EGU2020-620
EGU General Assembly 2020

Numerical study on evolution of an internal solitary wave over a horizontal cylinder at various topography

Ming Hung Cheng[1], Chih-Min Hsieh[2], and Robert R. Hwang[3]
[1]Marine Industry and Engineering Research Center, National Academy of Marine Research, Kaohsiung, Taiwan (chengminghung@gmail.com)
[2]Department of Maritime Information and Technology, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan (chihmin_623@yahoo.com.tw)
[3]Department of System Engineering and Naval Architecture, National Taiwan Ocean University, Keelung, Taiwan (phhwang@gate.sinica.edu.tw)

In South China Sea, internal solitary waves (ISWs) exist in a density stratified flow and usually generated by the tide-topography. Due to its large amplitudes up to 170m and strong velocity difference exceeding 2.4 ms^{-1} between its upper and lower water layers, an ISW has significant ramification not only in marine ecology but also engineering works in the ocean. While an ISW propagates over continental shelf, the submarine cable or pipeline may be subjected to be damaged. Although the effect of surface waves on the submarine cable or pipeline has been studied in literature, the interaction between ISW and horizontal cylinder is still unclear. Hence, a series of numerical simulations about an ISW with depression ISW propagating over a horizontal cylinder on a trapezoidal obstacle are investigated in order to discuss the variations of flow field and forces.

In present investigation, the Improved Delayed Detached Eddy Simulation (IDDES) model based on the spatial filtering of Navier-Stokes equations is adopted to calculate the interaction on an ISW over a horizontal cylinder on a trapezoidal obstacle. Beyond, a depression ISW is generated by the so-called collapse mechanism and the different depth ratio between upper and lower layer are employed in order to generate like-elevated or original depression ISW on trapezoidal obstacle. Based on the numerical results, the waveform type causes different variations of vortices as the wave approaches the horizontal cylinder. As the depth in upper layer is larger than that in lower layer on the plateau, the like-elevated ISW encounters the horizontal cylinder and induces the vortices in the rear of the submarine cable; when the depth in upper layer is less than that in lower layer on the plateau, the depression ISW approaches the obstacle and the vortices are generated in front of submarine pipeline. Moreover, the height of submarine cable also affects the strength of the wave-obstacle interaction. Based on these numerical simulations, the mechanism of ISW-horizontal cylinder is further studied and may support the significant foundations for ocean engineering.

EGU2020-2502
EGU General Assembly 2020

Evolution of Internal Solitary Waves on the Slope-shelf Topography in the Northern South China Sea

Shuya Wang[1,2], Qun Li[2], Xu Chen[1], Jing Meng[3], and Saisai Li[3]
[1]Key Laboratory of Physical Oceanography / Collaborative Innovation Center of Marine Science and Technology (CIMST), Ocean University of China and Qingdao National Laboratory for Marine Science and Technology, Qingdao, China
[2]Polar Research Institute of China (PRIC), Shanghai, China
[3]College of Oceanic and Atmospheric Sciences, Ocean University of China, Qingdao, China

Based on a non-hydrostatic two-dimensional and high-resolution model, evolution of internal solitary waves (ISWs) on the typical slope-shelf topography in the northern South China Sea is investigated numerically, and the influences of the initial amplitude, seasonal stratification and topographic characteristics are analyzed with a series of sensitivity runs. The results indicate that the initial amplitude affects the fission of ISW, resulting in three wave groups for large ISW and two wave groups for small ISW. In addition, the generation of mode-2 waves is influenced since energetic beams are engendered by large initial ISW, which impact the pycnocline and generate the mode-2 ISWs. Seasonal stratification has significant impacts on the evolution of the ISW. In winter, the changing sign of the nonlinearity coefficient at the bump near the shelf break implies the inversion of polarity of the ISW. Therefore, the transmitted and fissioned waves behave differently from those in summer and annual stratifications. Furthermore, the speed and energy of the leading wave are minimal in winter but maximal in summer. The bump near the continental shelf has two impacts: promoting the fission of the incident ISW and generating mode-2 ISWs by increasing the Ursell number (the ratio of nonlinear coefficient to dispersion coefficient). However, the formation of the trailing nonlinear wave packet is not affected by these factors, despite of the variations in detail in sensitivity runs.

EGU2020-3997
EGU General Assembly 2020

Dynamics and energetics of nonlinear internal wave around a double-canyon system

Qun Li
Polar Research Institute of China, Oceanography, China (505407069@qq.com)

The continental shelf/slope northeastern Taiwan is a 'hotspot' of nonlinear internal wave (NLIW). The complex spatial pattern of NLIW indicates the complexity of the source and the background conditions. In this talk, we investigated the dynamic and energetics of the internal tide (IT) and NLIW around this region based on a 3D high resolution nonhydrostatic numerical model. Special attention is paid on the role of two main topographic features-the Mien-Hua Canyon and the North Mien-Hua Canyon, which are the energetic sources for ITs and NLIW.

The complex IT field is excited by the double-Canyon system and the rotary tidal current. ITs from different sources and formation time interference with each other further strengthen the complexity. The area-integrated energy flux divergence (the area-integrated dissipation rate) is ~0.45GW (~0.28GW) and ~0.26 GW (~0.17 GW) over the Mien-Hua Canyon and the North Mien-Hua Canyon, respectively. Along with the energetic internal tides, large-amplitude NLIW and trains are also generated over the continental shelf and slope region. The amplitude of the NLIW can reach to about 30 m on the continental slope with a water depth of 130 m and shows similar spatial complexity, which is consistent with in situ and satellite observations. Further analysis shows that the dominant generation mechanism of the NLIW belongs to the mixed tidal-lee wave regime. In addition, the dynamic processes can be significantly modulated by the Kuroshio. With the present of Kuroshio, the energy flux of the M2 internal tide shows a distinct gyre pattern and strengthens over the double canyon system, which is more close to the mooring observations and previous study.

EGU2020-4056
EGU General Assembly 2020

Bottom pressure induced by the long nonlinear internal waves

Tatiana Talipova[1,2] and Efim Pelinovsky[1,2,3]
[1]Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation (tgtalipova@mail.ru)
[2]Nizhny Novgorod State Technical University na. R.E. Alekseev, Nizhny Novgorod, Russia
[3]National Research University - Higher School of Economics, Nizhny Novgorod, Russia

The bottom pressure sensors are widely used for the purpose of registration of the sea surface movement. They are particularly efficient to measure long surface waves like tsunami and storm surges. The bottom pressure gauges can be also used to record internal waves in coastal waters. For instance, the perspective system of the internal wave warning in the Andaman Sea is based on the bottom pressure variation data. Here we investigate theoretically the relation between long internal waves and induced bottom pressure fluctuations. Firstly, the linear relations are derived for the multi-modal internal wave field. Then, the weakly nonlinear theory is developed. Structurally, the obtained formula for the bottom pressure induced by the long internal waves is similar to those known for the surface waves within the Green-Naghdi system framework, but the coefficients are determined through the integrals for the water density stratification and vertical mode wave functions. In particular, the bottom pressure variations are calculated for solitary waves in two- and three-layer flows described by the Gardner equation.
The research is supported by RFBR grants No. 19-55-15005 and 19-05-00161.

EGU2020-4287
EGU General Assembly 2020

Internal Solitary Waves with shear: beyond DJL theory

Marek Stastna, Aaron Coutino, and Ryan Walter
University of Waterloo, Applied Mathematics, Waterloo, Ontario, Canada (mmstastn@uwaterloo.ca)

While background shear is ubiquitous in the natural environment, the vast majority of theoretical and numerical studies of internal solitary waves do not include a background shear. Walter et al 2016, Continental Shelf Research reported on measurements in Monterey Bay in which large amplitude internal solitary wave trains were observed but corresponding waves could not be computed from DJL theory due to the strength of the background shear. In this talk I will revisit this issue using a classical stratified adjustment set up. For the case of an exponential, surface trapped background current I will demonstrate that internal solitary wave trains with and without trapped cores coexist with a substantial region dominated by stratified shear instability and/or Rayleigh Taylor instability. I will then demonstrate the type of internal wave train that results in cases when the the variational formulation of the DJL equation fails to converge. I will speculate on implications for theoretical description of such waves and for more realistic simulations in the coastal ocean.

EGU2020-4519
EGU General Assembly 2020

On the generation and evolution of internal solitary waves in the northwestern South China Sea

Jianjun Liang, Tong Jia, and Xiao-Ming Li
Aerospace Information Research Institute, Chinese Academy of Sciences, China (liangjj@aircas.ac.cn)

The northern South China Sea (SCS) forms the most active oceanic internal solitary waves (ISWs) among the global oceans. Most previous studies focused on the ISWs from the Luzon Strait to the northeastern continental shelf. An internal wave distribution map compiled by multiple ENVISAT ASAR and ALOS PALSAR images shows that the ISWs are also very active in the northwestern SCS ; however, the generation and evolution of the ISWs remain less understood in this area. By analyzing the SAR images, we divide the ISWs in the northwestern SCS into four regions: (1) the region to the northeast of Hainan Island, (2) the region to the southeast of Hainan Island, (3) the region from the south of Hainan Island to the north of Vietnam coast and (4) the region along the north of Vietnam coast□Fig.1). Here we focus on the ISWs observed in regions 2 and 3. First, the generation and evolution of internal waves in region 2 are investigated using synergistic satellite observations, in situ measurements and numerical simulations. We found that a diurnal internal tide emanates from the Xisha Islands, propagates through the deep basin in the form of a wave beam and undergoes consecutive reflections in the westward propagation. Then the diurnal internal tide excites short scale nonlinear bores at the shelf break. The nonlinear bore continues to evolve into an ISW train on the mid-shelf which finally emerges to the southeast of the Hainan Island and is observed on SAR images. Second, assuming the ISWs in region 3 are of tidal origin, we diagnosed their generation through calculating the body forcing term. In some cases, the strong tidal forcing along the shelf break suggests that the ISWs are probably generated by local tide-topography interaction along the shelf break. However, in other cases the weak tidal forcing along the shelf break cannot support the local generation mechanism and these ISWs may originate from the remote sources (i.e. Xisha islands) via the same generation mechanism as that reported to the southeast of Hainan Island. On the other hand, the statistics on the occurrence frequency of ISWs show that the ISWs are not regularly linked to the spring/neap tides, which strengthens the finding that the ISWs in region 3 arise from the contribution of both local tide-topography interaction mechanism and the remote internal tide mechanism. Finally, a two dimensional numerical experiment is carried out to examine the generation of ISWs by the local tide-topography interaction.

EGU2020-5098
EGU General Assembly 2020

Mixing induced by ISWs breaking over a sloping boundary: an analytical heuristic model

Davide Cavaliere[1], Giovanni la Forgia[2,3], and Federico Falcini[3]
[1]Sapienza University of Rome, Department of Basic and Applied Sciences for Engineering, Rome, Italy (davide.cavaliere@uniroma1.it)
[2]Roma Tre University, Department of Civil Engineering, Rome, Italy
[3]ISMAR-CNR, Rome, Italy

We propose an analytical approach to estimate mixing efficiency in Internal Solitary Waves (ISWs) breaking processes. We make use of the theoretical framework of Winters et al. [1995] to describe the energetics of a stratified fluid flow, calculating the Available Potential Energy (APE) of an ISW of depression in a two-layer system, assuming that the symmetric density structure on both sides of the feature is exactly the same. Starting from the definition of mixing efficiency given by Michallet and Ivey [1999], through the Ozmidov and Thorpe length-scales we derive an expression for the mixing efficiency avoiding the use of any wave model (as KdV-type models or strongly nonlinear models) to estimate the wave energy. The model is successfully verified through laboratory experiments performed in a wave tank and is meant to be applied by using real field CTD casts.

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EGU2020-6370
EGU General Assembly 2020

Propagation and transformation of nonlinear internal waves of tidal origin observed in the northeastern East China Sea

Seung-Woo Lee and SungHyun Nam
Seoul National University, College of Natural Sciences, School of Earth and Environmental Sciences, Korea, Republic of (lsw.ocean@gmail.com)

Oceanic nonlinear internal waves (NLIWs) play an important role in regional circulation, biogeochemistry, energetics, vertical mixing, and underwater acoustics, causing hazards to marine engineering and submarine navigation. Mainly generated by the interaction of the barotropic tides with the bottom topography, they propagate and transform due to wave-wave interaction process. Here, we present characteristics of first two modes of NLIWs observed using high-resolution spatiotemporal data collected in a relatively flat area in the northeastern East China Sea in May 2015. Six groups of NLIWs were identified from the observations: four groups of mode-1 and two groups of mode-2. The amplitude, propagation speed, and characteristic width of mode-1 NLIWs had ranges of 4–16 m, 0.53–0.56 m s^{-1}, and 310–610 m, respectively. The mode-2 NLIWs propagate eastward slowly with a speed less than 0.37 m s^{-1} with a comparable amplitude of 4–14 m and longer characteristic width of 540–1920 m. Intermodal interactions may take a role in the evolution of mode-1 NLIWs west of the observational area. Our results characterizing the two modes of NLIWs highlight the significance of propagation and transformation of NLIWs and their modal interactions on a broad and shallow shelf.

EGU2020-6932
EGU General Assembly 2020

Transformation of the first mode internal solitary wave over topography in three-layer flow

Kateryna Terletska[1], Tatiana Talipova[2], Roger Grimshaw[3], Zihua Liu[3], and Vladimir Maderich[1]

[1]Marine and River Systems Modelling Department, IMMSP (NASU), Kiev, Ukraine (kterletska@gmail.com)
[2]Department of Applied Mathematics, Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Nizhny Novgorod,603950, Russia
[3]Department of Mathematics, University College London, London, United Kingdom

Transformation of the first mode internal solitary wave over the underwater bottom step in three-layer fluid is studied numerically. In the three layer flow two modes (the first and the second) of the internal waves are existed. It is known that interaction of the first mode internal solitary wave with an underwater obstacle is the mechanisms of second-mode internal solitary waves generation. Different scenarios of transformation are realized under different wave characteristics: wave amplitude, position of the step and thickness of the layers as is the two layer case [1]. Formation of the second mode internal solitary waves during interaction of the first mode internal solitary waves occurs only for special range of wave characteristics and thickness of the layers that was defined in this investigation. The second mode internal solitary waves appear as in the reflected wave field as well as in the transmitted wave field. Transfer of energy from incident mode one wave into reflected and transmitted waves (the first and the second modes) during transformation is also studied. Dependence of the amplitudes of generated solitary waves (transmitted and reflected) from amplitude of the incident wave is obtained. Comparison of numerical results (reflected and transmitted coefficients) with the theoretical calculations [2] shows good agreement in the range of wave characteristics that corresponds to the weak interaction.

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EGU2020-7455
EGU General Assembly 2020

Synchronization of traveling waves in coupled dispersive systems

Nikolay Makarenko[1,2] and Zakhar Makridin[1,2]
[1]Lavrentyev Institute of Hydrodynamics, Novosibirsk, Russian Federation (makarenko@hydro.nsc.ru, makridin@hydro.nsc.ru)
[2]Novosibirsk State University, Department of Mechanics and Mathematics, Novosibirsk, Russian Federation

Coupled KdV-type equations arise in multimodal dispersive models such as the Gear – Grimshaw system which describes weakly nonlinear internal waves in neighboring pycnoclines. Coupling occurs when two or more phase speeds of different modes are close together. This phenomenon of kissing modes is known as the Eckart resonance providing energy transfer between pycnoclines in stratified fluid. Decoupled basic equations generate separated modes of traveling waves with different phase shifts. In this context, synchronization means the existence of coupled phase-shifted solutions which can be constructed from decoupled modes by appropriate perturbation procedure. In the present paper, we consider analytic conditions which provide the existence of periodic solutions describing synchronized cnoidal-type wave trains. Application of the Lyapunov – Schmidt method reduces this problem to the nonlinear system of implicit bifurcation equations for unknown phase shift and wave amplitude. Asymptotic analysis of these equations results sufficient condition of synchronization, which involves the Poincare – Pontryagin function depending on coupling nonlinear terms. In addition, we illustrate two different limit cases which lead to the same existence condition. First of them corresponds to a solitary-wave limit for cnoidal waves (i.e. a nonlinear long-wave limit), and the second one is adapted to a small-amplitude limit of coupled harmonic wave packets.

This paper was supported by RFBR (grant No 18-01-00648).

EGU2020-9318
EGU General Assembly 2020

Mode-2 internal solitary waves offshore Central America discovered by seismic oceanography method

Wenhao Fan, Haibin Song, Yi Gong, Shaoqing Sun, and Kun Zhang
School of Ocean and Earth Science, Tongji University, Shanghai, China (wenhaofan@tongji.edu.cn)

In the past, most of the internal solitary waves (ISWs) found by seismic oceanography (SO) method were mode-1 ISWs. We discover many mode-2 ISWs in the Pacific coast of Central America by using SO method for the first time. These mode-2 ISWs are convex mode-2 ISWs with the maximum amplitudes of about 10 m, and most of them are ISWs with smaller amplitudes. The pycnocline for the mode-2 ISWs on the shelf (ISW3) is displaced 6.4% of the total seawater depth from the mid-depth of the total seawater. The deviation is large, and it shows a strong asymmetry feature of the peaks and troughs on the seismic profile. This is consistent with the results of previous numerical simulation. Observing the changes in the fine structure of mode-2 ISWs packet through pre-stack migration, it was found that the overall waveform of the three mode-2 ISWs (ISW1, ISW2, and ISW3) on the shelf during the acquisition time period of about 40 seconds is stable. The apparent phase velocity of these mode-2 ISWs calculated by the pre-stack migration section using the Common Offset Gathers is about 0.5 m/s, and their apparent propagation directions are from SW to NE along the seismic line (44 ° N, 0° pointing north). The vertical amplitude distribution and estimated apparent velocities of these mode-2 ISWs are basically consistent with the theoretical values calculated from the KdV equation. By analyzing the apparent velocities of the three mode-2 ISWs (ISW1, ISW3, and ISW5) with relatively small apparent velocity errors, it is found that the apparent velocity of mode-2 ISWs generally increases with the increasing depth of seawater. In addition, the apparent phase velocity of the mode-2 ISWs with a larger maximum amplitude is generally larger. Based on the analysis of hydrological data in the study area, it was found that a strong anticyclone developed on the northwest side of the seismic survey line and a weaker anticyclone developed on the southeast side. These anticyclones will increase the depth of the thermocline in the surrounding seawater. According to previous studies, the deepening of the thermocline (pycnocline) maybe conducive to the generation of mode-2 ISWs.

EGU2020-9365
EGU General Assembly 2020

Observation of dynamic fine structure in ocean using pre-stack seismic data

Yi Gong, Haibin Song, Wenhao Fan, Yongxian Guan, and Kun Zhang
Tongji University, School of Ocean and Earth Science, State Key laboratory of Marine Geology, China (1970393599@qq.com)

We propose a method for observing the dynamic thermohaline fine structure using pre-stack seismic data, and combine it with PIV(Particle-Image-Velocimetry) technology to obtain a series of vertical two-dimensional flow velocity sections.
Because of the redundancy of the multi-channel reflection seismic data, the reflection seismic structure at the same location can be observed multiple times from pre-stack seismic data. First, we extract the common-midpoint gathers (CMPs) from the multi-channel reflection seismic data. Then extract the common-offset gathers (COGs) from CMPs. Finally, a seismic processing sequence, such as noise attenuation, normal move out (NMO), velocity analysis and migration, is applied for imaging the reflection structure in COG sections. These COG sections with different offsets are the images of the thermohaline fine structure of seawater at different times. We apply this method to study a typical internal solitary wave in the Dongsha plateau of the South China Sea. We find that the waveform of the internal solitary wave(ISW) in shallow water region does not change much during propagation, but the front becomes flatter and the rear becomes steeper in deep water region, so there is a ISW shoaling change vertically.
We apply the PIV technique to the COG pre-stack migrated sections and calculate the flow velocity sections of the internal solitary wave. To verify the correctness of the flow velocity sections, we compare it with the theoretical flow velocity section calculated from the KdV equation. It is found that the two sections are consistent in flow directions, and the PIV result shows the structure of wave induced velocity well. In the PIV calculation results, the average value of the velocity in the horizontal direction is 1.7 m/s, and in the vertical direction is 0.3 m/s. This result is larger than the theory, especially the horizontal velocity. We speculate that the horizontal velocity contains not only the wave induced velocity component of the internal solitary wave but also the phase velocity component.
In summary, we use pre-stack seismic data to observe changes in the thermohaline fine structure during the propagation of internal solitary waves, and find that the waveforms of internal solitary waves vary differently at different depths. We use the PIV technique to calculate the flow velocity section of the internal solitary wave and compare it with the theoretical results. We find that our method is feasible to describe the flow velocity qualitatively, but it needs further improvement in quantitative description. This method has great potential in studying the dynamic evolution of mesoscale or submesoscale ocean processes.

EGU2020-11319
EGU General Assembly 2020

Modulation instability of weakly nonlinear long internal wave packets

Tatiana Talipova[1,2] and Efim Pelinovsky[1,2,3]
[1]Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation (tgtalipova@mail.ru)
[2]Nizhny Novgorod State Technical University na. R.E. Alekseev, Nizhny Novgorod, Russian Federation
[3]National Research University - Higher School of Economics, Nizhny Novgorod, Russian Federation

We exam the problem of the modulation instability of long internal waves. Such weakly nonlinear weakly dispersive wave packets in one-modal approximation are described by the Gardner equation (Korteweg-de Vries equation with both, quadratic and cubic nonlinearity and necessity condition for modulation instability of such quasi-harmonic waves is the positive coefficient of cubic nonlinear term, which is realized for certain density stratification. Nevertheless the linear dispersive relation used within the Gardner equation is valid for very long waves and does not describe waves of moderate length. It is why some other nonlinear evolution equations are applied in the theory of long surface waves like the Benjamin-Bona-Mahony (BBM) and Whitham equations. We use the extended versions of these equations including cubic nonlinear term and express all coefficients through modal functions and density stratification. Then, the modulational instability of weakly modulated wave packets is investigated after deriving the nonlinear Schrodinger equation. Improved dispersion relation influences on the increment and size of modulational instability. Obtained results are compared with those, which known within the Gardner model.

EGU2020-12175
EGU General Assembly 2020

Modeled acoustic propagation through a measured large-amplitude nonlinear internal wave in northern South China Sea

Peng Qi
(pqi@qdio.ac.cn)

Preliminary results are presented from an analysis of modeled mid-frequency sound propagation through a measured large-amplitude nonlinear internal solitary wave, and in-situ measurements of trains of nonlinear internal waves in northern South China Sea (SCS) as well. An acoustic propagation model based on ray theory was utilized to compute the transmission loss (TL) associated with passing the large depression measured internal waves. The TL was computed using the model considering (1) range-dependent and range-independent environmental scenario and (2) for different source and receiver depth configurations. This presentation will propose several interesting aspects of influence of internal waves on acoustic propagation, including "shadow zones", with or without eddy, etc.

EGU2020-12560
EGU General Assembly 2020

Phase velocity of internal solitary waves in the Dongsha region of the northern South China Sea

Yunyan Kuang[1], Haibin Song[1], Yongxian Guan[2], Wenhao Fan[1], Yi Gong[1], and Kun Zhang[1]
[1]State Key laboratory of Marine Geology, School of Ocean and Earth Science, Tongji University, Shanghai 200092, China (1531048803@qq.com)
[2]Guangzhou Marine Geological Survey, China Geological Survey, Guangzhou 510760, China

Phase velocity is a fundamental parameter to characterize internal solitary waves(ISW) dynamics. Seismic oceanography method to derive the phase velocity of internal solitary waves has been reported recently. In addition, seismic oceanography data can be used to image the internal solitary waves and extract ISW's vertical structure. In this paper, we study the relation between ISW phase velocities with wave amplitude and corresponding water depths based on lots of seismic oceanography data in the Dongsha region of the northern South China Sea.

A seismic survey cruise was carried out on Dongsha Plateau in the summer of 2009. We used Seismic Unix to reprocess the seismic dataset. Our process method can image the water column below 50m. We identify 8 single depression solitons , 4 ISW packets on the shelf and upper continental slope. We extracted phase velocities, corresponding water depths and maximum wave amplitudes of these ISWs. The result shows that phase velocities are positively correlated both with wave amplitude and water depths. We obtain one relation formula between ISW phase velocities with wave amplitude and corresponding water depths by linear regression fitting. Then we have a detailed discussion on ISWs features in the Dongsha region.

EGU2020-13326
EGU General Assembly 2020

Resonant coupling of mode-1 and mode-2 internal waves by topography

Zihua Liu, Roger Grimshaw, and Edward Johnson
University College London, FACULTY OF MATHEMATICAL AND PHYSICAL SCIENCES, Department of Mathematics, London, United Kingdom of Great Britain and Northern Ireland (zihua.liu.15@ucl.ac.uk)

We consider the resonant coupling of mode-1 and mode-2 internal waves by topography. The mode-2 wave is generated by a mode-1 internal solitary wave encountering variable topography in the framework of a pair of coupled Korteweg-de Vries (KdV) equations. Three cases (A) weak resonant coupling, (B) moderate resonant coupling, (C) strong resonant coupling, are examined using a three-layer fluid system with fixed total depth but different layer thicknesses, and each case has two different topographic slopes, gentle and steep, respectively. The criterion for the strength of the resonant coupling is the ratio of the linear phase speeds c_2 for mode-2 and c_1 for mode-1 waves. This ratio c_2/c_1 varies from 0.42-0.48 (A), 0.58-0.72 (B), to 0.44-0.92 (C). The simulations using the coupled KdV model are compared with a KdV model for the evolution of a mode-1 wave alone. In case (A) a convex mode-2 wave of small amplitude is generated by a depression incident mode-1 wave and the feedback on mode-1 wave is negligible. In case (B) a concave mode-2 wave of comparable amplitude to the incident mode-1 wave is formed from a depression incident mode-1 wave; strong feedback enhances the polarity change process of the mode-1 wave. In (C) a concave mode-2 wave of large wave amplitude with wave fission is produced by an elevation incident mode-1 wave; strong feedback from the mode-2 wave suppresses the fission of the mode-1 wave. In all cases, the amplitudes of the generated mode-2 waves are proportional to the topographic slope.

EGU2020-13854
EGU General Assembly 2020

Features of internal solitary waves revealed by seismic oceanography data

Haibin Song[1], Wenhao Fan[1], Shaoqing Sun[1], Yongxian Guan[2], Kun Zhang[1], Yi Gong[1], Hao Li[1], and Yunyan Kuang[1]

[1]Tongji University, School of Ocean and Earth Science, Shanghai, China (hbsong@tongji.edu.cn)

[2]Guangzhou Marine Geological Survey, China Geological Survey, Guangzhou, China

In this paper, we used the seismic oceanography method to study the structural characteristics of internal solitary waves (ISWs) near the Strait of Gibraltar in the Mediterranean Sea, South China Sea and offshore Central America.

The ISWs near the Strait of Gibraltar are the first mode depressional type, mostly medium amplitude and large amplitude internal solitary waves. The maximum vertical amplitude is up to 74.5m, and the amplitude increases with depth□the propagation velocity increases with amplitude. It can be determined that the "true" maximum amplitude position is near the pycnocline. After correction, the maximum half-height-width can reach 1721.8m, but there is somewhat different from the theoretical result□which may be related to the development stability of ISWs. As the solitary wave packet continuously moves eastward, the overall wave width becomes larger, and the vertical velocity becomes smaller. In this paper, seismic oceanography is applied to the analysis of ISWs in the Mediterranean Sea, which further proves the feasibility of using seismic oceanography to study the movement of sea water.

We reprocess some multi-channel seismic (MCS) data which is acquired recently in the Dongsha region of the northeastern South China Sea and we obtain new seismic oceanography data. The research suggest that there are the mode-2 internal solitary wave(ISWs) not just the mode-1 ISWs and a special reflection pattern (hair-like reflection configuration)usually above sand dunes in the seismic images. In new seismic oceanography data, there are some mode-1 ISWs with amplitudes less than 50m and wavelength of 1~5 km and the biggest mode-1 ISWs have the amplitude about 45m. The internal solitary waves packets are not prototypical rank-ordered ISW packets, their soliton amplitudes are smaller than 40. The mode-2 ISWs is well-shaped and its' amplitude is approximate 30m, the vertical structure height is about 200m.The reflection configuration of water column above sand dunes usually include weak reflection layer-maybe called turbulent bottom boundary layer, and there is hair reflection configuration that must not appear. Whether there will be hair reflection configuration or not may depend on the angle between the seismic line and the sand dunes.

In the region offshore Central America, there are lots of mode-2 ISWs revealed from seismic oceanography data. We combine seismic data with hydrographic data to study the features of ISWs in these different regions. The preliminary results show the phase velocity in SCS is the

largest, that in the Strait of Gibraltar is the second and that offshore Central America is the last. The phase velocity depends on the amplitude of ISW. Usually the mode-1 depressional ISW has the largest phase velocity, while the mode-1 elevation ISW is the second, and the mode-2 ISW is the last. The location of the maximum amplitude from the characteristic function is consistent with the pycnocline as shown from floating frequency curve. The polarity of ISW is consistent with nonlinear parameter of alpha. Seismic data in global continental margins will provide more and more key evidence to increase our understanding of ISW evolution in the ocean.

EGU2020-17453
EGU General Assembly 2020

Spatial-temporal variability of M2 internal tides modulated by the Kuroshio currents and mesoscale eddies northeast of Taiwan

Hang Chang and Yahao Liu
IOCAS, Key Laboratory of Ocean Circulation and Waves, China (justintimberwind@126.com)

The spatial-temporal variability and energetics of M2 internal tides during their generation and propagation through the Kuroshio flows and robust eddies northeast of Taiwan are investigated using a high-resolution numerical model. The corrugated continental slopes, particularly the I-Lan Ridge and Mien-Hua Canyon, are identified as the energetic sources of M2 internal tides. The M2 internal tide generation is influenced by the horizontally varying and zonally tilting stratification associated with the Kuroshio currents and mesoscale eddies. In this situation, the magnitude of conversion rate and energy beam exhibit highly temporal variability. An energetic along-slope tidal beam from the I-Lan Ridge radiates southward against the northward Kuroshio flows, causing strong vertical displacement. Complex background currents lead to the time-varying inhomogeneous diapycnal mixing induced by internal tide dissipation.

EGU2020-18704
EGU General Assembly 2020

Latitudinal Variation and Nonlinear Behavior of Internal Tides in the East China Sea

Weidong Wang[1] and Robin Robertson[2]
[1]Institute of Oceanology, Chinese Academy of Sciences, Key Laboratory of Ocean Circulation and Waves, China (wangweidong@qdio.ac.cn)
[2]China-Asean College of Marine Science, Xiamen University Malaysia, Sepang, Malaysia(robin.robertson@xmu.edu.my)

We present four sets of concurrent ADCP data obtained from the East China Sea shelf, and it suggests that near-inertial waves induced by parametric subharmonic instability (PSI) associated with harmonic transfer beyond diurnal critical latitude (O_1:27.6°, K_1:30°). Two type different nonlinear behavior (harmonic transfer and subharmonic transfer) occur varying with the latitude on different location. The velocity data indicated a transfer of diurnal internal tidal energy poleward of the diurnal critical latitude. Kinetic energy and shear spectra analysis at these moorings reveals that the prominent peaks enhance and appear at not only at the even order of diurnal tide such as semidiurnal band, 4cpd, 6cpd and even 8cpd, but also some unfamiliar odd harmonics 3cpd and 5cpd. Furthermore, additional energy is converted to higher mode locally through continuum internal wave spectrum. Besides the harmonic transfer, on the critical latitude for D_2/2 wave(28.9°), D_1 wave is extracted from a D_2 tidal driven model output current. PSI conversion of semidiurnal internal tidal energy was confirmed by spectra analysis and bi-spectra, because of the distinguish of M_2/2 separated from the diurnal tidal (O_1, K_1).

EGU2020-19083
EGU General Assembly 2020

Internal wave energetics modulated by Indonesian Throughflow at Lombok Strait

Zhenhua Xu
Institute of Oceanology, Chinese Academy of Sciences, China (xuzhenhua@qdio.ac.cn)

The interaction between the energetic internal waves in the Indonesian Seas and the Indonesian Throughflow (ITF) is not well known. Here we conduct a series of high-resolution numerical simulations surrounding the Lombok Strait, Indonesia, which is an important exit channel for the ITF, to explore the influences of the ITF on the spatiotemporal variations of M2 internal tides and associated internal solitary waves from the Strait. The ITF enhances the north-south asymmetry of internal tide propagation from the Lombok Strait, thus resulting in the spatial variability of northward and southward internal solitary waves. Interannual variability of internal tide generation and dissipation are due to ITF and air-sea freshwaterflux induced stratification variations associated with El Niño-Southern Oscillation. The local dissipation efficiency q exhibits substantial seasonal and interannual variations, which may provide effective feedback to the climate processes in the low-latitude equatorial oceans.

EGU2020-19318
EGU General Assembly 2020

Radiation of multi-source and multi-band internal waves in the northwestern Pacific

Yang Wang and Baoshu Yin
Institute of Oceanology, Chinese Academy of Sciences, Institute of Oceanology, Qingdao, China (effwang@126.com)

The northwestern Pacific is the most energetic area of internal waves in the world ocean. Generation and evolution processes of multi-source and multi-band internal waves at tidal frequency are examined by driving high-resolution numerical model. The semidiurnal and diurnal internal waves exhibit distinct-different generation and radiation patterns. The multi-source distribution of internal waves favours the occurrence of complex interference patterns which contribute significantly to the inhomogeneous internal wave field. The improved ideal line-source model can well reproduce the interference processes of both semidiurnal and diurnal internal waves. Simulation results show that geostrophic circulations such as Kuroshio Current, North Equator Current, influence both semidiurnal and diurnal internal waves' radiation path. And this modulation process is further demonstrated by theoretical model. Energetic dissipation occurs both near the sources and in the basin. A locally dissipated fraction $q \leq 0.4$ is estimated at the generation sites with continuous bathymetry features, while $q \geq 0.6$ is estimated at areas with discrete topographic variability. A lower locally dissipated fraction indicates a higher proportion of internal wave energy radiating into the basin, where enhanced dissipation coincides closely with the interference-modulated flux field.

EGU2020-20929
EGU General Assembly 2020

The fate and impact of internal waves induced by strong shear current over a marginal ridge

Peiwen Zhang and Wenjia Min
Institute of Oceanology, Chinese academy of sciences, Qingdao, China (zpw@qdio.ac.cn)

Internal waves with strong vertical mixing could be induced by stratified flow over seafloor obstacles. Noted that the stratified flow not only trigger internal tides, but also highly nonlinear internal waves like internal lee waves and internal solitary waves over steep topography features, and the highly nonlinear internal waves are suggested to play an important role in turbulence and mixing. As a typical seafloor obstacle, ridge could significantly modified the propagation of internal tide, internal lee wave and internal solitary wave. We focused on I-Lan ridge with asymmetrical topography feature in Kuroshio region. To the north of the I-Lan ridge, the depth of Philippine basin reached 4000m compared with the depth of 1500m in the south of the ridge, leading to different characteristics of internal wave energy field and ecological characteristics between two sides. Based on numerical simulations, we revealed the generation and propagation of internal waves over marginal ridge, causing by the shear current induced by Kuroshio. We also discussed the turbulence kinetic energy contributed by linear internal waves and nonlinear internal waves, providing the strength of vertical turbulent mixing around the I-Lan ridge. Then we demonstrated the characteristics of complex internal wave field in the strong background shear current over I-Lan ridge.