Effects of Koshu Seamount on the Development of Baroclinic Instability Leading to the Kuroshio Large Meander

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The Kuroshio south of Japan shows bimodal path fluctuations between the large meander (LM) path and the nonlarge meander (NLM) path. It is well known that the transition from the NLM path to the LM path is triggered by a small meander generated off the southwestern coast of Japan. The small meander first propagates eastward (downstream) along the Kuroshio and thereafter rapidly amplifies over Koshu Seamount located about 200 km to the south of Japan, leading to the formation of the LM path of the Kuroshio. Although it is shown that the existence of Koshu Seamount is essential for the rapid amplification of the small meander, the underlying physical mechanism has not yet been fully understood.

In this study, the effects of Koshu Seamount on this rapid amplification leading to the LM path formation are revisited using a two-layer quasi-geostrophic model that takes into account the effect of bottom topography. Numerical experiments show that the transition processes from the NLM path to the LM path can be successfully reproduced only when the bottom topography mimicking Koshu Seamount is incorporated. In this case, the upper layer meander trough is rapidly amplified through baroclinic interaction with a lower layer anticyclone during their passage over the seamount. A linear stability analysis shows that baroclinic instability over a seamount can be caused by the coupling between the upper layer Rossby wave propagating eastward in the background flow and the lower layer topographically trapped wave propagating clockwise around the seamount. These two waves propagate in the same direction over the northern slope of the seamount so that they can resonantly interact with each other. The wavelength and the spatial structure of this unstable mode are close to those of the numerically reproduced small meander in the early stage of its rapid amplification over the seamount, showing that the baroclinic instability catalyzed by a seamount is an essential process in the formation of the LM path of the Kuroshio.

Keywords: Large Meander of the Kuroshio, Koshu Seamount, Baroclinic Instability, Topographically Trapped Wave, Two-Layer Quasi-Geostrophic Model, Linear Stability Analysis

The Reynolds Stress Produced by Accumulation of Axisymmetric Oceanic Eddies

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The aim of this study is to analytically reveal a fundamental nature of the horizontal Reynolds stress caused by axisymmetric mesoscale eddies widely populated in the ocean. To accomplish our objective, we consider an idealized model, in which the eddies having the same amplitude emerge with probability whose horizontal distribution follows a two-dimensional Gaussian function corresponding to the number of eddies observed at a location during a certain period. We examine the Reynolds stress by decomposing into isotropic component equivalent to eddy kinetic energy and anisotropic component. The result shows that the isotropic component dominates near a site of the highest probability, while the anisotropic component becomes large as increasing distance from the location of the highest probability. This feature can be interpreted as isotropization of velocity field associated with eddies that intensively occurs near the region of the highest probability. The degree of isotropization depends on a horizontal scale of eddy relative to that of the probability distribution: an area of isotropy expands (shrinks) as the scale of the probability distribution becomes large (small) under the same eddy size. Application to a condition near a mid-latitude oceanic jet, such as the Kuroshio extension region, indicates that this Reynolds stress, resulting from incompleteness of isotropization, contributes to deceleration and acceleration of the jet in its upstream and downstream regions, respectively, This pattern is consistent with stabilization and destabilization of the jet due to eddy-mean flow interactions in these two regions. The Reynolds stress excited by axisymmetric eddies, however, yields dynamic pressure, which has no contribution to dynamics of incompressible fluid such as quasi-geostrophy, but yields ageostrophic circulation over the jet’s region. This suggests that occurrence of the axisymmetric eddies obscures the Reynolds stress that is meaningful for the dynamics in the real ocean. To eliminate contamination by the axisymmetric eddy in the Reynolds stress, we propose a shape-dependent calculus of the Reynolds stress, which may be applicable to studies on parameterization of eddy influences.

Keywords: Mesoscale eddies, Reynolds stress, Oceanic jets, Kuroshio Extension, Gulf Stream

Eddy transport of North Pacific Tropical Water and its impact on the salinity distribution

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North Pacific Tropical Water (NPTW), characterized as a subsurface salinity maximum in the subtropical gyre, is a major high-salinity water mass in the North Pacific. NPTW is formed in the surface layer in the central North Pacific, where evaporation is much larger than precipitation, and subsequently subducted due to Ekman pumping, and finally advected westward along the North Equatorial Current. Nakano et al. (2015) suggested that not only the variations of large-scale atmospheric forcing like Ekman pumping velocity and Evaporation-Precipitation but also mesoscale activity in the subtropical countercurrent (STCC) region may influence distribution of NPTW. In addition, Zhang et al.(2014) showed that eddy-induced zonal mass transport is comparable in magnitude to that of the large-scale wind-driven circulation mainly in subtropical regions, assuming that the fluid inside a closed potential vorticity contour on isopycnal surfaces will move with the eddy. It is thus important to investigate whether NPTW is trapped by mesoscale eddies and transported by their movement or not for clarifying the mechanism that mesoscale eddies affect the NPTW distribution. Furthermore, it is expected that if NPTW is transported by mesoscale eddies, this effect can appear not only in the interior region but also the western boundary region (southeast of Ryukyu Islands). The aim of our research is to show that mesoscale eddies transport NPTW by trapping it based on characteristics of spatio-temporal distribution of salinity in the STCC region, and show impacts of the mesoscale eddies' transport of NPTW on salinity variation in the western boundary region.

First we focus on spatially inhomogeneous distribution of salinity on an isopycnal surface in the STCC region because high salinity water would exist in a patchy fashion if mesoscale eddies transport NPTW with trapping it. Based on JMA hydrographic section data along 24˚N, Argo data, and OFES output, it is indicated that some higher salinity water masses compared with surroundings are distributed inside mesoscale eddies. By considering the advection process of NPTW demonstrated in the OFES output, we conclude that this feature is formed by the eddy transport of higher salinity water.

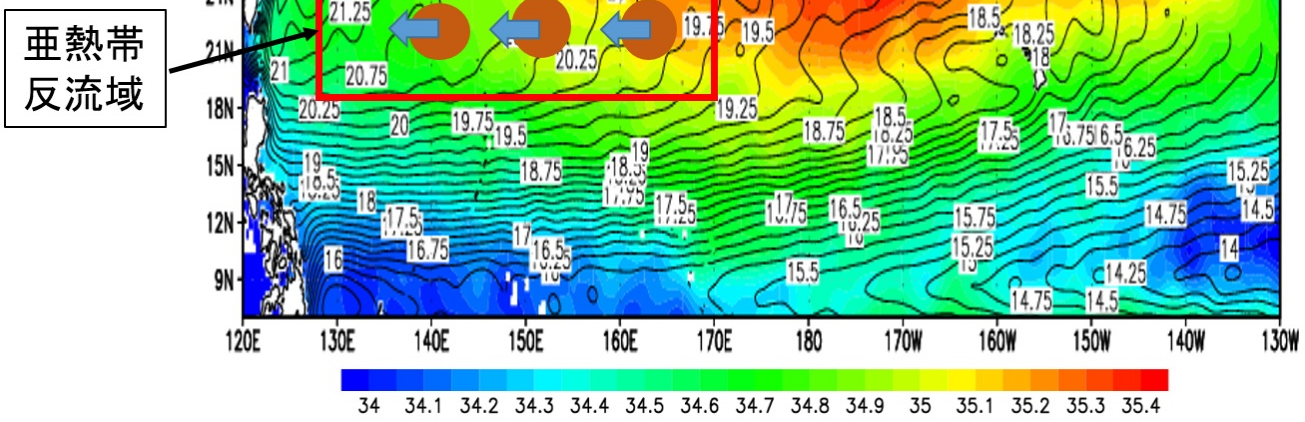
Next, we examine impacts of the eddy transport of NPTW on salinity variation in the western boundary region. We show that the time lag of salinity interannual variation at the western boundary region southeast of Okinawa Island behind that at 137ºE is shorter than the advection time due to mean flow. In addition, we observe that some mesoscale eddies transport high-salinity water quickly to the area southeast of Ryukyu Islands across the streamline of mean flow in the OFES output. Moreover, by means of investigating the salinity along Ryukyu current annually using observation data and OFES data, we find that, when the salinity along Ryukyu current is entirely high, locally (200-500km) and temporarily (a couple of months) high-salinity spots, which might be related to mesoscale eddies, are frequently observed and the shorter-period variation of salinity along Ryukyu current is enhanced.

Based on the results described above, it is suggested that the transport of NPTW by mesoscale eddies deliver the signal of salinity variations in the interior region to the area southeast of Ryukyu Islands more rapidly than the mean flow, and influences the characteristics of the salinity interannual variation in the western boundary region. The present study contributes to the understanding of a type of interscale interactions by clarifying impacts of mesoscale eddies on large-scale distribution of water masses. We

hope that it will lead to better understanding of not only spatio-temporal variations of water masses but also air-sea interactions and marine biogeochemical cycles.

Keywords: mesoscale eddy, eddy transport, salinity, Tropical Water, interscale interaction

中規模渦によるNPTW輸送の模式図
色影：海面塩分　コンター：24.0σ_θ面加速度ポテンシャル（単位m^2/s^2）



On the seasonal variation of the Bering Slope Current and anticyclonic eddies

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The Bering Slope Current (BSC) flows along the continental slope between the broad continental shelf and the deep basin in the Bering Sea. In this study, we consider the seasonal variability of the BSC and associated eddies by using a high-resolution model output. The BSC is strong (weak) in winter (summer), when isopycnal surfaces deepens (shoals) through the propagation of coastally trapped waves. The eddies are generated as a result of baroclinic instrability when the BSC is strengthened, extracting potential energy from the BSC. The seasonality of the BSC, as well as the eddies, is controlled by the seasonal variation of the Alaskan Stream via coastally trapped waves, generation of which is attributed to the seasonal variation of winds along the Alaskan coast.

Keywords: Bering Slope Current, eddies, seasonal variation

On the Leeuwin Current System and its linkage to zonal flows in the South Indian Ocean as inferred from a gridded hydrography

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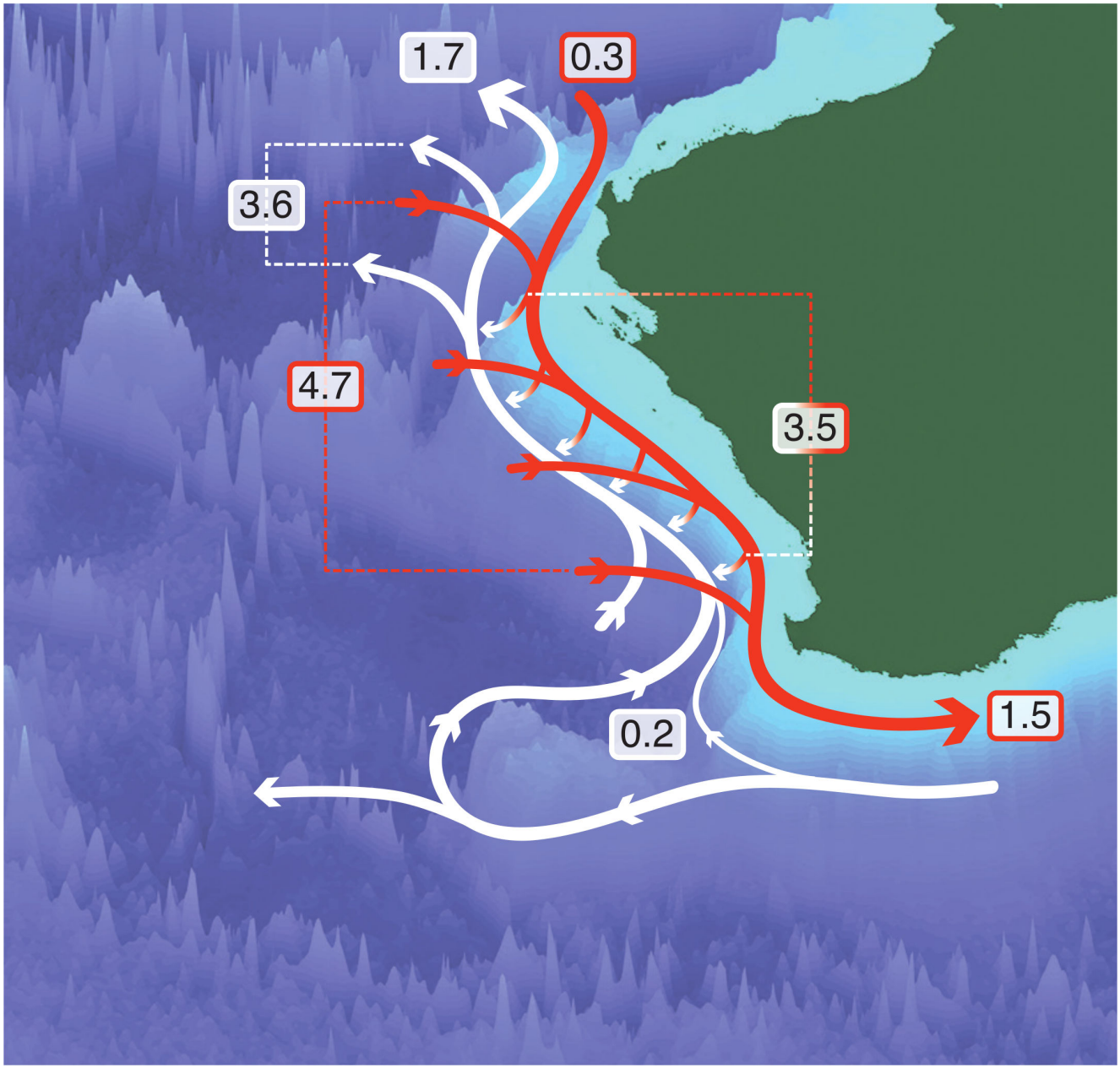
[My poster is in English.] The Leeuwin Current System (LCS) along the coast of Western Australia consists of the poleward-flowing Leeuwin Current (LC), the equatorward-flowing Leeuwin Undercurrent (LUC), and neighboring flows in the South Indian Ocean (SIO). Using geostrophic currents obtained from a highly-resolved (1/8 deg) hydrographic climatology (CSIRO Atlas of Regional Seas, CARS), we describe the spatial structure and annual variability of the LC, LUC, and SIO zonal currents, estimate their transports, and identify linkages among them.

In CARS, the LC is supplied partly by water from the tropics (an annual mean of 0.3 Sv) but mostly by shallow ($z < -200$m) eastward flows in the SIO (4.7 Sv), and it loses water by downwelling across the bottom of this layer (3.4 Sv). The downwelling is so strong that, despite the large SIO inflow, the horizontal transport of the LC does not much increase to the south (from 0.3 Sv at 22S to 1.5 Sv at 34S). This LC transport is significantly smaller than previously reported.

The LUC is supplied by water from south of Australia (0.2 Sv), by eastward inflow from the SIO south of 28S (1.6 Sv), and by the downwelling from the LC (1.6 Sv), and in response strengthens northward, reaching a maximum near 28S (3.4 Sv). North of 28S it loses water by outflow into subsurface westward flow (−3.6 Sv between 28S and 22S) and despite an additional downwelling from the LC (1.9 Sv), it decreases to the north (1.7 Sv at 22S). The seasonality of the LUC is described for the first time.

Keywords: zonal overturning, downwelling, comparison with OGCM



The observed south Java upwelling process and its intraseasonal variations

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The South Java Upwelling(SJU) develops in response to the southeastern monsoon wind forcing. Based on the in situ mooring, tide gauge, satellite and model data, we document its development, mature and decay process. It is interesting to note that SJU exhibits strong intraseasonal variability, in sharp contrast to the conventional picture of smooth seasonal upwelling. In extreme case, SJU even breaks for a while. This reflects its strong nature of remote forcing from the Equatorial Indian Ocean, except for its local wind forcing. High resolution model simulation is assessed on its capacity to capture the key upwelling features.

Keywords: South Java Upwelling, Monsoon, Seasonal Variation

Near-source detection of lowest and very high modes of internal tide in comparison with the JCOPE-T ocean circulation model

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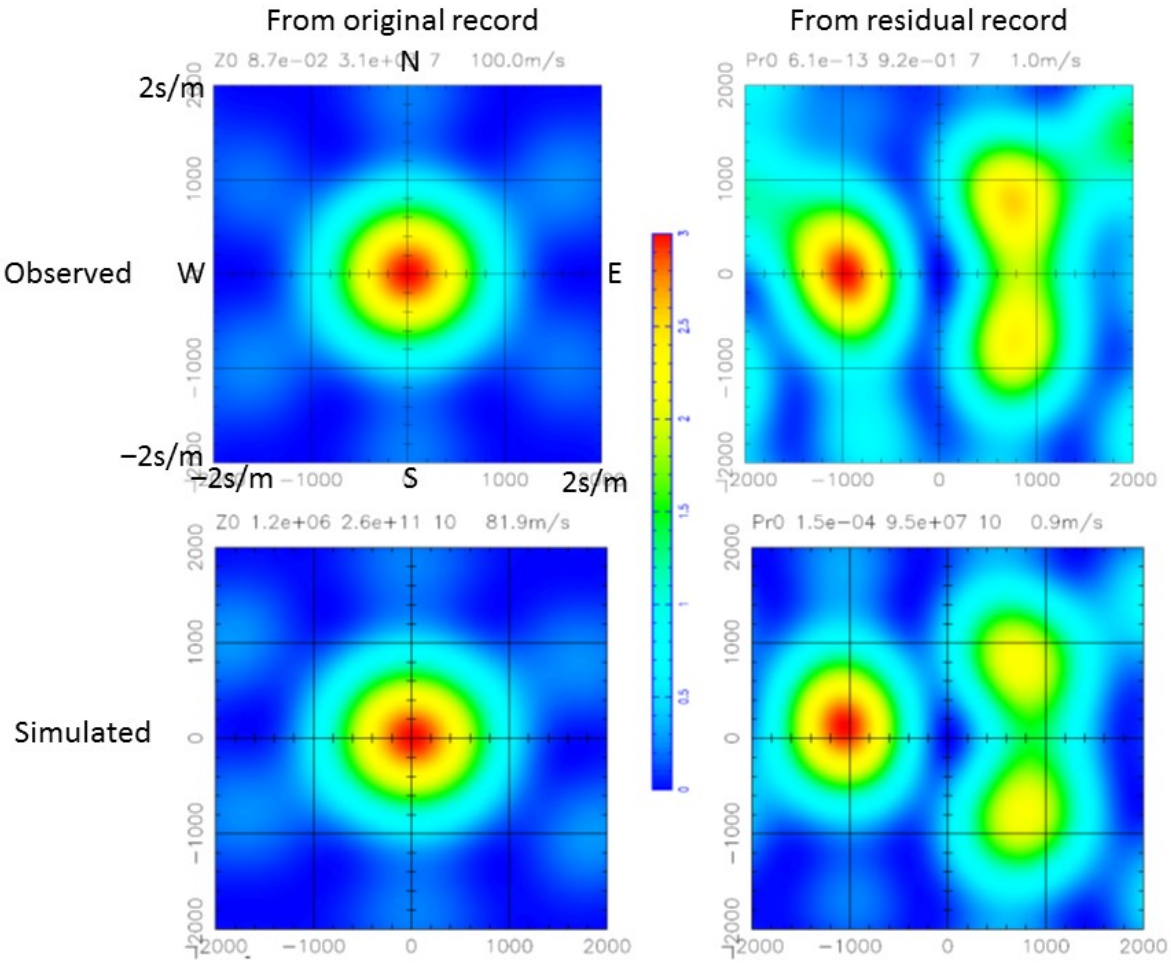
1. Japan Agency for Marine-Earth Science & Technology, 2. MEXT, 3. Kobe Univ., 4. Univ. of Tokyo

We detected persistent generation of the lowest mode of the M2 internal tide by the array of ocean bottom pressure gauges, which was deployed on the eastern slope of Aogashima Is. of the Izu Ridge at depths 1500 - 2200 m in the period May 2014 - May 2015. We measured the horizontal phase speed and propagating direction of the M2 internal tidal wave by a slant-stacking technique under the plane wave approximation. The measurement shows a phase speed of 1 m/s in the offshore direction normal to the Izu Ridge. This is, to our knowledge, the first quantitative measurement of horizontal propagation of internal tidal wave by an ocean bottom array of pressure gauges. The PSD (power spectral density) of the M2 internal tide is about 0.03 % of the PSD of the M2 external tide. There is a clear positive correlation in PSD between the internal and external tides, indicating that the observed internal tide is generated along the slope somewhere between the ridge crest and our array by conversion of the external tide.

In order to examine the consistency of the above observational result with a state of art tide-resolving ocean general circulation model (JCOPE-T), we analyzed the synthetic bottom pressure records for this model using the same method with the same array configuration in the same period as for the observed data. The analysis detected a clear signal of eastward propagation of the M2 internal tide with amplitude and speed comparable to those of the observation (Fig. 1). By successively moving the hypothetical array upslope from the observational site, we found a location at which the propagating direction of the simulated internal wave is reversed. This location can be regarded as a generation site of the mode-1 internal tide. The simulated temperature fluctuation field tuned to the M2 frequency range shows how unique this location is. For example, the 11˚C isotherm above this location undergoes semidiurnal vertical oscillation, the disturbance of which propagates both eastward and westward with an approximate speed of 1 m/s.

In this area, an extensive MCS (multi-channel seismic) survey was carried out in 2008.
The longest EW survey line passes right through our pressure gauge array. This legacy MCS data were reanalyzed to obtain ocean acoustic reflection images, which largely consist of reflections from high-mode tidal beams (vertical wavelengths around 30m). We compared the longest EW reflection profile to the simulated temperature fluctuation profile along the same line. Although the seismic profile delineates the spatial distribution of very high-mode tidal beams while the simulated profile describes the temperature disturbances due to very low modes of internal tide, their overall patterns commonly indicate a largest cell of the mode-1 internal tide with the source longitude at ~140˚E and a half horizontal-wavelength of ~50 km. The wave field near the generation site appears to be rich in high-mode internal waves carried with and created from the lowest several modes of internal tides generated at the source.

Keywords: internal tide, ocean bottom observation, seismic oceanography, ocean circulation



Modeling of Coastal Current Using the Coupled Ocean-Wave Model with Two-Way-Nesting Considering Stokes Drift Effect on Random Waves

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1. Introduction

The importance of coastal current analysis has become well established in terms of assessment of coastal physical environments to determine the coastal sedimentation and ecosystem. Thus wave-current interactions is important phenomenon in coastal areas where the ocean waves are composed of such large ranges of frequency and direction as mixed swells and wind waves. This study simulates the coastal current for Tanabe Bay in Wakayama Prefecture in high-resolution regional current system using a coupled ocean-wave model with two-way-nesting to consider Stokes drift effect on random waves. Two re-analysis calculations are performed, one considering the Stokes drift on random waves and the other on regular waves, for Tanabe Bay in Wakayama. The results are compared with field observation data to evaluate the precision of the developed model.

2. Treatment of Stokes drift on random waves

There is a large interaction effect between currents and surface gravity waves in finite depth areas such as in the coastal ocean. The wave spectra to compute Stokes drift can be calculated by a spectrum wave model (Simulating WAves Nearshore: SWAN) and is passed to an ocean model (Regional Ocean Modeling System: ROMS) to be considered in vortex force term of ocean model (Uchiyama et al., 2010). To reduce the computational costs in passing the wave spectra the spectra parameters of both frequency and direction is represented approximately by the two-dimensional Gaussian spectrum.

3. Analysis of coastal current for Tanabe Bay

Two runs are performed for Tanabe Bay in Wakayama prefecture with horizontal resolution of 2.5km on the coarse grid and 500m on the nested grid, and with 10 vertical layers. One (referred to as Wave2d) uses the model in which wave-induced transport is provided by random waves and the other (referred to as Wave1d) uses a model in which wave-induced transport is provided by regular waves. The Wave2d velocity results are more highly correlated to field observation data more than the Wave1d results.

4. Conclusion

This study analyzed coastal current for Tanabe Bay in Wakayama Prefecture using a newly developed coupled ocean-wave model with two-way-nesting to consider Stokes drift on random waves. It was shown that comparison in velocity between the calculated results of the Wave2d case and field observation data was highly correlated. In conclusion, the results highlight the importance of considering wave-current interaction on random waves to reproduce coastal currents in finite depth areas.

Keywords: Stokes drift, Coupled Ocean-Wave Model, Nesting

Simulation of Wave Effects on Turbulence in Ocean Environment

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Turbulence in upper oceans and marine atmospheric surface layer is strongly affected by ocean waves. Previous simulation-based studies often use simplified models and parameterizations for the wave effects on turbulence. With the advancements in numerical algorithms and the increase in computing power, it has recently become feasible to resolve the wave motions explicitly in the simulations of many problems. In this talk, some of our recent developments in numerical methods for nonlinear wave field evolution and turbulence in wave environment will first be introduced, and then the flow physics learned from our wave-phase-resolved simulations of wave-turbulence interactions will be discussed.

Keywords: Wave, turbulence, atmosphere, ocean, simulation

Effects of time interpolation of sea surface winds considering propagation of disturbance on wave hindcast

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A hincast of ocean waves is important for climate study, and practical applications such scheduling the ship navigation and fishery. Ocean wave model for the hindcast is driven from archived atmospheric reanalysis data set. However, the time resolution of archived atmospheric reanalysis data is much longer than the time step required for wave prediction. Therefore, the surface wind is interpolated with respect to time. A linear interpolation with respect to time is often used because it is simple and robust. However, the linear time interpolation cannot retrieve atmospheric fields in the case of moving cyclone. A moving tropical cyclone is expressed by the parametric form such as a Rankine vortex and surface wind field is deduced from the parametric model. This approach may be useful for the case study that investigates the ocean response to moving the storm. It is difficult to apply the method for both moving cyclone and stationary fields co exist. It is also difficult to express a moving extra tropical cyclones by the parametric form such as a Rankine eddy. We developed a new and simple time interpolation method of atmospheric field which can apply to both moving and stationary disturbances. In this method, a value is interpolated from the data on the same positions not in a fixed coordinate system but in the coordinate that is moving with a disturbance such as a cyclone.
The predicted wave heights and periods from the liner interpolated winds and winds by the present method are compared with in-situ observations from NDBC deployed buoys and JMA drifting buoys. The improvement of wave prediction is evident in the case that the difference of predicted wave parameters between from the linear interpolation and from the the present method is large. The improvement of wave prediction is statistically significant. This case occurs frequently anywhere, although the case is not often in the in-situ observation point. It is shown that the wave prediction can be improved only by improving the time interpolation method.

Keywords: wave hindcast, sea surface wind, time interpolation, cyclone

Modeled ice thickness in Lake Erie with different parameterizations of the ice strength

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An unstructured grid Finite-Volume Community Ocean Model (FVCOM) is applied to Lake Erie to simulate seasonal ice cover. The model is coupled with an unstructured-grid, finite-volume version of the Los Alamos Sea Ice Model. Given that there has been no solid formulation for the ice strength P for relatively thin ice in Lake Erie, a sensitivity study was conducted using the existing formulations of P. The probability density distribution of modeled ice thickness presented significant variability with the P parameterizations. The energy-based parameterization from Rothrock (1975) and Lipscomb et al. (2007) produced too thick ice, but this is not surprising as this parameterization was originally developed for thick ice in the Arctic Ocean where pressure ridges are more common, while thin ice and rafting would be more common in Lake Erie. Overall, the simple Hibler (1979)'s parameterization presented better agreement with the observed ice conditions. A better set of ice thickness observations is needed for a more rigorous formulation of P in Lake Erie and the four other Great Lakes.

Keywords: Lake Erie in the North American Great Lakes, ice model, ice strength

The Study of Proper Radius of Maximum Wind for Storm Surge Prediction in Taiwan and the South China Sea Regions

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In Taiwan, we are under the threat of storm surge because locating at the densest storm-generated area in the world. The operational storm surge model is required to predict water elevation at specified tidal stations and associated inundation before typhoon making landfall in Taiwan. In storm surge prediction, the radius of maximum wind (RMW) and the drag coefficient (Cd) are both key parameters when the parametric typhoon model is applied. Therefore, the predicted storm surges will be influenced if RMW and Cd would not be determined well. The Cd value used in storm surge modeling have been discussed in many works of literature by field observations or experiments (e.g. Large and Pond, 1981; Wu, 1980; Powell et al., 2003; Donelan et al., 2004; Peng and Li, 2016) but the RMW is not widely discussed. In this study, the applicability of different formulas to determine the RMW will be discussed and conducted in our storm surge model. The storm surge model we adopt here is COMCOT-SS (COrnell Multi-Grid Coupled of Tsunami Model –Storm Surge) model which transforms from a well-known tsunami model to storm surge model after adding meteorological forcing terms. Our in-house COMCOT-SS has abilities: solve nonlinear shallow water equation on both spherical coordinate and Cartesian coordinate, adopt large enough computational domain to cover the complete typhoon life cycle and full storm surge propagation and calculate high-resolution inundation area for risk assessment. The 2015 Severe Typhoon Soudelor in Taiwan is chosen as case study to validate the applicability of the RMW after different formulas have being conducted. The simulated results by different RMW’ s formulas are compared with observed storm surges. More details will be presented in 2017 JPGU conference.

Keywords: Storm Surge, Radius of Maximum Wind (RMW), COMCOT-SS

