Similarities and differences between the Kuroshio Extension and a baroclinic jet in a channel

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There are many similarity in PV structure between the Kuroshio Extension (KE) and a baroclinic jet in a channel (hereafter, just a baroclinic jet). PV along the front has a sharp contrast in the upper layer and nearly homogeneous in the lower layer. For the baroclinic jet, it is proposed that PV contrast is generated due to the suppressed mixing across the front and vigorous mixing at their flanks, resulting in the formation of a eastward narrow jet. Despite the distribution similarity, it is difficult to apply the proposed mechanism directly to the formation of the KE. The PV contrast along the KE is the strongest at the separation and disappears into the interior Sverdrup region, suggesting that its primary source is from the western boundary rather than the barrier effect along the fronts. In fact, eddies reduce the PV contrast in the upstream part of the KE. In addition, the barrier effect is not so simple for the Kuroshio Extension. The KE is a blender for Kuroshio-origin water, whereas it is a barrier for other water masses in the upper layer. From these fact, it seems that the formation and maintenance of the Kuroshio Extension seems essentially different from those of the baroclinic jet. Some diagnostic approaches will be also discussed.

キーワード：黒潮続流、傾圧ジェット
Keywords: Kuroshio Extension, baroclinic jets

漂流ブイで観測された北太平洋移行領域の流動構造
Structure of the Transition Domain observed with drifting buoys

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北太平洋移行領域は亜熱帯と亜寒帯の海水交換が行われ，海洋学的・気象学的・生物学的に非常に重要な海域である。本研究では，漂流ブイ観測及び粒子追跡モデル (TRACMASS: Döös 1995, Blanke and Raynaud 1997) の解析結果から移行領域の流動構造や亜熱帯から亜寒帯への海水の輸送過程を明らかとする。

漂流ブイ観測は磯口ジェット (Isoguchi et al., 2006, Wagawa et al., 2014) 及び移行領域の流れの構造を可視化した。また，粒子追跡モデルから得られた粒子の軌跡の頻度分布は，海底地形に沿う流れと海底地形の谷を通過し亜寒帯へ入り込む流れを示しており，亜熱帯から亜寒帯への海水輸送経路が示唆された。

粒子の通りやすい高頻度分布領域は，42˚N –155˚E周辺にも確認できた。漂流ブイの軌跡もほぼ同じ場所で渦を描くような軌跡を示していた。この渦の原因として，42.5˚N –157˚Eに位置する小さな海底地形に伴う順圧流と海面付近での傾圧流が示唆された。この渦も，亜熱帯と亜寒帯の海水の交換に寄与している可能性がある。

キーワード：移行領域、磯口ジェット、漂流ブイ観測、海底地形
Keywords: transition domain, Isoguchi jet, drifting buoy observation, bottom topography

渦からの自発的な慣性重力波の放射とその反作用　～海洋のエネルギー収支の再考～

Generation and backreaction of spontaneously emitted inertia-gravity waves -An update of the ocean energy budget-

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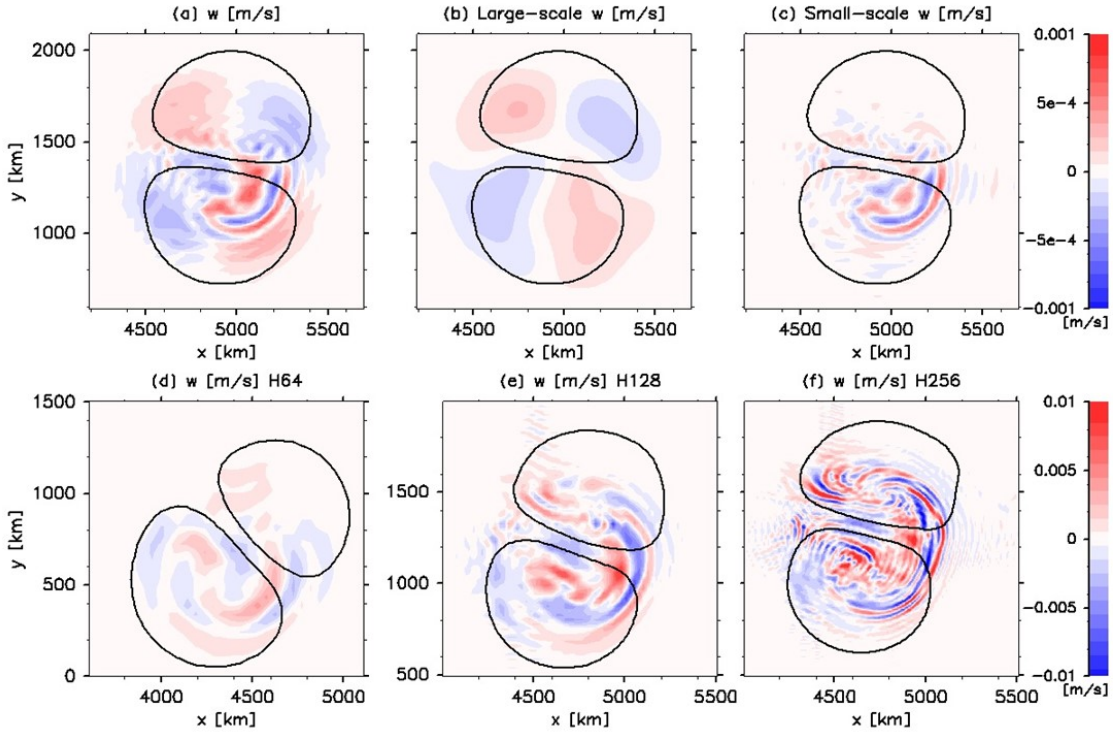
大気重力波（慣性重力波）は運動量を遠方まで輸送し, 中層大気の大循環を駆動する. 中層大気の大循環は物質輸送を通して, 気候に大きな影響を与える. このため, 重力波の励起, 伝播, 散逸の諸過程の解明は, 将来の気候変動予測の精度向上のためにも, 重要な研究課題の一つになっている.

ジェット気流等からの慣性重力波の放射は自発的な重力波放射過程と呼ばれる. 近年, ダイポールを用いた数値実験により, 放射過程についての理解が進展してきた. しかし, 重力波放射の反作用や解像度の依存性についての理解は十分でない.

本研究では, ダイポールからの重力波放射を再検討した. 重力波放射の反作用を調べるため, 長時間の数値実験を様々な水平解像度で行った. 重力波の振幅は水平解像度に比例し, 反作用はダイポールの運動エネルギーに現れた. 発表では, これまでの自発的放射の研究を簡単にレビューするとともに, 海洋のエネルギー収支の観点から中規模渦が自発的放射で失うエネルギーについての議論も行う.

キーワード：慣性重力波、自発的放射、反作用
Keywords: inertia-gravity wave, spontaneous emission, backreaction



Dynamics and Predictability of Downward Propagation of Stratospheric Planetary Waves Promoting Blocking Formation over the North Pacific: A Case study for March 2007

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The atmospheric blocking is one of the most important circulation features in the troposphere causing anomalous weather in the extratropics. Recent theoretical studies have revealed that the blocking is basically maintained against dissipative processes through the selective absorption of synoptic anticyclones due to vortex-vortex interactions. On the other hand, its formation mechanism still remains controversial, but our recent observational studies indicate that downward propagating planetary waves from the stratosphere into the troposphere is a key to promote the blocking formation, especially over the North Pacific. However, the dynamics and predictability of the downward propagation of stratospheric planetary waves have not been revealed as yet.

In this study, predictability of a downward propagating event of planetary waves in the lower stratosphere observed in early March 2007 is examined by conducting ensemble forecasts using an AGCM. It is detected that the predictable period of this event is about 7 days. Regression analysis using all members of an ensemble forecast also reveals that the downward propagation is significantly related to an amplifying quasi-stationary planetary-scale anomaly with barotropic structure in polar regions of the upper stratosphere. Moreover, the anomaly is 90˚ out of phase with the ensemble mean field. Hence, the upper stratospheric anomaly determines the subsequent vertical propagating direction of incoming planetary waves from the troposphere by changing their vertical phase tilt, which depends on its polarity. Furthermore, the regressed anomaly is found to have similar horizontal structure to the pattern of greatest spread among members for predicted upper-stratospheric height field, and the spread growth rate becomes maximum prior to the occurrence of the downward propagation. Hence, we propose a working hypothesis that the regressed anomaly emerges due to the barotropic instability inherent to the upper stratospheric circulation.

In fact, the stability analysis for basic states comprised of the ensemble-mean forecasted upper-stratospheric streamfunction field using a non-divergent barotropic vorticity equation on a sphere supports our hypothesis. Thus, the barotropic instability inherent to the distorted polar vortex in the upper stratosphere forced by incoming planetary waves from the troposphere determines whether the planetary waves are eventually absorbed in the stratosphere or emitted downward into the troposphere.

キーワード：ブロッキング、惑星規模波、下方伝播
Keywords: blocking, planetary wave, downward propagation

Vortex-vortex interactions for the maintenance of atmospheric blocking: The selective absorption mechanism

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Atmospheric blocking is a quasi-stationary anticyclone with a radius of ~5000 km persisting for about 1 week or more, characterized by a pronounced meandering of the middle-latitude westerly jet stream. To clarify why blocking anomalously persists beyond the typical time scale of synoptic eddies has been an important issue for the blocking dynamics. In this stream, we proposed a new maintenance mechanism for atmospheric blocking, the selective absorption mechanism (SAM). According to this mechanism, which is based on vortex-vortex interactions (i.e., the interactions between a blocking anticyclone and synoptic eddies with the same polarity), a blocking anticyclone actively and selectively absorbs synoptic anticyclones (strictly, air parcels with low potential vorticity) from the storm-track regions in mid-latitudes. The blocking anticyclone, which is thus supplied with low potential vorticity of the synoptic anticyclones, can subsist for a prolonged period, withstanding dissipation. The SAM is one of the eddy-feedback mechanisms that describes the interaction between blocking and synoptic eddies with different time scales each other. At first, through the comparison with the famous maintenance mechanisms proposed in the previous studies, uniqueness and distinction of the SAM from other previously proposed maintenance mechanisms are discussed. And then, the SAM was verified in case studies and idealized numerical experiments.
In the case studies, trajectory analyses were conducted by using a reanalysis dataset provided by the Japan Meteorological Agency and the Central Research Institute of the Electric Power Industry. Ten actual cases of blocking were examined. Trajectories were calculated by tracing parcels originating from synoptic anticyclones and cyclones located upstream of the blocking. Parcels starting from anticyclones were attracted to and absorbed by the blocking anticyclone, whereas parcels from cyclones were repelled by the blocking anticyclone. The numerical experiments performed here were based on the nonlinear equivalent-barotropic potential vorticity equation, with varying conditions with respect to the shape and amplitude of blocking, the characteristics of storm tracks (displacement and strength), and the characteristics of background zonal flow. The experiments indicate that the SAM effectively maintains blocking, independently of the above conditions. The above results verify that the SAM is an effective general maintenance mechanism for blocking.

キーワード：大気ブロッキング、ストームトラック、渦位、対流圏界面、大気力学
Keywords: Atmospheric blocking, Storm tracks, Potential vorticity, Tropopause, Dynamical meteorology

準地衡擾乱に関する位相依存性のないエネルギー変換の定式化とその応用
Formulation and application of phase-independent evergy conversions for quasi-geostrophic eddies

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Estimating energy conversions could be useful to clarify dynamics of low-frequent variability of quasi-geostrophic disturbances. Energy conversion terms are composed of quadratic terms in disturbance amplitudes and shear terms of basic flows, so that they can mean energy conversions between disturbance fields and the basic flows. The quadratic terms in the energy conversions are usually expressed by the velocities of the disturbances, such as momentum transports u’v’, so that they inherently include an oscillatory component of one-half wave-length. Therefore, in traditional forms of the energy conversions, phase-averaging such as time-averaging should be needed to express energy-conversion distributions in the phase-independent forms.
In this study, a new formulation of energy conversions for quasi-geostrophic eddies is proposed under an assumption that a eddy is almost a plane wave in the WKB sense. Because of a phase-independent form, the new formulation can be applicable to estimating energy conversions for stationary eddies or snapshot of transient eddies. Actual applications of the new form of the energy conversions to the data analysis will also be given.

キーワード：準地衡擾乱、エネルギー変換、長周期変動
Keywords: quasi-geostrophic eddy, energy conversion, low-frequent variability in the extra-tropics

赤道域と中緯度域の相互作用解析に適したエネルギーフラックス診断式
Towards a seamlessly diagnosable expression for the energy flux associated with both equatorial and mid-latitude waves

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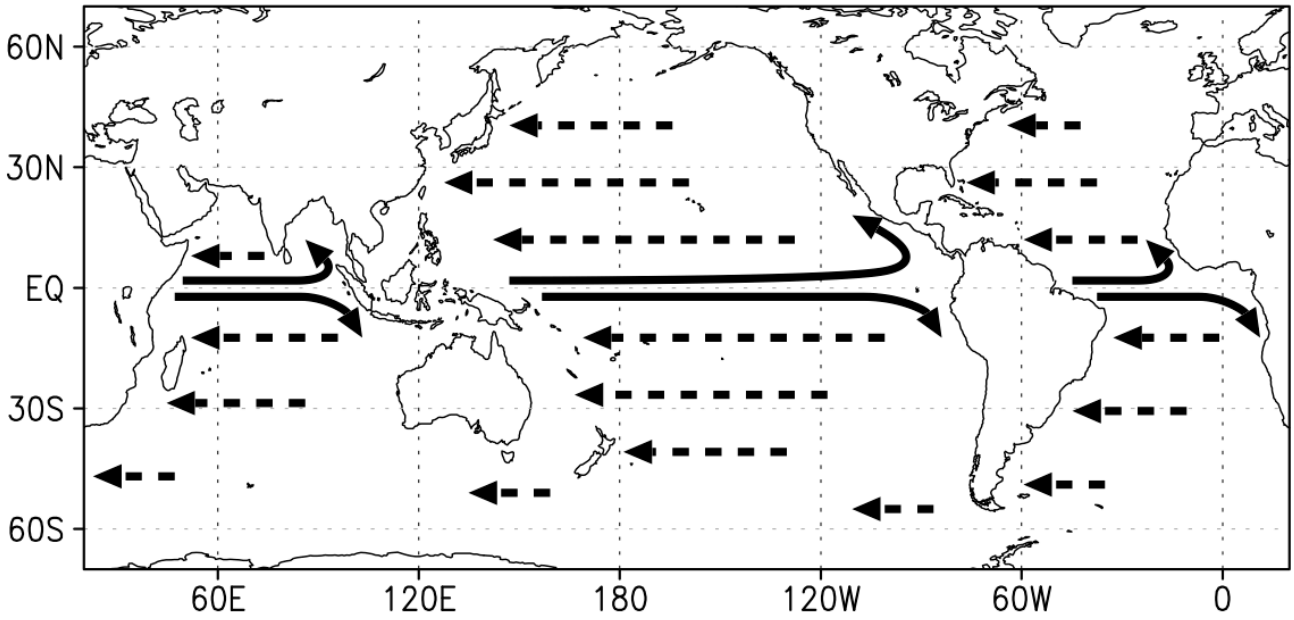
For mid-latitude Rossby waves (RWs) in the atmosphere, the expression for the energy flux for use in a model diagnosis, and without relying on a Fourier analysis or a ray theory, has previously been derived using quasi-geostrophic equations and is singular at the equator. By investigating the analytical solution of both equatorial and mid-latitude waves, the authors derive an exact universal expression for the energy flux which is able to indicate the direction of the group velocity at all latitudes for linear shallow water waves. This is achieved by introducing a streamfunction as given by the inversion equation of Ertel’s potential vorticity, a new and novel aspect when considering the energy flux. For ease of diagnosis from a model, an approximate version of the universal expression is explored and illustrated for a forced/dissipative equatorial basin mode simulated by a single-layer oceanic model that includes both mid-latitude RWs and equatorial waves. Equatorial Kelvin Waves (KWs) propagate eastward along the equator, are partially redirected poleward at the eastern boundary of the basin as coastal KWs, followed by the shedding of mid-latitude RWs that propagate westward into the basin interior. The connection of the equatorial and coastal waveguides has been successfully illustrated by the approximate expression of the group-velocity-based energy flux of the present study, which will allow for tropical-extratropical interactions in oceanic and atmospheric model outputs to be diagnosed in terms of an energy cycle in a future study.

キーワード：group velocity、model diagnosis、tropical-extratropical interactions
Keywords: group velocity, model diagnosis, tropical-extratropical interactions



Generation of internal solitary waves by frontally forced intrusions in geophysical flows

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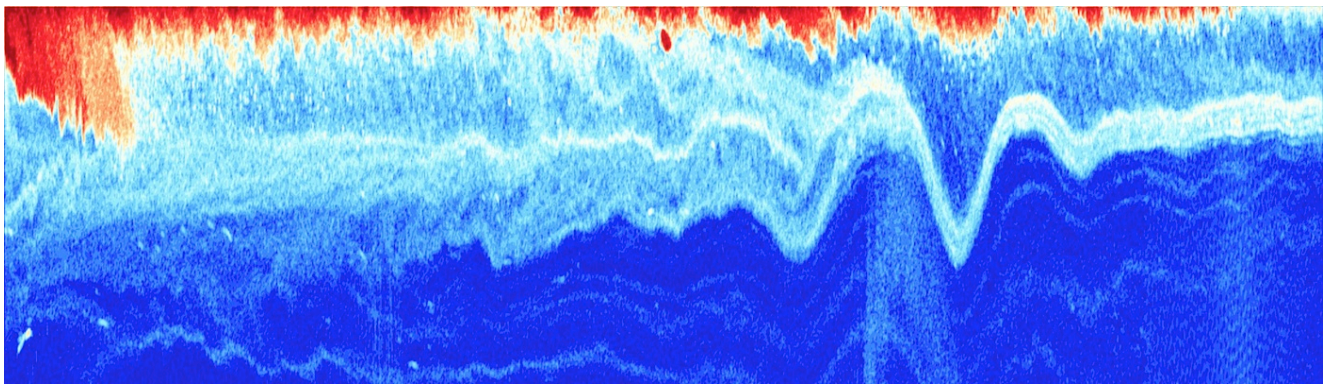
Internal solitary waves are hump-shaped, large-amplitude waves that are physically analogous to surface waves except that they propagate within the fluid, along density steps that typically characterize the layered vertical structure of lakes, oceans and the atmosphere. As do surface waves, internal solitary waves may overturn and break, and the process is thought to provide a globally significant source of turbulent mixing and energy dissipation. Although commonly observed in geophysical fluids, the origins of internal solitary waves remain unclear. Here we report a rarely observed natural case of the birth of internal solitary waves from a frontally forced interfacial gravity current intruding into a two-layer and vertically sheared background environment. The results of the analysis carried out suggest that fronts may represent additional and unexpected sources of internal solitary waves in regions of lakes, oceans and atmospheres that are dynamically similar to the situation examined here in the Saguenay Fjord, Canada.

Keywords: internal solitary waves, front, intrusion



日本海深層の底層水における近慣性周期のGyroscopic Wave
Near-inertial Gyroscopic Wave in the Bottom-layer Water of the Japan sea

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１．はじめに

水深200m前後で水温1℃以下となる日本海深層の密度成層は非常に弱く，2500m以深では鉛直的に密度一様（浮力振動数Nはほぼ零）な底層水（Bottom-layer Water：以下，BWと略す）が形成されている。このBW内を含め，日本海深層域で最も卓越した流速変動の周期は近慣性周期にある（Mori et al., 2005）。内部慣性重力波の慣習的な線形理論（コリオリの鉛直成分のみを考慮）に従えば，その存在周波数帯はN～f（慣性周波数）に制限される。それゆえ，BW（N～0）直上でN=fとなる日本海深層の場合，上方から下方へ伝播（群速度）する近慣性周期の内部波がBW内まで侵入することは不可能である。しかし，現実には近慣性周期の何らかの変動がBW内へ侵入しており，本研究ではコリオリの鉛直成分（以下，fsと略す）に加えて，水平成分（以下，fcと略す）も考慮すれば，それが可能であることを示す。なお，fc項を考慮した非成層（N=0）流体に存在し得る，非静水力学の線形波動は，LeBlond and Mysack（1978）が提唱したGyroscopic Wave（以下，GsWと略す）と呼ばれる。

２．伝播方位に依存した近慣性波のBW内侵入の可否

コリオリの両成分を考慮したGsWでは，方位が重要なパラメータとなる。それゆえ，f平面近似であっても，GsWの伝播方位（東西南北）により，その分散関係には非対称性が生じる。以下の計算では，日本海の緯度を40°Nで，深層で卓越した近慣性波の周波数はσ=1.01fsで代表させる。詳細は省略するが，BW内まで侵入可能な周波数帯は，GsWの伝播方位（θ=0°～90°で東西伝播から南北伝播を表現）を考慮した解の存在範囲から求められる。Fig.1は伝播方位θの関数で表示した，GsWが存在可能な最大周波数σ_{max}（fs値で規格化）分布である。東西伝播（θ=0°）する近慣性波（σ=1.04fs）のBW内侵入は不可能であるが，$20^\circ < \theta < 90^\circ$ の比較的広い方位の近慣性波が侵入可能である。ただし，南北伝播に近いほどBW内侵入の周波帯が拡がり，完全な南北伝播（θ=90°）の侵入可能な周波数帯は0～fs～2Ω（Ωは地球自転の角速度）となる。

３．WKB近似による近慣性波の解析解

fc項を考慮した内部波及びGsWの分散関係は，同じ伝播方位であっても，上方からの入射波と海底からの反射波では大きく異なる鉛直伝播方向を示す。講演では日本海のCTD観測で得られた密度データを用いて，WKB近似による近慣性波（σ=1.04fs）の解析解を示すが，本要旨では入射波と反射波の非対称性が特に顕著なBW内（厚さ1000m）の解析解（鉛直流成分）をFig.2に示した。(a)が南北伝播（θ=90°）のケース，(b)が東西伝播に近いθ=20°のケースである。両ケースで入射及び反射の角度は異なるものの，どちらも入射角度に比して反射角度が非常に小さい。すなわち，反射波は海底面を這うような方向に伝播し，これは鉛直高波数の波（GsW）への変化を意味する。

上記の分散関係の議論から，日本海北方から下方へ入射する近慣性波がGsWの性質をもてば，BW内（N～0）への到達が可能となり，鉛直高波数となる反射波は海底付近に捕捉され，さらに，BWの鉛直混合（BWの密度一様性）にも寄与している可能性が示唆される。

キーワード：コリオリの水平成分、近慣性周期、Gyroscopic Wave、日本海深層
Keywords: horizontal component of Coriolis parameter, Near-inertial frequency, Gyroscopic Wave, Bottom-layer Water

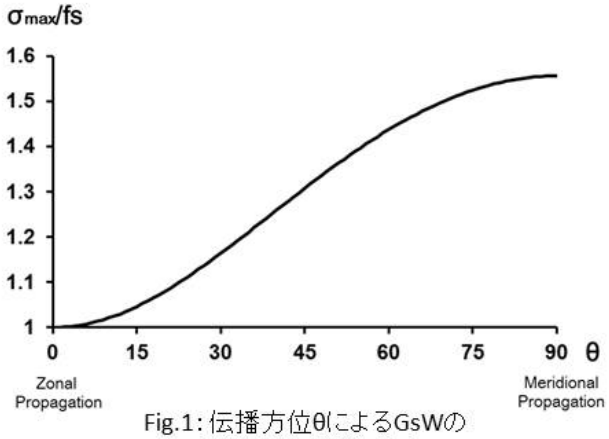

Fig.1: 伝播方位θによるGsWの存在最大周波数分布

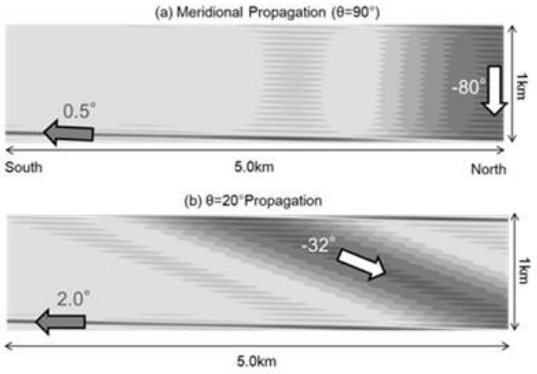

Fig.2: 伝播方位(a)θ=90°，(b)θ=20°のケースにおけるBW内の近慣性波

Impact of Ocean Surface Waves on Air-Sea Momentum Flux

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In this study, we investigated the structure of turbulent air flow over ocean waves. Observations of wind and waves were retrieved by air-sea interaction spar (ASIS) buoys during the shoaling waves experiment (SHOWEX) in Duck, NC in 1999. It is shown that the turbulent velocity spectra and co-spectra for pure wind sea conditions follow the universal forms estimated by Miyake et al [1970]. In the presence of strong swells, the wave boundary layer was extended and the universal spectral scaling of u'w' broke down [Drennan et al, 1999]. On the other hand, the use of the peak wave frequency (fp) to reproduce the "universal spectra" succeeded at explaining the spectral structure of turbulent flow field. The u'w' co-spectra become negative near the fp, which suggests the upward momentum transport (i.e., negative wind stress) induced by ocean waves. Finally, we show the relationship between the turbulent flow structures and roughness of the sea surface.

太平洋を横断する海洋外部重力波の発生場所とその季節変化
The excitation location of external gravity waves traveling across the Pacific Ocean and its seasonal variation

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At deep seafloor, large amplitude of external gravity wave, i.e., infragravity wave (IGW), is persistently observed at frequencies of 0.003–0.03 Hz (30–300 s) in noise spectrum of pressure records. Previous works reported that the generation of the IGW is possibly related to ocean swell and its location is near shoreline. In this study, we investigate the characteristics of the IGW propagating in the ocean, by examining a spectral analysis and an interferometric method. Comparing these observations with the spatio-temporal distribution of ocean swell, we try to find possible locations where the IGW observed off Aogashima is generated.
Off Aogashima in the Izu-Ogasawara region, south of Japan, 10 pressure gauges with a station spacing of 10 km were deployed during May 2014 and May 2015. The locations are 50–100 km east of Aogashima, and the water depth ranges from 1400 to 2300 m. The sampling rate is 4 Hz.
In the obtained results, we found the following three remarkable observations relevant to the IGW observed off Aogashima. Firstly, we calculated running spectrum, i.e., spectrogram, of ambient noise records for a time-period of four months (June–Sep. on 2014). As a result, we found temporal and frequency variations of the IGW amplitude. For example, there are several events that show large amplitude at lower frequencies (0.003–0.01 Hz), and also at higher frequencies, e.g., 0.03 Hz, but with a time-delay of 3 days relative to that at lower frequencies (one example is shown by an arrow in Fig. 1a). The amount of the delay is continuous as a function of frequency. Secondly, we investigated the propagation direction of the IGW. We extracted the IGW propagating between all pairs of two pressure gauges deployed off Aogashima by using an interferometric method, and performed an array analysis. As a result, the IGW is persistently coming from east in summer. If we calculate the ray path of the IGW eastward from the station, it reaches to the shoreline in South America. Moreover, the propagation times between South America and one station off Aogashima were approximately 360,000 s and 95,000 s at frequencies of 0.03 Hz and 0.007 Hz, respectively, resulting in 265,000 s (3.07 days) in differential time; the differential propagation speed as a function of frequency is caused by dispersion of the IGW. This is in good agreement with the observation of the time delay of 3 days. Thirdly, as mentioned above, several events with relatively large IGW amplitude can be seen in the running noise spectrum. It seems that the occurrences of these events correlate with the timings at which strong swell in the southern hemisphere approaches eastward to the shoreline in South America, rather than swell observed around Aogashima (Fig. 1b). Based on these observations, we interpret that the IGW observed off Aogashima in summer is excited near the shoreline in South America. On the other hand, in winter in the northern hemisphere, it seems that the excitation location of the IGW is changed to the shoreline in North America.

キーワード：海洋外部重力波、海底圧力計アレー

Keywords: external gravity wave, deep seafloor observation

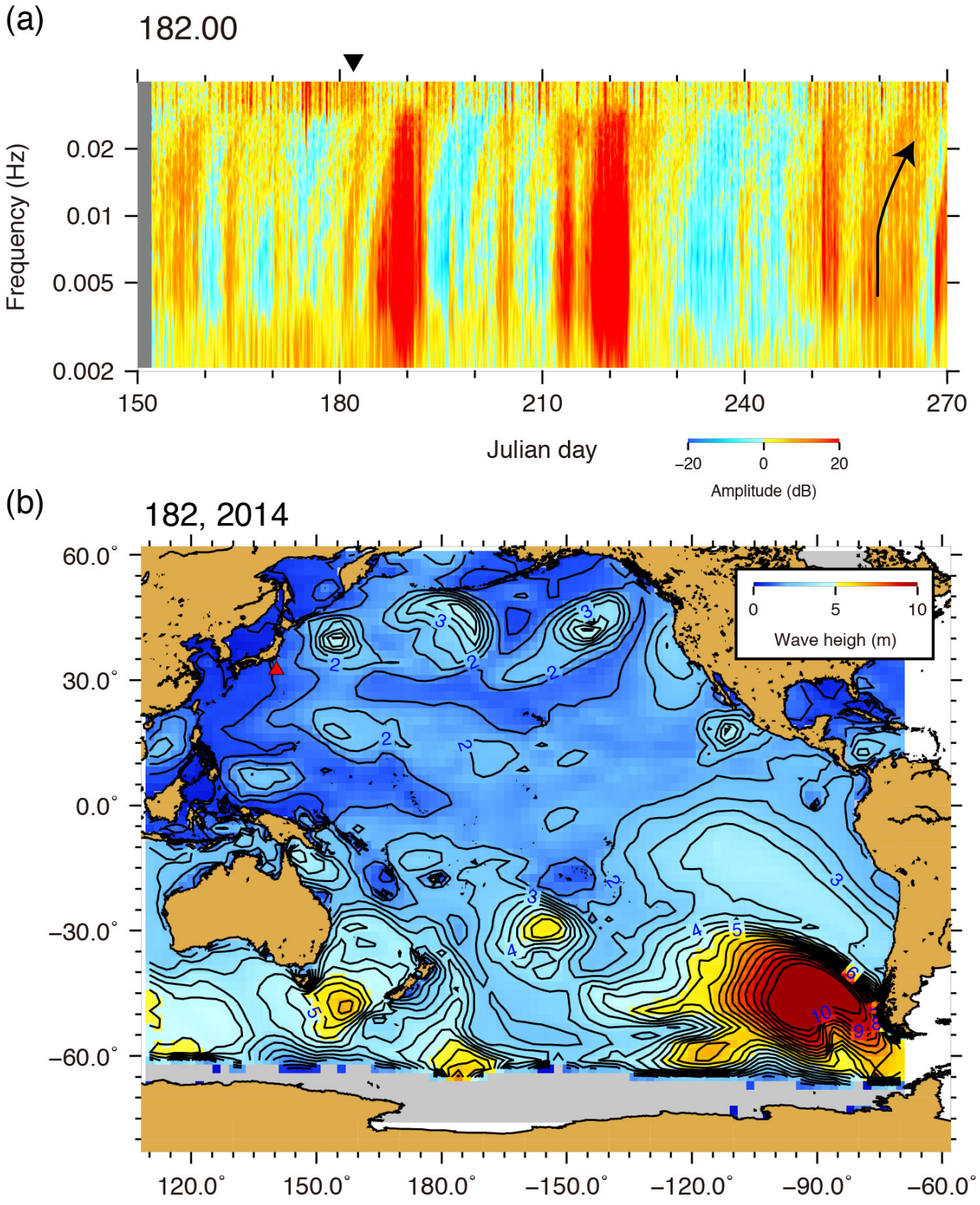

Figure 1. (a) Perturbations of the IGW amplitude as functions of time (day) and frequency, i.e., running spectrum. (b) Wave height distribution on 182 (julian day), 2014, from WAVE WATCH III (Tolman, 2005). A strong swell can be seen near South America, and a large IGW amplitude can also be seen on 182, indicated by inverted triangle in Fig. 1(a).

Topography-dependent relation between offshore wind field and swell-dominant surface waves observed inside bays on the Sanriku ria coast of Japan

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Real-time monitoring of wind and surface waves in Otsuchi Bay, a ria in the Pacific coast of Sanriku, the northeastern portion of Japan, has been continued since October 2012, using a mooring buoy with an ultrasonic anemometer and a single-mode GPS wave sensor. We analyzed two-dimensional energy spectra of surface waves and wind data monitored hourly over four years in order to assess the variability and occurrence of wind and waves and to elucidate the main reasons for wave variation in Otsuchi Bay. The monitoring data revealed in all seasons that surface waves in the bay were predominantly affected by swells propagated from the northeastern offshore region and that the wave height was significantly correlated with the component of wind velocity toward the bay in the northeastern offshore region that faces the bay mouth. The offshore wind field was expected to provide information useful for predicting coastal waves in rias bays in Sanriku such as Otsuchi Bay. More interestingly, comparison of the horizontal distribution of strong correlation between the offshore wind field and the significant wave height in rias bays, Miyako and Kamaishi Bays close to Otsuchi Bay clarified that the offshore wind field which affects predominantly surface waves in rias bays depends heavily on the topographic shape of the bay.

キーワード：海面波、リアス湾、うねり、沖合海上風
Keywords: surface wave, ria bay, swell, offshore wind

黒潮大蛇行を引き起こす傾圧不安定の発達に膠州海山が果たす役割
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.

キーワード：黒潮大蛇行、膠州海山、傾圧不安定、地形性捕捉波、二層準地衡流モデル、線形安定性解析
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.

キーワード：中規模渦、レイノルズ応力、中緯度ジェット、黒潮続流、湾流
Keywords: Mesoscale eddies, Reynolds stress, Oceanic jets, Kuroshio Extension, Gulf Stream

渦による北太平洋回帰線水の輸送と その塩分分布への影響
Eddy transport of North Pacific Tropical Water and its impact on the salinity distribution

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北太平洋回帰線水は，蒸発が降水よりも盛んな回帰線付近で形成される，高塩な特徴をもつ表層水塊である．回帰線水は形成後，エクマンパンピングにより海洋内部に押し込まれ，北赤道海流により西向きに移流され，亜熱帯循環南西部で塩分極大層として現れる． Nakano et al. (2015)は， 正味の淡水フラックスやエクマンパンピング流速の大規模な変動だけでなく，中規模渦による輸送も，回帰線水の空間分布変動に影響を与える可能性を示唆した．また，Zhang et al. (2014)は，等密度面上で閉じた渦位コンター内の海水がトラップされると仮定し、多数のアルゴデータから合成された中規模渦の3次元密度分布と渦位分布を海面高度データで検出される渦に当てはめることで、全球の中規模渦による体積輸送量を推定した．その結果，中規模渦による東西方向の体積輸送量は，風成循環に匹敵することを示した．以上より，回帰線水が中規模渦に捕捉されて輸送されているのかを調べることは，中規模渦が回帰線水の時空間分布に影響を与えるメカニズムを，より詳細に理解する上で非常に重要であるといえる．さらに，回帰線水が中規模渦により西方輸送されているとすれば，この影響は亜熱帯循環南西部の内部領域だけでなく，より西岸境界に近い領域でも観察されると期待される．そこで，本研究では観測データおよび海洋大循環モデル（OFES）を用いて，中規模渦が回帰線水を渦内に捕捉して輸送していることを塩分の時空間分布特性から示しとともに，中規模渦による回帰線水輸送が琉球海流上の塩分変動に与える影響を考察することを目的とした．

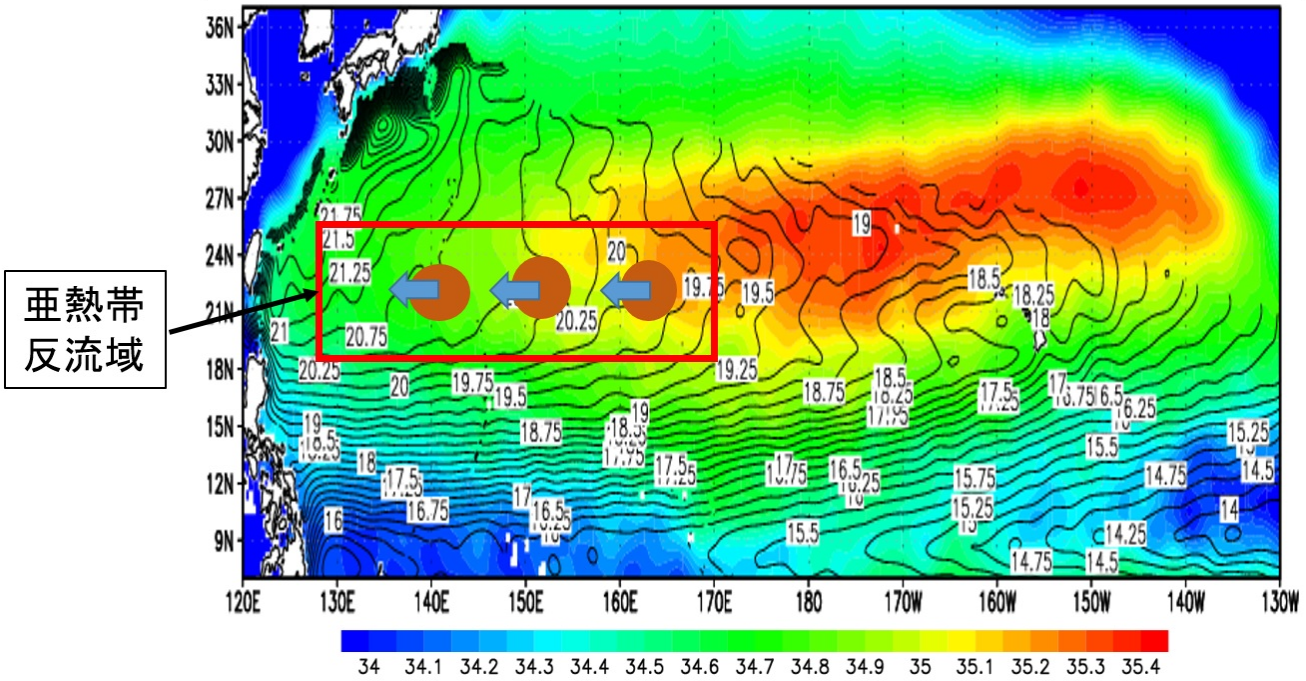
はじめに，回帰線水が渦に捕捉されて形成域から西向きに輸送されていると仮定すれば，高塩な海水が斑状に現れると期待されるため，塩分の空間分布の不連続性に着目した．アルゴの個々のプロファイルから観察される亜熱帯反流域の塩分極大層における塩分とアルゴによる月ごとの格子化データMOAA GPVの塩分との比較，および亜熱帯循環南西部における塩分極大層塩分観測値のヒストグラムから，高塩な海水が時空間的に小さい空間スケールで存在する可能性が示された．つづいて， 24°Nに沿った観測断面の解析から，高気圧性渦内に周囲と比べて高塩な海水が存在している可能性が示された．さらに，アルゴフロートの観測間隔内（約10日間）の塩分変化と，衛星海面高度計による海面高度場から識別された中規模渦の位置との関係を調べることで，高（低）気圧性渦内は周囲と比べて高（低）塩な海水が存在する可能性が示された．これらの特徴は，塩分の空間分布の不均質性を示唆している．これらの時空間分布特性が中規模渦による回帰線水輸送によって生じたことを確かめるために，渦解像モデルを使って回帰線水の移流過程を詳しく調べた結果，中規模渦が回帰線水を渦内に捕捉して輸送しているために，亜熱帯反流域では高塩水が斑状に存在し，上述の塩分時空間分布特性が現れると推察された．

つぎに，中規模渦による回帰線水輸送が琉球海流上の塩分極大層における塩分変動に与える影響を考察した．アルゴフロートおよび渦解像モデルを用いて琉球海流に沿った塩分極大層における塩分を年毎に調べた結果，琉球海流全体で塩分が高い年には，塩分が局所的かつ一時的に高くなるような空間分布変動が現れること，および塩分の短周期変動が激しくなる可能性が示された．さらに渦解像モデルにより， 137°E線と沖縄南東の塩分極大層における塩分の経年変動のラグが，平均流による移流時間より若干小さいことが示された．また中規模渦に伴う輸送が，平均流の流線を横切って，高塩水を琉球列島南東に移流している様子が観察された．このことから，中規模渦に伴う輸送は，散発的に，かつ速く塩分変動シグナルを伝えるため，ラグが平均流による移流時間よりも若干小さくなることが推察された．以上をまとめると，中規模渦による回帰線水の輸送は，内部領域の塩分変動シグナルを平均流よりも速く琉球海流に伝え，琉球海流上の塩分を全体的に高め，さらに塩分の短周期変動を強めることが示唆された．

以上より，中規模渦による回帰線水の輸送は，内部領域の塩分変動を平均流よりも速く西岸境界域に伝えるとともに，西岸境界域の亜表層における塩分経年変動の特徴にも大きな影響を与えることが示唆された．

キーワード：中規模渦、渦輸送、塩分、回帰線水、スケール間相互作用
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）



Bering Slope Currentとそれに伴う高気圧性渦の季節変動について
On the seasonal variation of the Bering Slope Current and anticyclonic eddies

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Bering Slope Current（BSC）はベーリング海の大陸棚と海盆をつなぐ大陸斜面上を流れる海流である。BSCに沿って渦活動が活発であり、それが栄養物質の輸送に寄与することで、グリーンベルトと呼ばれる高生物生産海域を形成している。本研究では、海洋数値モデルの出力を用いて、BSCとそれに伴う高気圧性渦の季節変動について考察する。BSCの流速は、冬に大きく夏に小さい。この季節変動は、冬季（夏季）、アラスカンストリームに生じた等密度面の深化（浅化）が、アリューシャン列島の海峡を通る沿岸捕捉波（内部ケルビン波）として、BSCまで到達することによって生じる。さらに、これにより冬季にBSCの有効位置エネルギーが増加し、春季にかけて傾圧不安定が生じて渦が形成され、夏季まで成長が続くという、季節進行を見出した。これらは、衛星から観測されたBSCと渦の季節変動と整合的である。また、この等密度面の変動はアラスカ湾まで遡ることができ、アリューシャン低気圧の季節変動によりもたらされることが示された。

キーワード：Bering Slope Current、渦、季節変動
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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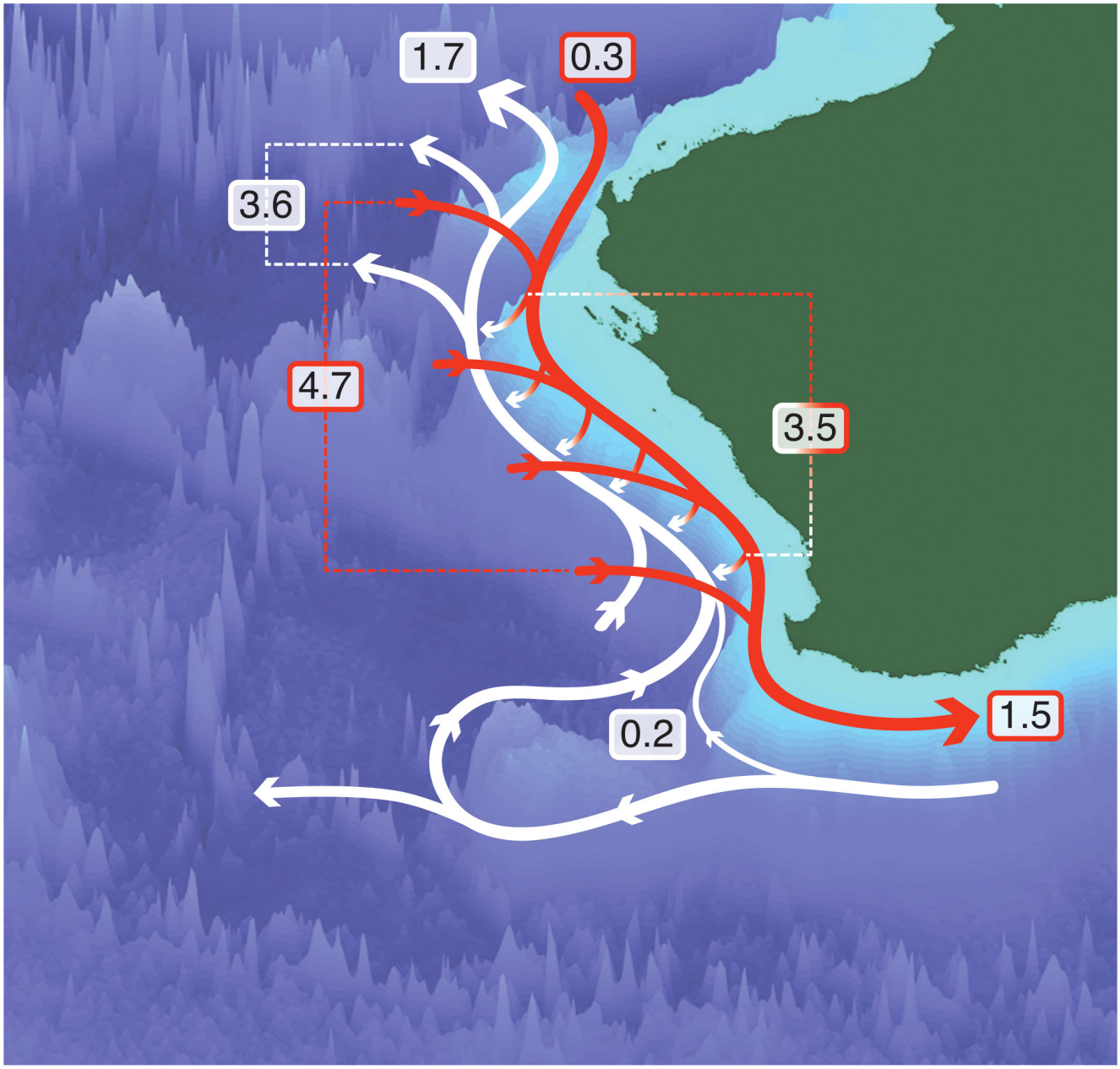
[My poster is in English.] The Leeuwin Current System (LCS) along the coast of Western Australia consists of the poleward-flowing Leeuwin Current (LC), the equatorward-flowing Leeuwin Undercurrent (LUC), and neighboring flows in the South Indian Ocean (SIO). Using geostrophic currents obtained from a 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.

キーワード：zonal overturning、downwelling、comparison with OGCM
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

波源近傍における最低次及び極高調モードの内部潮汐波検出：JCOPE-T海洋循環モデルとの比較

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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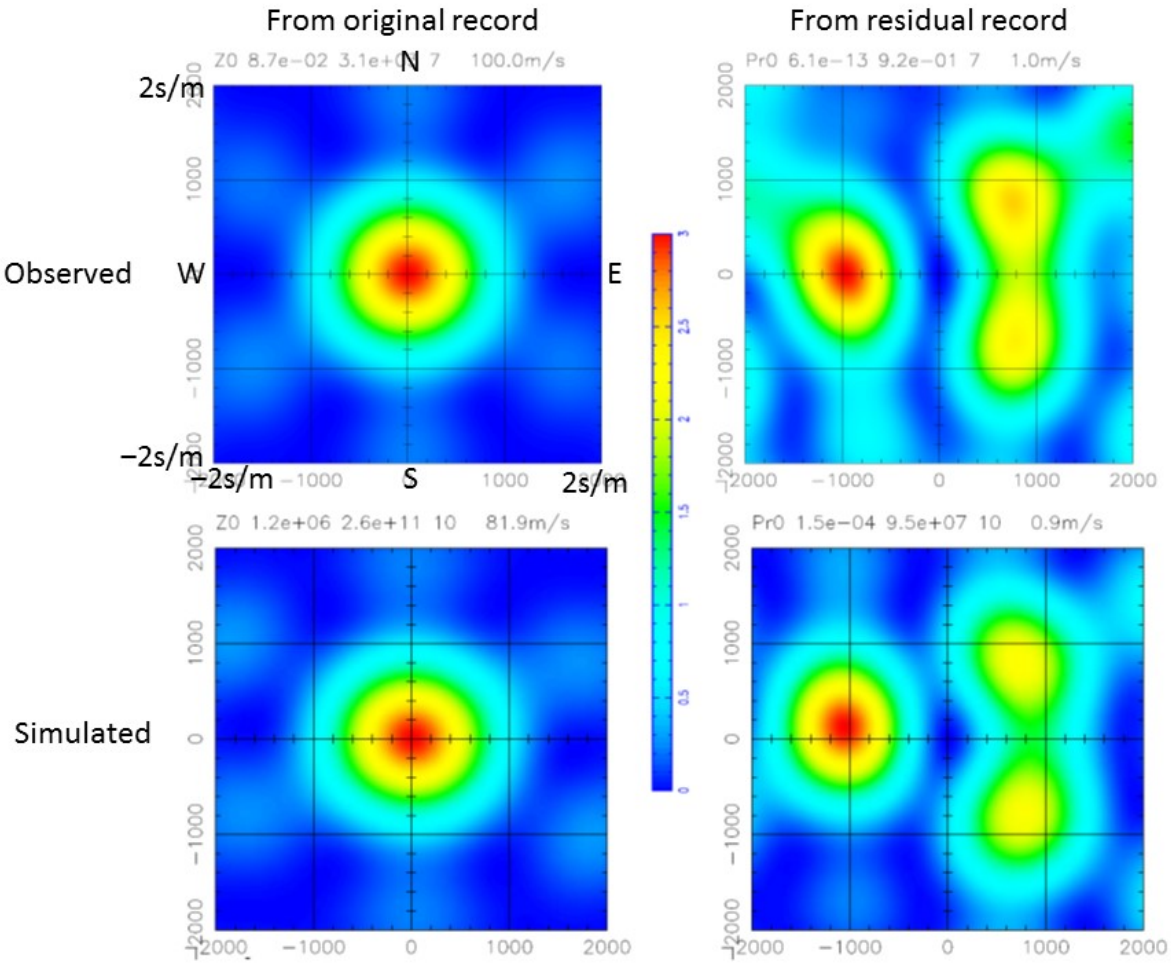
We detected persistent generation of the lowest mode of the M2 internal tide by the array of ocean bottom pressure gauges, which was deployed on the eastern slope of Aogashima Is. of the Izu Ridge at depths 1500 - 2200 m in the period May 2014 - May 2015. We measured the horizontal phase speed and propagating 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.

キーワード：内部潮汐、海底観測、地震海洋学、海洋循環
Keywords: internal tide, ocean bottom observation, seismic oceanography, ocean circulation



2段階ネスティングを適用した海洋・波浪結合モデルを用いた不規則波のStokes drift効果を考慮した沿岸流の解析
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.

キーワード：Stokes drift、海洋・波浪結合モデル、ネスティング
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

擾乱の伝播を考慮した海上風時間補間の波浪推算への効果
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.

キーワード：波浪推算、海上風、時間補間、低気圧
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

