioscience, Kitasato University, 4. Tropical Technology Plus

Phosphorus, the main ingredient of fertilizer, is a limiting factor for sustainable primary production and is recognized as a major source for eutrophication of lakes, estuaries, and watersheds. Phosphorus in the water environment exists in various forms, and its transport form have been remained in many regions. Many sequential extraction methods have been proposed for morphological fractionation of phosphate in soil, but there are problems such as not being usable for morphological classification of polyphosphate and organic phosphorus. However, in recent years, One-dimensional (1D) solution 31P nuclear magnetic resonance spectroscopy (NMR) is currently the tool of choice for molecular-level characterization of organic P in soils 31P nuclear magnetic resonance spectroscopy (31P-NMR) as a morphological separation method of phosphorus in soil in fields such as soil fertilizer has been conducted. In this method, it is possible to classify phosphate in a form which was difficult to classify by the continuous extraction method.
In the present study, 31P-NMR and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) are used to understand a characteristic of the transport form of phosphate in soil and groundwater. In addition, we estimated the phosphorus load through groundwater to the coral reefs sea region of Okinawa through field measurement and numerical simulations, and investigated the effect of phosphate on in vivo skeleton formation of primary polyp for hard coral Acropora digitifera.

Keywords: Phosphorus, 31P nuclear magnetic resonance spectroscopy, groundwater, coral reefs

Application of Hydro-debris2D into sediment yield prediction from mountain watershed

*Yosuke Yamashiki[1], Ryusuke Kuroki[1], Tsutao OIZUMI[2]

1. Global Water Resources Assessment Laboratory - Yamashiki Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2. Japan Agency for Marine-Earth Science and Technology

Hydro-debris2D model has been developed and improved for predicting occurrence of debris flow throughout hydrological regime changes. The model contains three components: (1) Shallow-water based surface flow modules, in order to calculate mountain zone torrential flow regimes, (2) rapid subsurface/interflow in weathered rock, and (3) debris flow and sendiment-transport components. The model has been applied into Izu Oshima Island’ s debris flow event in 2013 and to Hiroshima’ s debris flow disaster in 2014. The model was applied into Shirakawa-basin which contains catchment of Aso Volcano. Landslides occur in more frequent manner compared with actual occurrence when projected observed precipitation. This is due to the application of over-estimated value which had been extracted from Hiroshima debris flow disaster.

Keywords: Hydro-debirs2D, sediment transport, mountain watershed

Introduction of the SWOT satellite altimetry mission

*Dai Yamazaki[1], Pavelsky Tamlin[2]

1. JAMSTEC - Japan Agency for Marine-Earth Science and Technology, 2. University of North Carolina

SWOT (Surface Water and Ocean Topography) is a next-generation satellite altimetry mission by NASA and CNES to be launched in 2021, which will measure the spatial-temporal variation of water surface elevations of the land and ocean. Unlike conventional nadir altimeters which measures the elevation of water just below the spacecraft (e.g. Jason 1/2, Cryosat), SWOT is a "swath altimeter" which will observe the 2-dimentional distribution of water surface elevations using radar interferometer. With its 21-day sun-unsynchronized orbit, almost entire areas between N78 and S78 are to be measured without major gap by the observation swath of ~120km width. High-resolution (<100m) observations are planned over land to capture small rivers and lakes, whereas the observation over oceans will be at ~500m resolution mainly targeting mesoscale eddies.
Especially for hydrology, SWOT will be the first-ever comprehensive measurement of water surface elevations, as the spatial scales of rivers and lakes are much smaller than that of oceans. It will observe rivers wider than 100m and lakes and wetlands larger than 5ha with better than 10cm vertical accuracy, and will provide spatial and temporal distributions of surface water extent and storage. In addition to the directly-observable water surface elevations, by delineating water surface slope, SWOT is expected to estimate river discharge from space. The SWOT measurements, in combination with other ancillary datasets and models, will enhance our ability to assess the storage change in lakes and reservoirs, the occurrence of flood and draught, the dynamics of wetland and floodplain, at a global scale.
Toward its launch in 2021, tremendous efforts are ongoing for sensor development, error budget analysis, algorithm development, and ancillary data/model preparation. Overview of the SWOT mission, mainly focusing on hydrology components, will be presented during the JpGU-AGU joint meeting.

Keywords: SWOT, Satellite Altimetry, Surface Water, Sea Surface Height

A particle-in-cell modeling framework for simulating riverine and oceanic suspended sediment transport

*Yoshimasa Matsumura[1]

1. Institute of Low Temperature Science, Hokkaido University

Suspended sediments contained in the river water (and glacial melt water) runoff is one of the primary source for the terrigenous trace elements supply to the ocean and hence it plays an important role in the marine material circulation and biogeochemical cycle. The transport, settling and re-suspension processes of sediment particles in the ocean are controlled by the interaction between the dynamics of individual particles depending on its composition and size-distribution and the complex current systems in the coastal regions. In particular, the suspended sediment concentration at the greater discharge events is several orders of magnitude greater than that in the normal time runoff. In such cases the existence of suspended sediments increases the apparent density of turbid runoff water, and thereby dynamically affects the current structure. In numerical ocean models, the suspended materials have been usually represented by the cell-volume averaged concentration in the Eulerian form as well as salinity and other dissolved materials. However, individual particle is settling with its own settling velocity relative to the ocean current primarily determined by its size and composition. Therefore, the bulk representation of Eulerian cell-averaged concentration has limitations to trace wider range of sediment size-distribution. To address this issue, we introduce a new particle-in-cell (PIC) type modeling framework to simulate oceanic dispersed multiphase flow such as the turbid river water discharge, where the dispersed suspended materials are represented by large number of Lagrangian particles. In the present model Lagrangian particles are solved at each time-step simultaneously with the time progress of the ocean current predicted by a finite-volume non-hydrostatic ocean model. The dynamical effects of the suspended particles are included by appending the sum of the contribution of particles existing inside each cell to the right hand side of the Navier-Stokes equation that predict the velocity at corresponding cell. In the presentation we introduce the detail of the implementation and the result of an idealized experiment on the formation of hyperpycnal flow.

Keywords: sedimient transport, Lagrangian particle tracking, non-hydrostatic ocean model, hyperpycnal flow

The dynamics of the freshwater discharge at the Ganges-Brahmaputra river mouth

*Shinichiro Kida[1]

1. Research Institute for Applied Mechanics, Kyushu University

The Bay of Bengal receives significant freshwater input from the Ganges-Brahmaputra river. This freshwater discharge is observed with a prominent seasonal cycle, a minimum in late winter to early spring and a maximum in late summer to early fall. However, the river mouth of the Ganges-Brahmaputra river is a mega-delta and thus has multiple channels rather than just one. We have carried out regional numerical experiments utilizing a land-river-ocean seamless model to investigate the basic dynamics of how this river discharge events near the river mouth occur. On a large-scale, we find freshwater discharge to create river plumes along the coast and to establish a coastal current that flows southwestward when the oceanic currents are assumed quiescent. On a river mouth scale, however, the pathways of the freshwater discharge is complex. Preliminary analysis indicates that this is because of river-ocean interaction and that the various channels of the Ganges-Brahmaputra river delta are dynamically connected.

