ROFIの力学 ーバルーニングに対する理論的・実験的アプローチ
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.

キーワード：河川プリューム、バルーニング
Keywords: river plume, ballooning

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

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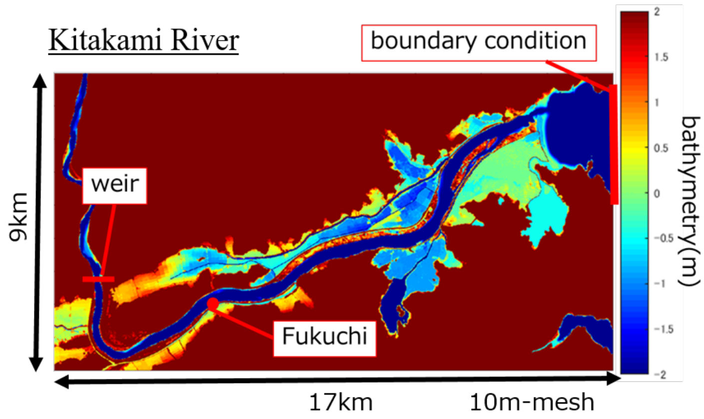
The 2011 Great East Japan Earthquake Tsunami induced huge damages on Pacific Coast of Japan. The rapid and farther run-up of the tsunami along rivers extended the damaged area to the area farther from the coast. Although there have been many researches on numerical simulation of tsunami run-up into rivers,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

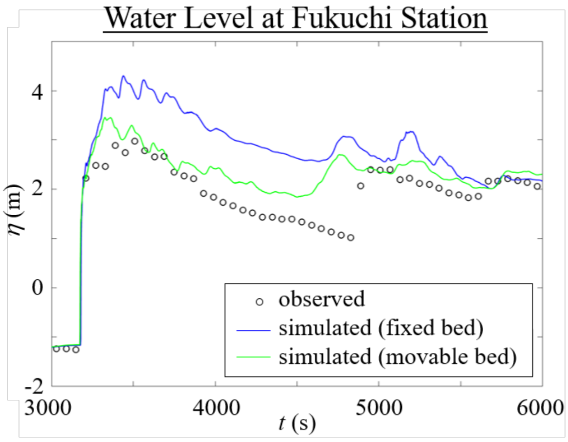
In this study, propagation of the 2011 tsunami into Kitakami River, located in Miyagi Prefecture, Japan, was simulated with Shallow Water Equation (SWE) model, which is horizontal 2D model and commonly used for tsunami simulation. A sand spit at the river mouth was flushed and a part of river embankment 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.

キーワード：浅水流方程式、津波河川遡上、土砂輸送モデル
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.

キーワード：洪水時、河川起源懸濁物、物理・物質循環相互作用
Keywords: Flood, Suspended sediment matter, Interaction between physical and biogeochemical processes

静止海色衛星による河川プリュームの高時空間分解能観測
High-resolution observation of a river plume by using the geostationary ocean color satellite

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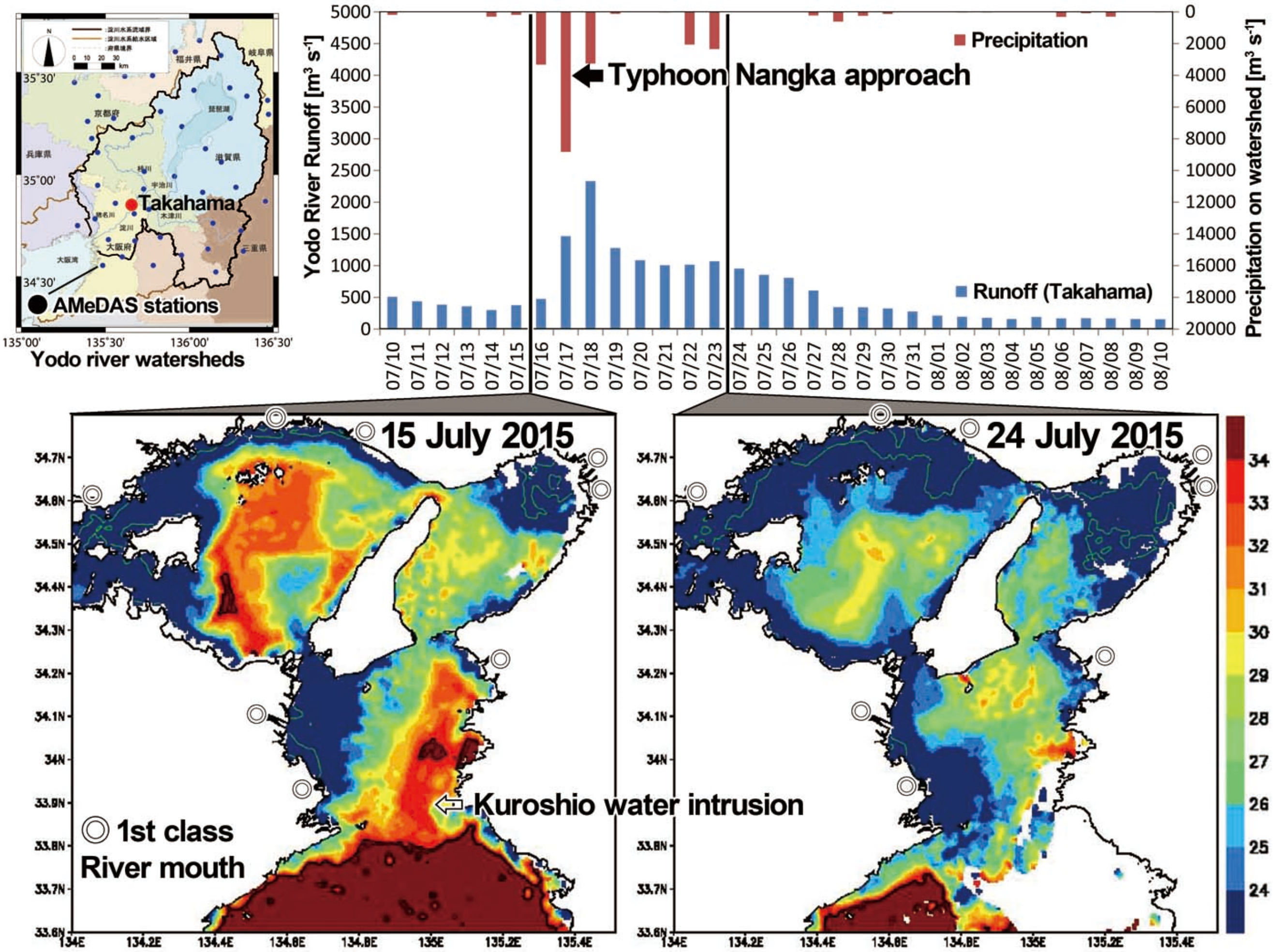
河川プリュームの指標となる海表面塩分(SSS)の情報は、沿岸域の水環境のみならず養殖漁場環境の観点から重要である。しかし、沿岸域においては衛星観測から得られるSSSデータの水平分解能は粗く(例えばSAC-D衛星は約50 km)、沿岸域に特化した塩分場推定手法を確立する必要がある。低塩な河川プリュームは陸域由来の有色溶存有機物(CDOM)を多く含み、CDOMと塩分には高い相関関係があることが知られている。2011年より、静止海色衛星GOCI-COMSによって1日8回毎時のCDOMマップが高い水平解像度(500 m)で得られている。本研究では、現場海洋観測結果に基づいて衛星観測により得られたCDOMマップから海表面塩分を推定する方法を開発し、沿岸域における海表面塩分マップを整備した。河川からの陸水負荷が大きく、現場観測データが豊富である大阪湾・播磨灘・紀伊水道を実験対象として、主に台風襲来前後における河川プリュームの動態を解析した。河川出水が卓越する夏季から秋季にかけて対象海域において現場観測を実施した結果、衛星CDOMと現場CDOMデータとの良好な回帰式が得られ(相関係数は0.88)、また、CDOMとSSSには良好な負の相関関係(相関係数は-0.92)が見出された。衛星CDOMからSSSの推定式が作成され、衛星CDOMデータからSSSマップが作成できた。解析結果の一例として、2015年7月3日に発生した台風11号の近畿地方上陸前(7月15日)と後(7月24日)において変化した海表面塩分を、淀川流域降水量と河川流量の時系列ともに図１に示す。台風上陸後に降雨と淀川の出水が多くなった後、大阪湾奥に形成されていた河川プリュームが沖側に張り出し、ほぼ大阪湾東部全体に広がっていた。播磨灘の沿岸域に注目すると、沿岸に張り付いていたプリュームが台風上陸後に沖側へ数km張り出した。淡路島の集水域の狭い河川からの出水のため、沿岸に張り付く河川プリュームは幅が狭い。7月15日において紀伊水道に貫入していた高塩な黒潮水塊が、7月20日は河川出水により低塩化していた。このように、海色衛星を用いて海表面塩分マップを得ることで、河川プリュームの特徴を定性的かつ定量的に捉えることができる。整備されたSSSマッププロダクトは、すでに沿岸域における高解像度海洋シミュレーションの初期値や検証データとして利用され始めており、津波、高潮、急潮などの防災面や、赤潮や陸水由来栄養塩の分布などの水環境面研究の基礎データとなりえる。

キーワード：有色溶存有機物、海面塩分、河川プリューム、沿岸域、静止海色衛星
Keywords: Colored dissolved organic matter, Sea surface salinity, River plume, Coastal oceans, Geostationary ocean color satellite



Takahama
AMeDAS stations
Yodo river watersheds
Yodo River Runoff [m³ s⁻¹]
Precipitation on watershed [m³ s⁻¹]
Precipitation
Typhoon Nangka approach
Runoff (Takahama)
15 July 2015
24 July 2015
Kuroshio water intrusion
1st class
River mouth

次世代衛星高度計をデータ同化する全球河川流量推定フレームワークの開発
A development of global-scale river discharge estimation framework by assimilating satellite altimetry

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地表水の時空間的変動を全球スケールで把握することは，内陸水域・海洋問わず地球全体の水循環解明や水資源管理に重要である．河川流量は陸域水動態における最も重要な要素の一つであり、その高精度な推定が望まれている．河川流量の計測は旧来より河川に設置した流量計によって行われてきたが，国や地域によってその数や分布には違いがある．また，情報公開の度合いも異なっており，全球で空間的に均一なデータを収集することは困難であった．2021年に打ち上げが予定されている次世代衛星高度計SWOT（Surface Water and Ocean Topography）は，レーダー干渉計を用いて100m未満の解像度で地表水の水面標高を面的に観測できる初めての人工衛星であり、全球規模で地表水動態の詳細を捉えることが期待される．しかし，SWOT衛星は同一地点を5~21日に一度しか観測できないため，SWOT観測の水面標高のみから時間的に連続して高精度な河川流量を推定することは困難である．空間的だけでなく時間的にも連続な流量推定の実現を目指し，SWOT観測と河川モデルを組み合わせて流量を推定するデータ同化手法の適用が検討されている．既往研究では計算コスト等の制約から特定の地域や河川に限定した同化が行われていたが，本研究ではSWOTの性能を最大限活かすために全球スケールでのデータ同化フレームワークを初めて開発した．河川モデルとしてCaMa-Floodを用いたことで，高速かつ高精度な流量推定が可能となっただけでなく，SWOT衛星の観測する水面標高を直接同化することが可能となった．また，データ同化手法としてはアンサンブルカルマンフィルタ（EnKF）の派生形であるLETKF（局所アンサンブル変換カルマンフィルタ）を採用し，河川モデルという非線形モデルに対しても現実的な計算コストで全球における同化が可能となった．2021年に予定されているSWOTの打ち上げ前にデータ同化手法の有効性を検証するため，ここでは開発したデータ同化フレームワークに対し，仮想観測を用いた仮想実験を行なった．これは，意図的に乱した河川モデルのシミュレーション結果に対して，河川モデルを用いて作成した仮想観測を同化することで河川流量の再現性を向上させられるかを試した実験である．実験の結果，大陸河川のような大規模河川において精度の向上が見られた．特に，河川の下流においてはその地点で観測のない日についても河川流量を小さい誤差で推定することができた．これは上流の多くの支流で観測・同化された流量が河川を流下し，下流の流量改善に貢献しているからである．また，降水量データ，あるいはそれより計算される局所的なグリッド内からの陸面流出量データが現実的でない場合でも，河口付近では高精度な流量推定する事が可能であることもわかった．本研究の結果より，全球スケールで時空間的に連続な河川流量推定における将来のSWOT観測の有効性が示唆された．

キーワード：データ同化、SWOT、局所アンサンブル変換カルマンフィルタ、河川流量、衛星高度計
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.

キーワード：河川プリューム、慣性不安定、ケルビン・ヘルムホルツ不安定
Keywords: river plume, inertial instability, Kelvin-Helmholtz instability