The Impact of Ocean Surface Currents on Global Eddy Kinetic Energy via the Wind Stress Formulation

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A more complete wind stress formulation takes into account the ocean surface currents, while the conventional wind stress popularly used in ocean circulation models is only a function of 10-m winds. A pair of 12.5-year (July 2002 –December 2014) HYbrid Coordinate Ocean Model (HYCOM) simulations that only differ in the wind stress formulation are used to study the impact of ocean surface currents on global Eddy Kinetic Energy (EKE). The model results (2004-2014) show that including ocean surface currents in surface wind stress formulation reduces global EKE by more than 40%. To understand the mechanisms behind the large difference, we calculate the global EKE budget using the standard Reynolds averaging procedure. The direct impact of surface wind stress on EKE is through surface wind work. The indirect impact is through changes in the mean circulation that affect the shear production, buoyancy work, and bottom friction. Model Results indicate that the reduction of global EKE is primarily due to the buoyancy work and shear production. Even though the surface eddy wind work is one order larger than buoyancy work, and two orders larger than shear production, it is mainly balanced by bottom friction and thus not the main contribution for the EKE differences.

Keywords: HYCOM, eddy kinetic energy, wind work, baroclinic instability, wind stress

Long-term change and variation of salinity in the western North Pacific subtropical gyre revealed by 50-year long observations along 137ºE

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The 137ºE repeat hydrographic section for 50 winters during 1967–2016 has been analyzed to examine interannual to interdecadal variations and long-term changes of salinity and temperature in the surface and intermediate layers of the western North Pacific, with a particular focus on freshening in the subtropical gyre. Rapid freshening on both isobars and isopycnals began in mid-1990's and persisted for the last 20 years in the upper main thermocline/halocline in the western subtropical gyre. In addition, significant decadal variability of salinity existed in the Subtropical Mode Water (STMW), as previously reported for the shallower layers. An analysis of the 144ºE repeat hydrographic section during 1984–2013 supplemented by Argo profiling float data in 2014 and 2015 revealed that the freshening trend and decadal variability observed at 137ºE originated in the winter mixed layer in the Kuroshio Extension (KE) region and was transmitted southwestward to 137ºE 1–2 years later in association with the subduction and advection of STMW. The mechanism of these changes and variations in the source region was further investigated. In addition to the surface freshwater flux in the KE region pointed out by previous studies, the decadal KE variability in association with the Pacific Decadal Oscillation likely contributes to the decadal salinity variability through water exchange between the subtropics and the subarctic across the KE. Interdecadal change in both the surface freshwater flux and the KE state, however, failed to explain the rapid freshening for the last 20 years.

Keywords: Western North Pacific subtropical gyre, Main thermocline/halocline, Long-term change, Decadal variability, Repeat hydrographic section

Interannual and inter-decadal variability of the North Equatorial Countercurrent in the Western Pacific

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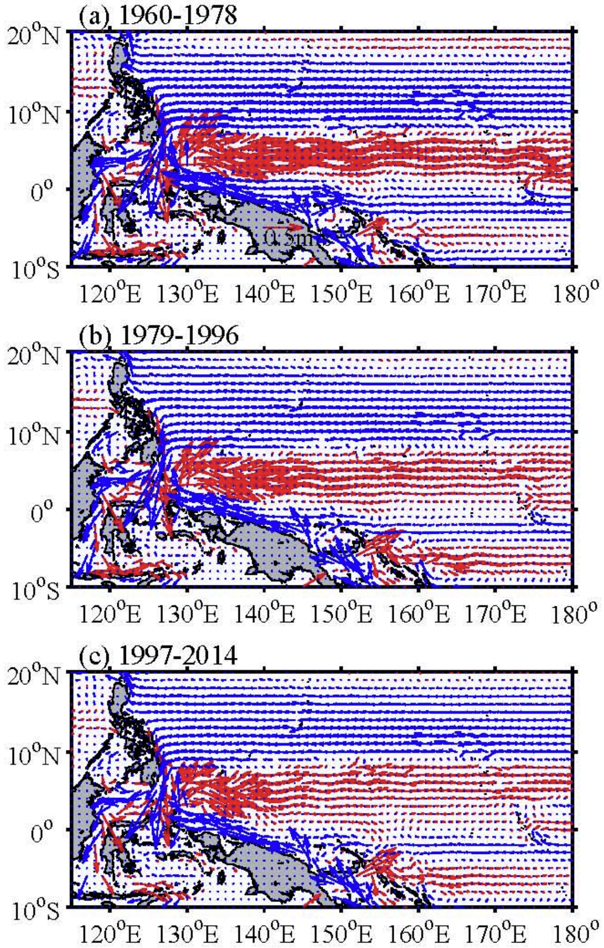
Abstract

Interannual and longer timescale variations of the North Equatorial Countercurrent (NECC) in the western Pacific are investigated using the multi-decade (1960-2014) hindcast by the Ocean general circulation model for the Earth Simulator (OFES). The OFES-simulated sea level and upper ocean circulation changes show favorable comparisons with available tide gauge data and repeat hydrographic surveys along the 137ºE meridian. An empirical orthogonal function (EOF) analysis reveals that the low-frequency NECC variability is dominated by two distinct modes. The first mode fluctuates interannually and shows strengthening and southward migration of the NECC concurrent with the development of El Niño events. Unlike the extra-tropical western Pacific Ocean circulation variability controlled by wind forcing west of the dateline, the interannual NECC variations are forced by equatorial wind forcing cumulative across the entire Pacific basin. The second mode of the NECC variability has a inter-decadal timescale and is characterized by NECC's progressive weakening in strength, migrating poleward, and broadening in width over the past 50 years. These long-term changes in NECC are caused by the corresponding changes in the trade wind system that weakened and expanded poleward in the past half a century across the Pacific basin.

Keywords: Interannual and Inter-decadal Variability, Western Pacific, Northern Equatorial Countercurrent


(a) 1960-1978
20°N
10°N
0°
10°S
0.5m
120°E 130°E 140°E 150°E 160°E 170°E 180°
(b) 1979-1996
20°N
10°N
0°
10°S
120°E 130°E 140°E 150°E 160°E 170°E 180°
(c) 1997-2014
20°N
10°N
0°
10°S
120°E 130°E 140°E 150°E 160°E 170°E 180°

Seasonal transport variaiton over the entire Kuroshio region

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As the observations of the Kuroshio were conducted regionally by different groups, studies for the seasonal variation and its mechanism were also proceeded separately. By using the data collected by satellites and assimilation model’ s outputs, we focus on the seasonal transport variation over the entire Kuroshio region. Our main purpose is to show the temporal and spatial feature of the seasonal transport variation and give an insight for its driving mechanism.
The results from Aviso data reveal that the surface transport variation reaches maximum in July for most of the Kuroshio region, but its minimum appears in different months. Near Luzon Island and in the East China Sea, the minimum values appear in October or November. For the area of Taiwan, most of the minimum values are found in January or February. Time when the minimum values occur also shows propagation signals: it shifts from September to November in Luzon Strait, while moves gradually from November to June south of Japan. Another feature is that the amplitudes of the surface transport variation are large near Luzon Island, Taiwan, and south of Japan, where there is a land boundary to the west of the Kuroshio.The results from EOF analysis, which is conducted by using an assimilation dataset estimated from the Multivariate Ocean Variation Estimation system, also indicate that the transport variation tends to dominate in the areas where the western land boundary exists.
Czeschel et al. (2012) suggested that fast barotropic waves propagate the signals due to wind-induced costal upwelling (downwelling) southward along the simple slope off the North American coast and contribute largely to the annual circle of the Florida current transport. While for the North Pacific western boundary, the barotropic waves are considered to propagate along the complicated coastline with large topographic modulation. This might be a possible cause that leads to the regional features of seasonal transport variation revealed in this study.

Keywords: Kuroshio, seasonal transport variation

Mooring Measurement of the Abyssal Circulations in the Western Pacific Ocean

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A scientific observing network in the western tropical Pacific has initially been established by the Institute of Oceanology, Chinese Academy of Sciences (IOCAS). Using fifteen moorings that gives unprecedented measurements in the intermediate and abyssal layers, we present multi-timescale variations of the deep ocean circulations prior to and during 2015 El Niño event. The deep ocean velocities increase equatorward with high standard deviation and nearly zero mean. The deep ocean currents mainly flow in meridional direction in the central Philippine Basin, and are dominated by a series of alternating westward and eastward zonal jets in the Caroline Basin. The currents in the deep channel connecting the East and West Mariana Basins mainly flow southeastward. Seasonal variation is present in the deep jets in the Caroline Basin, associating with vertical propagating annual Rossby wave. The high-frequency flow bands are dominated by diurnal, and semi-diurnal tidal currents, and near-inertial currents. The rough topography has a strong influence on the abyssal circulations, including the intensifications in velocity and internal tidal energy, and the formation of upwelling flow.

Keywords: Abyssal Circulation, Western Pacific, Mooring Measurement

Ocean variability at intermediate depth in the western equatorial Pacific

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Intermediate ocean variability at the depth of 300 - 750m in the western equatorial Pacific west of 156E is investigated using data from underwater sensors of the Triangle Trans-Ocean Buoy Network (TRITON) buoys and CTD data by Japan Meteorological Agency, and others. Variability is dominant in the western boundary region. Seasonal variability is generally dominant, but, intraseasonal variability is not negligible around 2N, 138E, where the northwestward flowing New Guinea Coastal Undercurrent retroflects to the east as the Equatorial Undercurrent. There is the anti-cyclonic New Guinea Eddy, which interacts with neighbor eddies around this location. Interannual variability with ENSO and quasi-decadal time scales was observed. Because the pattern of correlations between temperature variability at the intermediate layer and indices of ENSO and quasi-decadal time scales is not simple, variability with these time scale is thought to be associated with thermocline structure variability due to the equatorial waves rather than zonal shift of the warm water pool. We also found freshening trend in the intermediate waters in the western equatorial Pacific. This is likely associated with the freshening of the North Pacific Intermediate Water and Antarctic Intermediate Water.

Keywords: Intermediate ocean variability, Western equatorial Pacific, TRITON buoy, Intermediate waters

Seasonal variability of salinity in the Indian Ocean in response to riverine freshwater forcing using ROMS

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Indian Ocean exhibits large spatial and temporal variability in the sea surface salinity distribution. The unique geographical features causes the salinity distribution over the Arabian sea and Bay of Bengal quite different. The Arabian sea being connected to highly saline waters from Red Sea and Persian Gulf remains salty when compared to the Bay of Bengal. Major rivers such as Ganges, Brahmaputra, Mahanadi, Godavari, Krishna, and Irrawaddy debouch an excess amount of freshwater into the Bay. In addition to this, the annual precipitation over Bay of Bengal always remains higher than evaporation when compared to Arabian Sea. Due to these factors the Bay remains fresher than Arabian sea throughout the year and also exhibits large seasonal variability in the circulation patterns. The seasonal variability of sea surface salinity in the Indian ocean is studied by using a ocean general circulation model 'Regional Ocean Modeling System' (ROMS). The model domain extends from 30^{o} S-30^{o}N, 30^{o}E-120^{0}E with quarter degree resolution in the horizontal and 40 sigma levels. The model is initialized with annual mean climatology of tracer fields from World Ocean Atlas 2013 (WOA13) and forced with daily climatological winds from Quikscat and ASCAT and other atmospheric forcing fields from TropFlux. It is found that there is significant contribution to freshening from riverine freshwater discharge in coastal regions near river mouths. Over the Indian Ocean, northern boundaries of Bay of Bengal found to have largest impact of river discharges on SSS simulations during monsoon (June-September) season when the peak discharge from major rivers Ganges, Brahmaputra, and Irrawaddy accumulate freshwater plume along coastal regions in Bay of Bengal. The impact of continental freshwater discharge on the seasonal salinity pattern are investigated. Satellite and in-situ observations are also used to understand the response of riverine freshwater forcing in controlling the spatial and seasonal variations of salinity in various sectors of the Indian Ocean.

Keywords: Indian Ocean, Sea Surface Salinity, Seasonal Variability, River Dischanrge

Numerical study of Internal tide energetics in the Andaman Sea

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The interactions of barotropic tides with irregular bottom topography generate internal waves with high amplitude known as large-amplitude internal waves (LAIW). The Andaman Sea is one of the potential region where such waves occur. These waves are an important phenomena in the ocean due to their influence on the density structure and energy transfer into the region. These waves are also important in submarine acoustics, underwater navigation, offshore structures, ocean mixing, biogeochemical processes, etc. over the shelf-slope region.

A three-dimensional MIT general circulation ocean model (MITgcm) is configured over the Andaman sea to investigate the generation and propagation of M_2 internal tides. Initially, the model simulations are validated by using *in-situ* observations of temperature, conductivity and currents from a buoy located at 10.5N, 94E. The spectral energy estimate of density shows that the peak estimate is associated with the semi-diurnal frequency at all the depths in both observations and model simulations. The vertical structure of baroclinic velocity is compared with observations and the analysis suggests that a multi-mode features of baroclinic tides are present at the buoy location. To understand the generation and propagation of internal tides over this region, energy flux and barotropic-to-baroclinic M_2 tidal energy conversion rates are also estimated. The model simulation suggests that the internal tides are mainly generated at the north of Sumatra coast and the regions around the Nicobar islands. The internal tides propagate away from the respective generation sites. The steepness of topography suggests that the internal tide mainly generate at the supercritical slope region and the energy flux reflected back to the deep water from the supercritical slope. The M_2 dissipation rate is also found to be maximum at the generation sites.

Keywords: Internal tide, Andaman Sea, Energetics

Simulation of storm surges by improving the cyclonic wind formulation

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Coastal regions of India are highly prone to sea level rise during tropical cyclones. Storm surges due to cyclones can produce high sea levels, especially when their occurrence coincide with the high tides. Storm surges, tides and wind waves are the main factors responsible for the variation in the total water elevation (TWE) near the coast. The accuracy in simulation of storm surges depends not only on the cyclonic track and its intensity, but also on the spatial distribution of winds which include its speed and direction. In the present study, the cyclonic winds are validated using buoy winds for the recent cyclones formed in the Bay of Bengal since 2010 using Jelesnianski wind scheme. It is found that the cyclonic winds computed from the scheme show an underestimate in the magnitude and also a mismatch in its direction. Hence, the wind scheme is suitably modified based on the buoy observations available at different locations using a power law which reduces the exponential decay of winds by about 30%. Moreover, the cyclonic wind direction is also corrected by suitably modifying its inflow angle. The significance of modified exponential factor and inflow angle in the computation cyclonic winds is highlighted using statistical analysis.
In the present study, simulation of storm surges for the recent cyclonic cases along the east coast of India are carried out using both stand-alone hydrodynamical depth integrated ADCIRC model and coupled ADCIRC+SWAN model. The coupled ADCIRC+SWAN model is used to incorporate the contribution of wind waves in the simulation of TWE near the coast. The cyclonic wind distribution is computed using both modified and unmodified Jelesnianski wind scheme. The experiments are performed to validate the TWE generated from the cyclones through computation of surge residuals with the available tide gauge data. On comparison of observed surge residuals with the simulations using modified winds from the uncoupled and coupled models, it is found that the simulated surge residuals are better compared, especially with the inclusion of wave effect through the coupled model.

Keywords: total water elevations, storm surge, cyclonic winds, ADCIRC MODEL

Numerical study of the amplification mechanism of the meteo-tsunami originating off the western coast of Kyushu

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A meteo-tsunami is generated by a travelling atmospheric pressure disturbance and is characterized by a rapid sea level rise with a period of several tens of minutes in the coastal areas. In Japan, meteo-tsunamis are frequently observed along the western coast of Kyushu during winter-spring and are called “Abiki”.

In shallow seas such as continental shelf areas, a propagating shallow water wave can be amplified through a resonant coupling to the atmospheric pressure disturbance traveling with nearly the same speed (“the first resonance”). The shallow water wave then enters local coastal areas while being further amplified by “geometrical resonance” effects (“the second resonance”). To predict the meteo-tsunami, therefore, it is essential to clarify the amplification mechanism of the shallow water wave, especially through “the second resonance” effect, in addition to draw the information about the atmospheric pressure disturbance causing “the first resonance” from the synoptic scale atmospheric data.

In this study, we investigate the amplification processes of the meteo-tsunami in Makurazaki Bay that occurred in 2004. The sea level variations in Makurazaki Bay are reproduced well using a barotropic numerical model in which an atmospheric pressure disturbance with a width of about 300 km is assumed to propagate east-southeastward with a constant speed of 31 m/s over the East China Sea. On the continental shelf of the East China Sea, the shallow water wave is amplified through “the first resonance” effect. Then, the shallow water wave propagates further eastward and enters the continental shelf running west to east off Makurazaki Bay. It is shown that the existence of Mt. Kaimon, located at the eastern end of this continental shelf plays an essential role in “the second resonance”; the reflection of shallow water waves from Mt. Kaimon causes the excitation of the eigen-oscillation on this continental shelf, which resonantly intensifies the eigen-oscillation in Makurazaki Bay.

Keywords: Meteo-tsunami, Western coast of Kyushu, Amplification mechanism

Numerical simulations of internal wave dynamics in the vicinity of Izu-Oshima Island, off Sagami Bay, Japan

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Physical processes off the southern part of Japan mainland are strongly influenced by both tides and Kuroshio (eastern boundary current). The tidal forcing generates internal tides, which results in nonlinear internal bores accompanied by strong flows and turbulent mixing. Currents and eddies induced by Kuroshio generate strong mass transports and turbulent mixing when they cross shallow ridges, such as Izu-Ogasawara Ridge. In this study, we focus on internal wave dynamics around Izu-Oshima Island located on Izu-Ogasawara Ridge, off Sagami Bay, Japan. Regional Ocean Modeling System (ROMS) was employed to simulate physical processes in the study area. By using a one-way offline nesting approach, the horizontal grid spacing was down to 300 m around the study area. Two model case were run to investigate internal wave dynamics: (1) numerical run with the tidal forcing, and (2) numerical run without tidal forcing. Numerical results from the case with the tidal forcing showed strong internal tidal bores generated around the Island, which results in strong currents near the coast. The volume-integrated kinetic energy was 2 times higher in shallow area (depth<250 m) for the case with tides than that of the case without tides. The strength of internal waves (internal wave energy flux) was an order of 10 times higher for the case with tidal forcing than that of the case without tides. In addition, the tidal forcing reduced the surface temperature over the shallow ridge because of strong vertical mixing induced by tidal flows and internal tides. This study indicates that tides and internal tides dominates in the flow filed and significantly contribute to oceanic physical processes in the vicinity of Izu-Oshima Island.

Keywords: internal waves, tide, numerical simulations, Kuroshio

Numerical simulations of mass transports processes in the lagoon of Funafuti Atoll,Tuvalu

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Understanding oceanic structures in atolls, formed by coral reefs, is essential for maintaining their ecosystems and environment. Contaminated water due to poorly sewage treatment outflows into the lagoon in Funafuti Atoll, Tuvalu (Fujita et al., 2013). However, water exchange between the lagoon and open ocean is limited through narrow channels on the coral reef. Therefore, the sea water in the lagoon is isolated from the open ocean and the lagoon is a highly closed ocean area. Contaminated water discharged from the urban area would causes deterioration of coral reefs, which leads to the changes in the form of the atoll and the loss of the land.
This study attempted to reproduce flow structures and mass transport processes in Funafuti Atoll lagoon by using the SUNTANS model (Fringer et al., 2006). In order to reproduce the typical flow structure in the lagoon, the model was forced by tides and six wind conditions (wind speed and direction). In addition, transport processes of contaminated water from the urban area were reproduced by a passive tracer model.
Numerical results showed that the wind stress strongly influences the flow field in the lagoon compared to the tidal forcing. In the middle of the lagoon, the tidal current generated weak currents, approximately 0.008 m/s. On the other hand, when the wind speed is 5m/s, the flow speed in the middle of the lagoon reached 0.1 m/s. According to numerical runs with three wind direction patterns, northeast winds enhance transports of contaminated water from the lagoon to the open ocean. 83% contaminated water from the urban area flowed into the open ocean within 20 days by northeast winds with the speed of 5m/s. Under the northwest and 5m/s wind condition, water from the urban area stays inside of the lagoon for a long time. 35% of contaminated water flowed into the open ocean within 20 days in this condition.
This study suggests that the wind condition plays a significant role in transport processes of contaminated water between the inside of the lagoon of Funafuti Atoll and the open ocean.